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THE SILT LOAD OF TEXAS STREAMS

BY

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

THE SILT LOAD OF TEXAS STREAMS[1]

By ORVILLE A. FARIS, *associate irrigation engineer, Division of Irrigation, Bureau of Agricultural Engineering*

CONTENTS

INTRODUCTION

One of the most important and valuable of the natural resources of Texas is its water supply. The development of all other resources, the extension of agricultural areas, and the growth of cities are largely dependent upon properly controlled supplies of water suitable as to quality and sufficient in quantity. A stream that periodically overflows its banks, submerging fertile bottom land, is a menace to life and health and a significant factor in retarding the progress of the community which it should serve.

In Texas, where stream flow is generally intermittent, being supplied by rainstorms of varying intensities occurring at irregular intervals, the full utilization of the water resources must necessarily include provision for the impounding of flood water in storage reservoirs. The function of such reservoirs is twofold—to retain the water for future use and to play a very important part in flood control by materially reducing the peaks of floods that inundate fertile areas adjacent to the streams.

[1] Prepared in cooperation with the Texas Board of Water Engineers.

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Run-off, erosion, and transportation of eroded and weathered material are affected by many diverse factors, the more important of which are amount and intensity of rainfall, topography, structure and texture of the soil, and amount and character of the surface cover. The major portion of the eroded and weathered material carried into a reservoir by the supply stream is deposited as soon as the velocity of the inflow is sufficiently diminished. Such deposits reduce the storage capacity and, in some instances, where proper allowance for the accumulation was not made, the usefulness of the reservoirs has been destroyed.

A vital requirement of a successful storage reservoir is that its life—the interval between its initial use and the time when its capacity is reduced by the deposition of silt to the extent that it no longer serves the purpose for which it was designed—shall be of sufficient length to return the cost plus a reasonable profit.

One of the important problems to be solved in properly designing a storage reservoir is that of estimating the silt load of the supply stream so that capacity can be provided to take care of the deposited material long enough to insure the economic soundness of the project. The best basis for estimating the silt load is a long-term record of silt measurements made at or near the reservoir site. However, when the construction of a new reservoir is contemplated such records are seldom available and it is rarely practicable to delay the project several years while one is being made. The result is that estimates are based on short-term or fragmentary records at the site, or on records taken in another locality where conditions are assumed to be comparable. Either procedure may lead to serious error.

In compliance with numerous requests from engineers practicing in the State and in recognition of the need for definite information concerning the silt load of Texas streams that might assist the State Board of Water Engineers in passing upon applications for permits to store flood water, an investigation was inaugurated in 1924 and is still being carried on under a cooperative agreement between the Bureau of Agricultural Engineering, United States Department of Agriculture and the Texas Board of Water Engineers. The following report is the first progress report of the studies thus far made.

The following organizations have assisted in the collection of water samples and other associated work: United States Geological Survey, International Water Commission, Walker-Caldwell Water Co., Wichita County water improvement district no. 1, and the city of Waco. Stream-flow records and drainage-basin areas have been furnished by the water resources branch of the Geological Survey.

R. G. Hemphill,[2] irrigation engineer, had general supervision of the investigations until May 1930. The writer has been in immediate charge of most of the field, office, and laboratory work since the inception of the project. Since September 1930 F. J. Fricke, junior civil engineer, has assisted with the laboratory work and the protracted computations required in connection with the tabulation of the daily records.

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[2] *Italic numbers in parentheses refer to Literature Cited, p. 56.*

PREVIOUS SILT INVESTIGATIONS IN TEXAS

During 1899, 1900, 1901, and 1902, J. C. Nagle directed a silt investigation which included Brazos River at Jones Bridge near College Station and Wichita River at Wichita Falls (*13, 14, 15*).[3]

On Brazos River at Jones Bridge, samples were taken at irregular intervals of from 1 to 90 days from May 29, 1899, to December 31, 1902. The samples were placed in glass tubes and after 7 days' settlement the percentage of silt by volume was determined from the heights of the prisms of silt in the lower parts of the tubes and the clear-water columns above. A few of the samples were allowed to remain in the tubes for 11 months. The percentages of silt by volume were determined after 30 days and also at the end of the 11-month period. At the end of 30 days there was an additional shrinkage of 10 percent over that of 7 days and at the end of 11 months an additional shrinkage of 15 percent was noted. There was no evidence that shrinkage had ceased at the end of the 11-month period and it seems reasonable to suppose that still greater subsidence would have been found if the period had been extended.

Using the percentage of silt by volume after 7 days' settlement and assuming that the percentage of silt determined at irregular intervals would, with some modification based on the color of the muddy water, apply to the intervening period, an estimate was made of the volume of silt passing the section. A 25 percent reduction was applied for the purpose of estimating the volume after settlement for 1 year (see table 1).

TABLE 1.—*Summary of silt measurements, Brazos River, at Jones Bridge*[1]

Time	Total discharge	Silt, 1 week's settlement		Silt, 1 year's settlement	
	Acre-feet	*Acre-feet*	*Percent*	*Acre-feet*	*Percent*
Aug. 1 to Dec. 31, 1899	1,165,300	10,090	0.866	7,567	0.649
Jan. 1 to Dec. 31, 1900	8,806,980	115,782	1.315	86,837	.986
Jan. 1 to Dec. 31, 1901	976,602	12,328	1.262	9,246	.947
Jan. 1 to Dec. 31, 1902	3,362,991	40,190	1.195	30,142	.896
Total[2]	14,311,879	178,390	1.248	133,792	.935

[1] U.S.Dept.Agr., Off. Expt. Stas. Bul. 133 (*15, p. 205*).
[2] For 41 months.

Daily samples taken since June 1924 at several stations on the Brazos River indicate that the color of the water depends upon the color of the soil where the flood originates and not upon the charge of silt in suspension. They indicate further that serious error may result from extending the periods between samplings.

On Wichita River at Wichita Falls (*13, 14*) samples taken at irregular intervals of from 2 hours to 228 days, between May 21, 1899, and February 15, 1902, were treated in the same manner as those from Brazos River at Jones Bridge. The volume of the silt passing the section was estimated on the basis of 7 days' settlement and reduced 25 percent to arrive at the volume after 1 years' settlement (table 2).

[3] Italic numbers in parentheses refer to Literature Cited p. 56.

TABLE 2.—*Summary of silt measurements on Wichita River at Wichita Falls* [1]

Date	Total discharge	Silt, 1 week's settlement		Silt, 1 year's settlement	
	Acre-feet	*Acre-feet*	*Percent*	*Acre-feet*	*Percent*
Feb. 10 to Dec. 31, 1900	842,453	10,171	1.207	7,629	0.906
Jan. 1 to Dec. 31, 1901	297,883	4,639	1.557	3,479	1.168

[1] U.S. Dept. Agr., Off. Expt. Stas. Bul. 119 (*14, p. 380*).

River discharge, especially at Wichita Falls, was based on estimates and is of doubtful value.

W. W. Follett analyzed, compiled, and discussed the results of silt investigations made by various agencies on the Rio Grande at El Paso and San Marcial, covering the period June 10, 1889, to December 31, 1912. His report (*3*) was published by the Department of State. His conclusions are summarized as follows:

From August 12, 1905, to May 31, 1910, at El Paso, and from October 2, 1905, to December 31, 1912, at San Marcial, samples were taken at regular 3-day intervals. Prior to these periods sampling had been done at irregular intervals. The silt load was determined in units by weight and converted to units by volume by using 53 as the number of pounds of dry material that would occupy 1 cubic foot of space when deposited under reservoir conditions. This value was determined from a single 3-inch cube of silt, free from gravel, carefully cut from a sedimentary bar just above the Mexican dam at El Paso. The bar showed signs of material shrinkage since the water had receded, there being cracks in it to such an extent that it was decided that the piece cut out, having already shrunk considerably from exposure to the air, would fairly meet the requirement that the shrinkage be enough to make up for the compression which it was supposed to undergo from the weight of the superimposed water.

Combining the records of the two stations for the period from 1897 to 1912, inclusive, the average annual discharge was 1,192,000 acre-feet of water containing a suspended silt load of 1.41 percent by weight. Converting the weight on the basis of 53 pounds of dry material per cubic foot of deposited mud, the estimated volume of suspended silt was 19,739 acre-feet per year. Based on the average annual silt volume and a drainage area above San Marcial of 30,000 square miles, the average annual contribution of silt per square mile of drainage area was estimated to be 0.66 acre-foot.

PLANS AND METHODS

Owing to the limitation of available funds, it was impossible to extend the detailed investigation to all streams of the State known to have satisfactory reservoir sites and the Brazos River Basin was selected as a drainage area typical, in its various sections, of conditions prevailing on other drainage areas. Brazos River has its source in New Mexico at an altitude of about 4,900 feet (*1*), where the average annual precipitation is approximately 15 inches (*21*), and flows in a southeasterly direction across Texas, discharging into the Gulf of Mexico at a point where the average annual precipitation is about 42 inches (*21*).

Sampling stations were established at gaging stations either near favorable reservoir sites or below areas comparable to other drainage basins. For convenience of sampling, it was necessary to select stations at or near highway or railroad bridges. Nine sampling stations were established in the beginning, and from time to time some of the original stations were discontinued, and new ones in other basins were established. Figure 1 shows the boundaries of the drainage basins and the locations of the silt sampling stations. Table 3 is a list of sampling stations, including locations, drainage areas, and dates of establishment.

SAMPLING EQUIPMENT

Considerable preliminary work was done in selecting containers and other equipment for taking samples of river water and transporting them from the field to the laboratory. Since it was found very difficult successfully and completely to transfer samples of

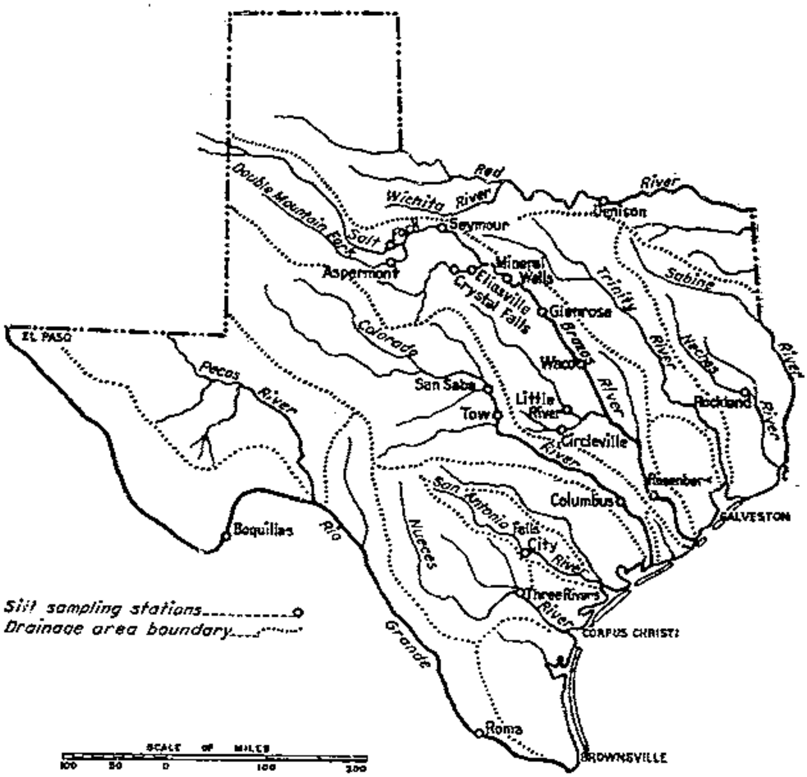

FIGURE 1.—Drainage basins in Texas and locations of sampling stations.

muddy water from one container to another, it was decided that, in the interest of accuracy, samples should be taken and transported to the laboratory without such transfer.

An 8-ounce sample was believed to be both convenient and sufficient in volume for all tests. Results obtained respectively from samples taken in round 8-ounce wide-mouth bottles, round 8-ounce narrow-mouth bottles, and round 8-ounce wide-mouth bottles with contracted openings formed by inserting a ⅛-inch glass tube through the cork agreed as closely as those obtained from samples taken simultaneously at the same depth in bottles of a single type. More trouble was encountered in pouring samples from the wide- than from the narrow-mouth bottles. The narrow-mouth bottles could be inverted over the filter and by a horizontal rotating motion the fine sand could be kept in suspension and poured from the bottle, while with the bottles with wide mouths it was necessary to tip them gently to avoid splashing. This permitted fine sand to settle on the walls of the bottles, requiring the addition of wash water in amounts that overtaxed the capacities of the funnels holding the filters.

TABLE 3.—*List of sampling stations, with locations, drainage areas, and dates of establishment*

Stream	Locality	Gross drainage area [1]	Probable noncontributing area [1]	Date established	Date discontinued
		Square miles	*Square miles*		
Double Mountain Fork of Brazos River.	Near Aspermont	7,980	6,470	June 4, 1924	
Salt Fork of Brazos River	do	4,990	2,770	do	Aug. 29, 1925
Clear Fork of Brazos River	Near Eliasville	5,740		June 3, 1924	Aug. 30, 1925
Do	At Crystal Falls	4,320		Sept. 3, 1925	Jan. 22, 1929
Brazos River	At Seymour	14,500	9,240	June 5, 1924	July 13, 1930
Do	Near Mineral Wells	23,100	9,240	June 2, 1924	
Do	Near Glen Rose	24,800	9,240	June 1, 1924	Aug. 31, 1929
Do	At Waco	28,500	9,240	May 31, 1924	
Do	At Rosenberg	44,000	9,240	June 11, 1924	
Little River	Near Little River	5,250		June 7, 1924	May 23, 1929
San Gabriel River	At Circleville	602		do	Oct. 31, 1929
San Antonio River	Near Falls City	2,070		Sept. 13, 1927	
Nueces River	Near Three Rivers	15,600		Oct. 1, 1927	
Colorado River of Texas	Near San Saba	30,600	11,800	Sept. 11, 1930	
Do	Near Tow	31,100	11,800	Oct. 3, 1927	
Do	At Columbus	40,800	11,800	Aug. 7, 1930	
Neches River	Near Rockland	3,540		Aug. 8, 1930	
Red River	Near Denison	39,400	[2]	Aug. 13, 1930	
Rio Grande	At Roma	93,600	[3]	Mar. 26, 1929	

[1] U.S.Geol. Survey files at Austin, Tex., office.
[2] Large percent.
[3] Not available, gross area does not include Pecos and Devil River areas.

The apparatus tried out and finally adopted for handling bottles in the process of taking samples, shown in figure 2, consists of a one-eighth by three-quarter by 15-inch steel hanger, to which a sheet-metal bottle container, 2½ inches in diameter is fastened in such a way that the top of the neck of a round 8-ounce bottle is 0.8 foot above the lower extremity when attached to an old style 15-pound current-meter weight. Above the container is a sliding clamp with a loop slightly larger in diameter than the lip on the neck of a bottle. This clamp prevents the lifting of the bottle from the container when the stopper is being removed. In order to prevent the stopper from being removed prematurely by tension produced in the stopper line by the current, a $\frac{5}{32}$- by 9-inch coil spring is attached to the top of the hanger and to the stopper wire in such a manner that the spring takes the tension. A medium quality no. 8 sash cord is used as a hand line for lowering and raising the apparatus, and a $\frac{3}{32}$-inch

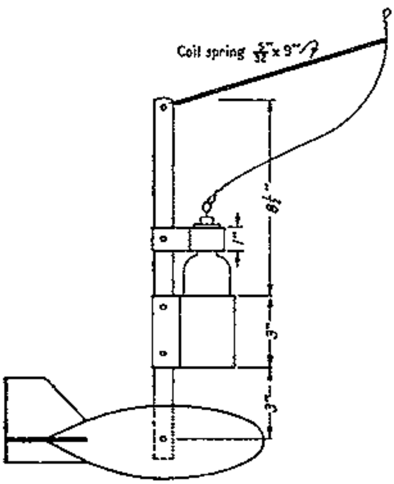

FIGURE 2.—Sampling apparatus used in Texas.

cotton chalk line is used to remove the stopper. In order to hold the stopper line away from the apparatus and prevent entanglement with the hoisting line, a piece of stiff baling wire 17½ inches long is used as a connection between the rubber stopper and the line.

Another sampler tried out was similar to the one described above with the exception that the bottle holder was a clamp which held the bottle on the hanger at an angle of 65° from the vertical, with the opening upstream. It proved to be difficult to handle, did not permit the taking of full-bottle samples, and the results agreed so closely with those obtained from samples taken in the sampler with the bottle held in a vertical position that the vertical container was adopted.

Experiments with an attachment for closing the bottle after filling and before hoisting proved of no advantage and this device was discarded.

For sampling floods with high velocities a special hanger made of steel one eighth inch thick, 1 inch wide, and 16¼ inches long with the vertical bottle container, using a 100-pound weight, was provided. The hoisting line used with this equipment was a $\frac{3}{16}$-inch diameter airplane-strand cable, and a hand winch with a 4-inch drum, attached to an A frame, was used to handle the load.

METHOD OF SAMPLING

The difficulty and cost of taking samples and determining their silt content in the laboratory made it imperative to determine the smallest number of samples whose mean could be relied upon to represent the mean silt content of the entire cross section of the stream with a reasonable degree of accuracy. To determine such number, from 30 to 60 samples in verticals throughout cross sections at different stages were taken at several gaging stations. In each, vertical samples were taken at regular intervals from one tenth to one fifth the depth at the surface and as near the bottom as it was possible to use the sampler without disturbing the natural flow conditions. Curves constructed by plotting percentages of silt by weight as abscissas and depths in feet as ordinates showed that a sample from six tenths the depth gave the mean percentage of silt in the vertical within limits of permissible error.

Curves constructed by plotting the mean percentages of silt by weight in verticals as abscissas and the distances from the edge of water surface in a cross section as ordinates showed that the mean of the results obtained from the three tests made at the center of the section and at distances of one sixth the width from each edge of the stream, gave mean percentages for the cross section. Hemphill's comments (*8, p. 972*) with reference to this method were as follows:

> The probable error in this method is well within the limit fixed by the degree of accuracy which can be obtained in stream gagings at stations such as are ordinarily found in Texas.

In accordance with the conclusions thus reached, samples were taken daily at one sixth, one half, and five-sixths the width and, when velocities were such that soundings could be made with a 15-pound weight, at six tenths of the depth in verticals. When velocities were too high for sounding with the light equipment, samples were taken at the surface and a factor was applied in order to arrive at the mean percentage of silt in the verticals. This factor was determined from the average ratio of the percentage of silt in surface samples to the mean percentages of silt in many verticals. The average ratio in 134 verticals was found to be 0.908. A label is filled out and attached to each bottle as soon as the sample is taken, in order properly to identify the water samples in the laboratory.

LABORATORY METHODS

The laboratory work includes the determination of the percentage of dry silt by weight and in some instances the percentage of saturated silt by volume after 7 days' settlement in glass tubes. In determining the percentage of dry [4] silt by weight the laboratory routine is as follows: First, from 20 to 40 (the number depending upon the speed of the weigher), Whatman no. 2 filter papers, 24 centimeters in diameter, are folded three times (for convenience in weighing), dried in an automatic-electric oven at 110° C. for 1½ hours, cooled in a desiccator one-half hour, removed from the desiccator, weighed on the analytical balance to the nearest five-thousandths gram, and then placed in no. 16 ribbed glass funnels to receive the samples. The bottles containing the samples are then weighed on a torsion balance to the nearest one-tenth gram and, after the muddy water is poured on the filter they are weighed again in order to determine the net weight of the sample. Finally the filters containing the silt are dried in the atmosphere and then returned to the oven, dried 1½ hours at 110° C., cooled in the desiccator one-half hour, and weighed on the analytical balance. Especial care is taken to keep the papers in the same order in the second weighing as they were in the first in order to minimize the error due to any difference in humidity during the two weighings.

The dry weight of the paper and silt together, minus the dry weight of the paper, is the dry weight of the silt, which, divided by the net weight of the sample and multiplied by 100, gives the percentage of dry silt by weight.

In many instances, when the samples contained large amounts of silt, one sample from each set was placed in a glass tube 40 inches in length and having a uniform inside diameter of three fourth inch and allowed to settle 7 days in order to determine the percentage of saturated silt by volume for that period. The volumetric samples were then passed through the regular routine of determining the percentage of silt by weight.

Work sheets were used for convenience and uniformity in recording laboratory determinations.

BED SILT

Bed silt, by which is meant material rolled along the bottom of the stream by the action of flowing water, is a part of the silt load for which no practicable means of measurement has been devised, although much experimenting has been done with this end in view. Traps placed on stream beds probably alter the normal conditions of flow to the extent of making results thus obtained of little value.

[4] "Dry" used in this connection in this report means oven-dried in accordance with standard practice.

Estimates of the relation of the bed to the suspended load cover a wide range of values. By comparing Yuma and Topock silt records, Fortier and Blaney (*4*) estimated the bed load of Colorado River at Yuma as equivalent to 20 percent of the suspended load. Humphreys and Abbot (*9*) from a study of the movement of bars at the mouth of the Mississippi, estimated the bed load to be 11 percent of the suspended load by volume. Follett (*3*) in connection with his study of Rio Grande believed it possible for the bed load to be 25 percent of the suspended load. By using silt traps in San Carlos River at Costa Rica, Davis arrived at the percentages 5.2, 1.7, and 7.1 for June, July, and August, respectively (*2*).

Experiments made under clear-water conditions when the bottom of the stream could be observed were carried on in Guadalupe River at New Braunfels, Tex. The bed of the stream at this location is composed of material ranging from fine sand to coarse gravel, and the depths of water ranged from zero to the limit of wading at existing velocities. The apparatus consisted of a metal plate 24 inches square with a shallow hopper 12 by 14 inches below and having a 10- by 12-inch opening in the plate, with the greater dimension parallel with the axis of the stream. With this device placed on the stream bed, the velocity of the water at the surface of the plate was determined with a current meter and observations of the behavior of bank-run sand and gravel released at the upstream edge of the plate were made (table 4).

TABLE 4.—*Observations of the behavior of bank-run sand and gravel at different velocities*

Observation no.	Depth of water	Velocity of flow	Remarks
	Feet	*Feet per second*	
1	1.05	2.65	Pebbles weighing 1.1 grams carried across 12-inch opening. Heavier pebbles which rolled in hopper were soon displaced. Sand, after release, was carried altogether in suspension.
2	1.50	2.53	Results same as for no. 1. Medium sand in suspension; coarse sand was carried over hopper opening.
3	1.30	1.64	Medium sand in suspension; coarse sand was carried over hopper opening.
4	1.20	1.38	All fine sand was carried over hopper.
5	1.05	.91	Fine sand was carried over hopper opening.
6	.80	.68	Fine sand displaced from hopper by impact of pulsations or eddies of non-uniform velocity.

On the bottom of the stream, where the velocity was 2.5 feet per second, the bed was in a state of stability, although handfuls of material containing fine sand could be picked up easily. The coarser material was able to withstand the velocity and prevented the displacement of the finer particles. The advance of the disturbed sand and gravel on the stream bed was not continuous nor uniform for a given stage. It was observed that the heavier particles would stop advancing for a period, blocking other particles, and then advance again. It is obvious that trapping material rolling along the bottom and assuming a continuous and uniform advance for a given stage is likely to give results varying materially from the truth.

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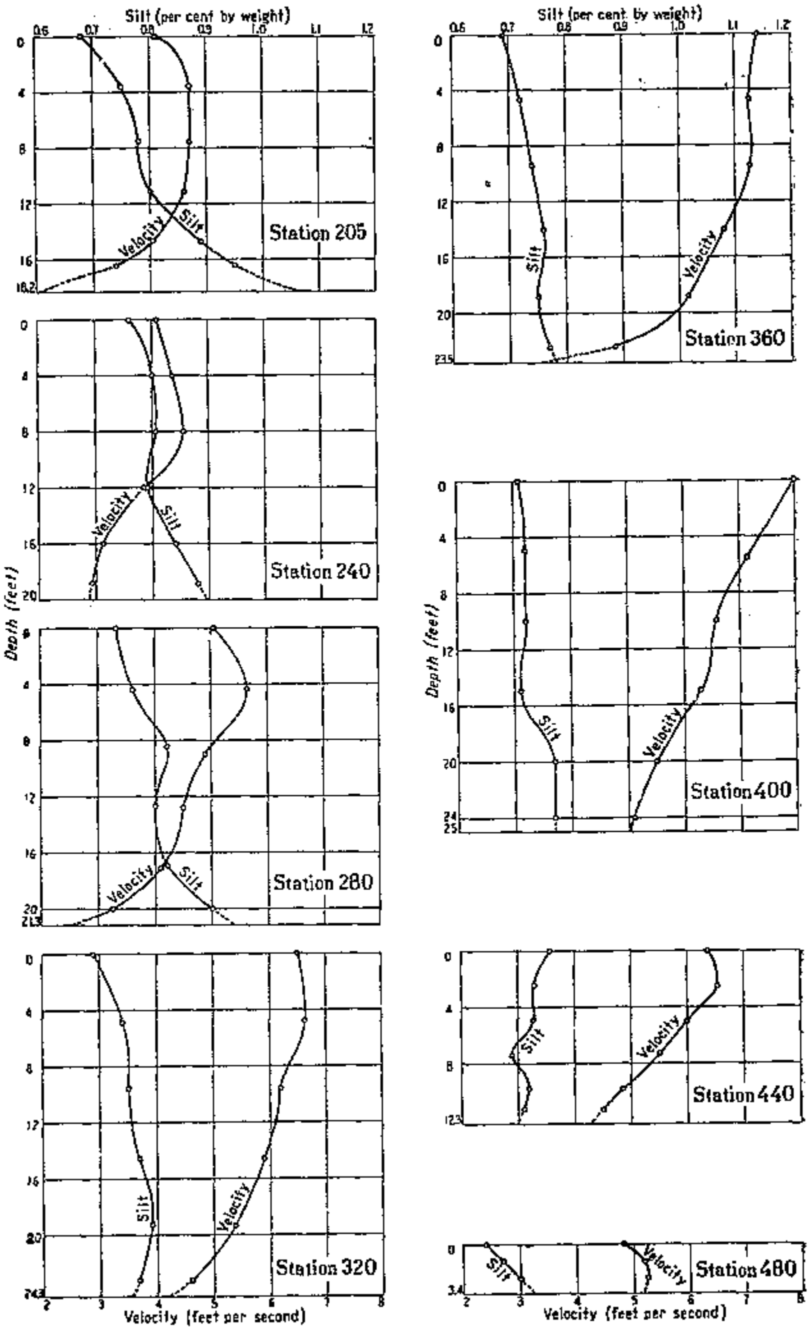

FIGURE 3.—Velocity and silt-percentage curves at different stations on the Brazos River at Rosenberg, on April 16, 1929.

The results of these observations indicate that at and above a velocity of 1.64 feet per second sediment of the grades found at all sampling stations operated in connection with the Texas investigations are held in suspension. Since bottom velocities during periods when silt is being transported in significant quantities are always in excess of 1.64 feet per second, the writer believes that the bed loads, if any, at sampling stations under consideration are negligible within the limits of accuracy of stream gagings at the respective stations. This belief is supported by inspection of the velocity and silt-percentage curves shown in figure 3.

DISTRIBUTION OF SILT THROUGHOUT STREAM CROSS SECTION AND RELATIONSHIP OF QUANTITY OF SILT TO VELOCITY

Many sets of special samples with the associated velocities were taken at a number of sampling sections for the purpose of determining the relationship of velocity to silt percentages, the distribution of silt in verticals and cross sections, and the distribution of various sizes of particles from the water surface to as near the bottom of the stream as samples could be obtained without disturbing the natural flow conditions. The record of a set of special samples taken from Brazos River at Rosenberg, April 16, 1929, given in tables 5 to 7, inclusive, and shown in figure 3, illustrates this part of the investigation.

TABLE 5.—*Distribution of silt in cross section of Brazos River at Rosenberg, Apr. 16, 1929* [1]

Station no.	Depth sample was taken	Velocity	Silt volume after 7 days	Percentages of silt by weight which passed and remained on sieves with specified number of meshes per inch						
				Passed no. 40, retained on no. 65	Passed no. 65, retained on no. 100	Passed no. 100, retained on no. 150	Passed no. 150, retained on no. 200	Passed no. 200, retained on no. 300	Passed no. 300	Total silt content
	Feet	*Feet per second*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
142	0									
	.2	4.11	2.049	0.002	0.002	0.004	0.006	0.009	0.655	0.678
	3.7	4.71	2.061	.006	.008	.013	.013	.023	.690	.753
	7.5	4.71	2.098	.010	.008	.017	.019	.025	.702	.781
205	11.2	4.61	2.034	.010	.014	.019	.020	.031	.706	.800
	15.0	4.04	1.742	.024	.041	.055	.034	.037	.700	.891
	17.2	2.78	2.294	.039	.085	.089	.037	.039	.706	.995
	[2] 18.2									
	.2	4.56	2.016	.002	.011	.019	.017	.026	.693	.758
	4.0	4.86	2.106	.008	.010	.018	.021	.031	.715	.801
	8.0	5.03	2.000	.010	.008	.017	.017	.023	.730	.805
240	12.0	4.35	2.161	.012	.017	.023	.021	.027	.691	.791
	16.0	3.62	2.245	.025	.021	.027	.027	.031	.712	.843
	18.9	3.42	1.964	.027	.029	.038	.032	.036	.720	.882
	[2] 20.0									
	.2	5.05	1.799	.006	.002	.006	.008	.014	.695	.731
	4.3	5.64	1.936	.010	.004	.008	.012	.017	.707	.758
	8.5	4.91	2.013	.008	.010	.020	.020	.066	.095	.819
280	12.8	4.51	2.028	.015	.012	.019	.021	.029	.702	.798
	17.0	4.11	2.194	.018	.012	.023	.023	.035	.711	.822
	20.2	3.32	2.314	.040	.029	.030	.032	.038	.727	.902
	[2] 21.3									

[1] The width of the river at water surface was 395 feet, extending from station 142 to station 537. Station numbers are distances in feet from initial point marked on face of left bridge abutment. The discharge was 31,000 second-feet.
[2] Stream-bed depth.

TABLE 5.—*Distribution of silt in cross section of Brazos River at Rosenberg, Apr. 16, 1929*—Continued

Station no.	Depth sample was taken	Velocity	Silt volume after 7 days	Percentages of silt by weight which passed and remained on sieves with specified number of meshes per inch						
				Passed no. 40, retained on no. 65	Passed no. 65, retained on no. 100	Passed no. 100, retained on no. 150	Passed no. 150, retained on no. 200	Passed no. 200, retained on no. 300	Passed no. 300	Total silt content
	Feet	*Feet per second*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
320	0.2	6.50	1.898	0.004	0.002	0.004	0.004	0.009	0.663	0.691
	4.9	6.63	1.907	.006	.004	.011	.013	.021	.683	.738
	9.7	6.20	1.963	.010	.004	.008	.013	.023	.688	.746
	14.6	5.89	1.948	.013	.006	.013	.017	.025	.694	.768
	19.4	5.37	2.238	.015	.006	.017	.021	.027	.707	.793
	23.2	4.58	2.278	.031	.010	.015	.013	.019	.687	.775
	[a] 24.3	------	------	------	------	------	------	------	------	------
360	.2	7.39	2.025	.004	.004	.007	.009	.016	.649	.689
	4.7	7.27	2.246	.002	.002	.010	.011	.019	.675	.719
	9.4	7.27	2.083	.004	.004	.011	.015	.023	.682	.739
	14.1	6.79	1.607	.006	.006	.011	.019	.023	.692	.757
	18.8	6.15	1.961	.008	.006	.014	.014	.022	.683	.747
	22.4	4.86	2.081	.017	.006	.014	.021	.021	.090	.769
	[a] 23.5	------	------	------	------	------	------	------	------	------
400	.2	7.96	1.949	.016	.004	.008	.010	.018	.650	.706
	5.0	7.12	1.955	.006	.004	.008	.014	.019	.673	.724
	10.0	6.56	1.726	.006	.006	.008	.010	.018	.671	.719
	15.0	6.26	2.135	.008	.004	.008	.012	.018	.060	.710
	20.0	5.50	2.013	.006	.002	.010	.018	.029	.707	.772
	24.0	5.08	2.137	.006	.006	.014	.018	.022	.703	.769
	[a] 25.0	------	------	------	------	------	------	------	------	------
440	.2	6.36	2.041	.006	.004	.008	.014	.026	.702	.760
	2.5	6.56	2.028	.004	.004	.010	.012	.023	[illegible]	.727
	4.9	5.99	2.123	.006	.006	.010	.014	.021	.678	.735
	7.4	5.51	1.988	.004	.004	.008	.010	.021	.639	.686
	9.8	4.86	2.085	.004	.004	.010	.014	.019	.673	.724
	11.3	4.50	2.085	.002	.002	.010	.010	.017	.666	.707
	[a] 12.3	------	------	------	------	------	------	------	------	------
480	.2	4.86	------	------	------	------	------	------	------	------
	1.2	5.20	1.954	.002	.004	.008	.010	.018	.627	.669
	2.4	5.26	1.029	.008	.004	.010	.012	.017	.650	.701
	[a] 3.4	------	------	------	------	------	------	------	------	------
537	0	------	------	------	------	------	------	------	------	------

[a] Stream-bed depth.

There is no evidence of any direct relationship between suspended load and the velocity of the water at the river stations under consideration. It is true that the higher the velocity the greater the carrying capacity but, since the capacity load is not even approximately reached, the magnitude of the silt charge carried must be a function of loading and not of capacity to carry.

The greater part of the silt load of a stream is made up in advance by the process of weathering. After a dry period the first water that runs off picks up the weathered material and carries it into the stream. After the first flushing, run-off from the wet area must depend on erosion for its silt load, which is comparatively light, since the portion of a large drainage basin where excessive erosion takes place is small in comparison with the entire area.

All of the samples listed in table 5 were placed in glass tubes, each 42 inches long and having an inside diameter of three fourths inch. After 7 days' settlement the heights of the silt columns were measured and the percentages of silt by volume calculated. The average ratio of the percentage of silt by volume to the percentage by weight was found to be 2.659. The results are tabulated in the fourth column of table 5.

The data shown in table 5 indicate that material of dimensions large enough to be retained on the no. 65 sieve was[5] present from a depth of 0.2 foot to the lowest limit of sampling—1 foot above the stream bed. Generally the amount of this grade of suspended material increased from the surface toward the bottom. The exceptions occurred in the direction of the right bank and were probably due to ascending currents noticeable at the water surface in swells similar to those appearing on the surface of boiling liquid. As the particles graded from coarser to finer, they were more uniform in their distribution in verticals. More than 90 percent of the total amount of suspended silt in the 44 samples listed consisted of particles small enough to pass the no. 300 sieve.

VELOCITY AND SILT-PERCENTAGE CURVES

Figure 3 shows velocities and silt percentages of samples listed in table 5. The extension of the curves from the points of the deepest samples to the bottom in each vertical are based on the assumption that they are straight lines or flat curves tangent to the defined curves at their lowest points. This assumption may not be quite correct, but any error in the final results is necessarily small, since the portion of the depth to which the extended part of the curve applies is slight in comparison with the total depth.

The direction of the velocity curves as established by the two lower points indicates that the bottom velocity is high enough to keep in suspension all material of the grades existing at this section, a conclusion supported by the silt curves.

Considering the silt percentages and velocities existing at station 205, the following data (table 6) are compiled from the curves of figure 3.

TABLE 6.—*Distribution of silt content and velocity of flow in vertical at station 205, Brazos River at Rosenberg, Apr. 16, 1929*[1]

Depth at which samples were taken	Silt content		Velocity	
	Percentage by weight	Ratio to mean	Feet per second	Ratio to mean
Surface	0.68	0.84	4.11	0.95
One tenth	.72	.89	4.52	1.04
Two tenths	.75	.92	4.71	1.09
Three tenths	.77	.95	4.72	1.10
Four tenths	.78	.90	4.71	1.09
Five tenths	.78	.96	4.08	1.08
Six tenths	.80	.99	4.61	1.07
Seven tenths	.82	1.01	4.42	1.03
Eight tenths	.89	1.09	4.04	.93
Nine tenths	.95	1.17	3.40	.79
Bottom	1.06	1.31	1.97	.45

[1] Silt percentages and velocities at surface, 0.2, 0.4, 0.6, and 0.8 the depth and within 1 foot of the bottom were observed. The others are taken from the curve.

The mean percentage of silt as determined from the curve with a planimeter is 0.81 and the observed mean (at 0.6 the depth) is 0.80, making the ratio of the latter to the former 0.99.

[5] All sieve analyses were made with Tyler standard sieves.

Similar compilations of data shown for the stations referred to in figure 3 are the bases for the summary given in table 7.

TABLE 7.—*Relation of mean silt content to silt content as observed at 0.6 depth, Brazos River at Rosenberg, Apr. 16, 1929*

Station no.	Silt content by weight		
	Mean estimated from curves [1]	Observed at 0.6 depth	Ratio of observed to means from curves
	Percent	*Percent*	
205	0.81	0.80	0.99
240	.81	.79	.98
280	.80	.80	1.00
320	.76	.77	1.01
360	.74	.75	1.01
400	.73	.71	.97
440	.71	.69	.97
480	.68	.69	1.01
Mean	.76	.75	.99

[1] Mean silt content determined from graphs in fig. 3.

Table 7 shows that the mean ratio of observed percentages of silt by weight at 0.6 depth, to the mean percentages by weight, is 0.99, indicating that samples from 0.6 depth in verticals give results well within the limits of permissible error for such work.

The average ratio in 132 verticals at various gaging stations, of the percentage of silt by weight, in (1) surface samples and (2) samples from 0.6 depth, to the mean percentages of samples taken

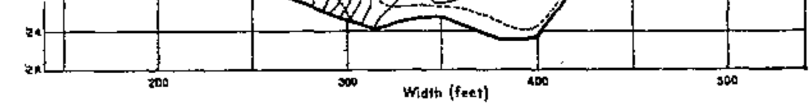

FIGURE 4.—Cross section, Brazos River, at Rosenberg, Apr. 16, 1929, showing lines of equal silt percentages by weight and equal velocities in feet per second. (Solid lines represent percentage of silt by weight and dotted lines velocity in feet per second.)

at the surface, 0.2, 0.4, 0.6, 0.8 depth and as near the bottom as it was possible to sample without disturbing the stream bed, were 0.908 and 0.999, respectively.

The distribution of silt in a cross section of the Brazos River at Rosenberg, April 16, 1929, and its relation to velocities are shown graphically in figure 4. The unsymmetrical forms of lines of equal silt percentages by weight and equal velocities in feet per second are due to unbalanced cross section and slight curvature of the river channel in close proximity to the section.

Analysis of tables 5 and 7 shows that the ratio of observed percentages of silt by weight at 0.6 depth to the mean percentage by weight in verticals having depths varying from 3.4 to 25.0 feet is approximately unity. The vertical curves of silt percentages in figures 5 and 6 show that the same relationship exists in comparatively deep water, being 1.00, 0.97, and 1.00 for depths of 41.5, 42.2, and 31.0 feet, respectively.

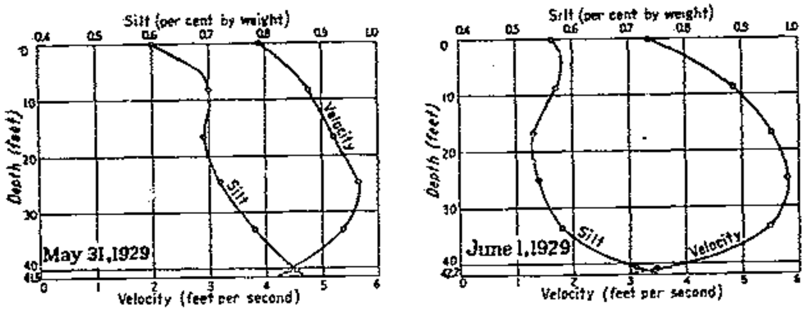

FIGURE 5.—Velocity and silt-percentage curves at station 210, Brazos River, at Rosenberg, May 31 and June 1, 1929.

In table 8 are listed samples, the vertical curves of silt percentage of which are shown in figures 5 and 6. The amount of coarser material generally shows an increase from the surface toward the bottom and the particles of sufficient fineness to pass the no. 300 sieve were very evenly distributed in the verticals. With the exception of the sample taken May 31 at a depth of 0.2 foot, material large enough to be retained on the no. 65 sieve was found at all depths.

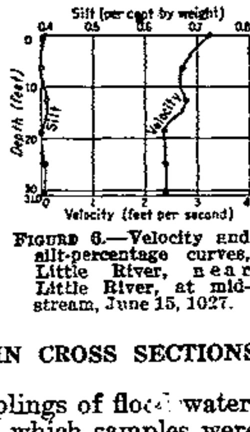

FIGURE 6.—Velocity and silt-percentage curves, Little River, near Little River, at midstream, June 15, 1927.

MEAN PERCENTAGE OF SILT, BY WEIGHT, IN CROSS SECTIONS

Table 9 is a compilation of results of 17 samplings of flood water, from 5 to 8 verticals, in river cross sections, in which samples were taken at the surface, as near the bottom as practicable and at 0.2, 0.4, 0.6, and 0.8 depth, respectively. The purpose of this table is to justify the use of the percentage of silt in samples from 0.6 depth as the mean percentage in verticals and the mean of the percentages from 0.6 depth in verticals at one-sixth, one-half, and five-sixths width as the mean percentage in cross sections. Values in columns 2, 3, and 4 are mean percentages of silt, in river cross sections, determined by using the mean of 6 samples from each of 5 to 8 verticals in sections, the percentages in samples from 0.6 depth in each of 5 to 8 verticals, and the percentages in samples from 0.6 depth in verticals at one-sixth, one-half, and five-sixths width, respectively.

TABLE 8.—*Distribution of silt in comparatively deep verticals and mechanical analyses of suspended material at various depths, 68 feet from left edge of water, in Brazos River at Rosenberg*

MAY 31, 1929, DEPTH 41.5 FEET, DISCHARGE 86,000 SECOND-FEET

Depth sample was taken	Velocity	Percentages of silt by weight which passed and remained on sieves with specified number of meshes per inch					
		Passed no. 40, retained on no. 65	Passed no. 65, retained on no. 100	Passed no. 100, retained on no. 200	Passed no. 200, retained on no. 300	Passed no. 300	Total silt content
	Feet per second	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0.2 foot	3.93	0.000	0.004	0.005	0.010	0.579	0.598
8.3 feet	4.75	.004	.022	.042	.028	.603	.699
13.6 feet	5.21	.010	.024	.028	.025	.604	.691
24.9 feet	5.64	.022	.024	.051	.014	.606	.717
33.2 feet	5.36	.024	.028	.052	.036	.642	.782
40.3 feet	4.45	.043	.065	.066	.043	.637	.854
41.5 feet (bottom)							

JUNE 1, 1929, DEPTH 42.2 FEET, DISCHARGE 88,000 SECOND-FEET

Depth sample was taken	Velocity	Passed no. 40, retained on no. 65	Passed no. 65, retained on no. 100	Passed no. 100, retained on no. 200	Passed no. 200, retained on no. 300	Passed no. 300	Total silt content
0.2 foot	3.36	0.016	0.036	0.034	0.032	0.445	0.563
8.4 feet	4.87	.008	.015	.053	.034	.457	.567
16.8 feet	5.51	.017	.021	.037	.009	.447	.531
25.2 feet	5.79	.015	.012	.021	.034	.458	.540
33.6 feet	5.49	.028	.023	.043	.020	.465	.579
41.0 feet	3.47	.099	.059	.075	.015	.462	.710
42.2 feet (bottom)							

TABLE 9.—*Mean percentage of silt by weight in cross sections of streams as determined in 3 ways and probable error resulting from using second and third methods*

River and river station	Date	Mean percentage of silt in section			Difference of means in sections, using from 5 to 8 verticals and 3 verticals	
		Using from 5 to 8 verticals in sections		Using 3 verticals in sections at ¼, ½, ¾ width, using value at 0.6 depth for mean in vertical		
		Using means of 6 samples in vertical	Using value at 0.6 depth for mean in vertical		Using means of 6 samples in vertical	Using value at 0.6 depth for mean in vertical
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
Brazos River:						
Mineral Wells	Mar. 17, 1924	0.23	0.23	0.22	[1] 4.5	[1] 4.5
Rosenburg	Mar. 22, 1924	.29	.20	.29	.0	.0
Waco	Apr. 27, 1924	.84	.83	.82	[1] 2.4	[1] 1.2
Do	May 1, 1924	.99	1.00	1.01	[2] 2.0	[2] 1.0
Do	May 1, 1925	2.34	2.34	2.36	[2] .8	[2] .8
Do	Sept. 15, 1925	1.39	1.42	1.44	[2] 3.4	[2] 1.4
Do	Sept. 21, 1925	.77	.78	.78	[2] 1.2	.0
Do	Sept. 10, 1925	1.40	1.41	1.43	[2] 2.0	[2] 1.3
Rosenberg	June 29, 1926	.90	.90	.91	[2] 1.1	[2] 1.1
Waco	May 14, 1927	.41	.40	.41	.0	[2] 1.7
Rosenberg	June 17, 1927	1.37	1.38	1.40	[2] 2.1	[2] 1.7
Waco	June 15, 1927	.23	.23	.23	.0	.0
Do	May 20, 1928	1.26	1.28	1.30	[2] 3.0	[2] 1.6
Glen Rose	Aug. 7, 1928	.40	.40	.40	.0	.0
Rosenberg	Apr. 16, 1929	.76	.75	.75	[1] 1.3	.0
Waco	Sept. 13, 1929	1.51	1.52	1.55	[2] 2.6	[2] 1.9
Three Rivers	May 15, 1928	.17	.17	.17	.0	.0

[1] Indicates decrease below value of true mean.
[2] Indicates increase above value of true mean.

The results given in column 6 indicate the probable error in mean percentage of silt, in cross sections, determined by using the percentage in samples from 0.6 depth for the mean in each of 5 to 8 verticals and those in column 7 indicate the probable error determined by using the percentage in samples from 0.6 depth in verticals at one-sixth, one-half, and five-sixths width. These results indicate that percentages of silt in samples from 0.6 depth in verticals and at one-sixth, one-half, and five-sixth width give mean percentages in cross sections within the limits of accuracy obtained in stream gaging at the respective stations.

GRAPHICAL COMPARISON OF DISCHARGE AND SILT PERCENTAGE

Figures 7, 8, and 9 show graphically discharge in cubic feet per second and silt percentage by weight of Brazos River near Mineral Wells, at Waco, and at Rosenberg, for the calendar year 1929. These figures show that the maximum silt percentage by weight usually occurs prior to the maximum stream discharge. When samples are

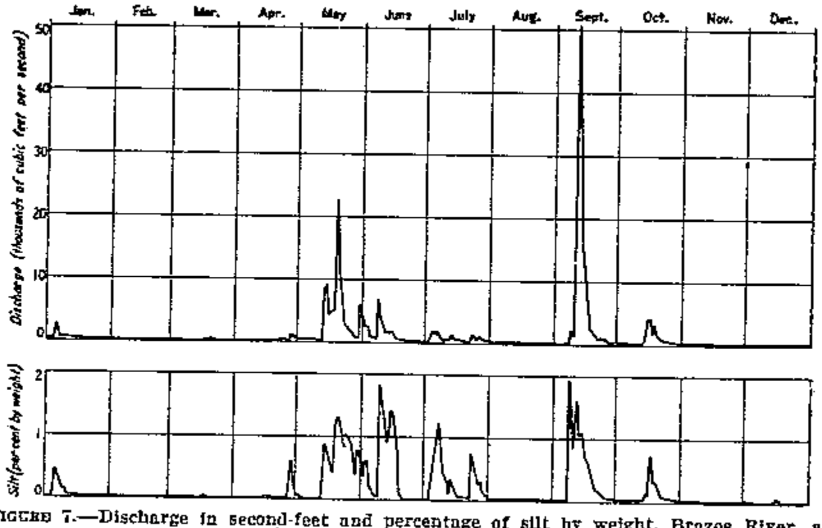

FIGURE 7.—Discharge in second-feet and percentage of silt by weight, Brazos River, at Mineral Wells, during 1929.

taken throughout a rise and fall in a stream, an increase is noticeable in silt percentage up to a certain discharge. A further increase in discharge is associated with a decrease in percentage of silt, due to dilution. As the water surface recedes during the falling stage the silt percentage is again increased, due to the sliding of recently deposited silt into the stream from the sloping banks where trees and brush had retarded the velocity so that deposition resulted. In some streams this secondary increase in silt percentage is due largely to the caving of banks undercut by the current.

The flood, the crest of which passed Rosenberg June 6, with a discharge of 123,000 second-feet, was made up of contributions received below Waco from Little Brazos River, Little River, Navasota River, Yegua River, and other smaller streams. The decrease of percentage of silt by weight as the discharge increased is clearly illustrated by the records of this flood. The maximum silt percentage was being transported May 28, when the discharge was 28,700 second-feet.

The flood, the crest of which passed Rosenberg November 11, with a discharge of 46,200 second-feet, also originated below Waco. The

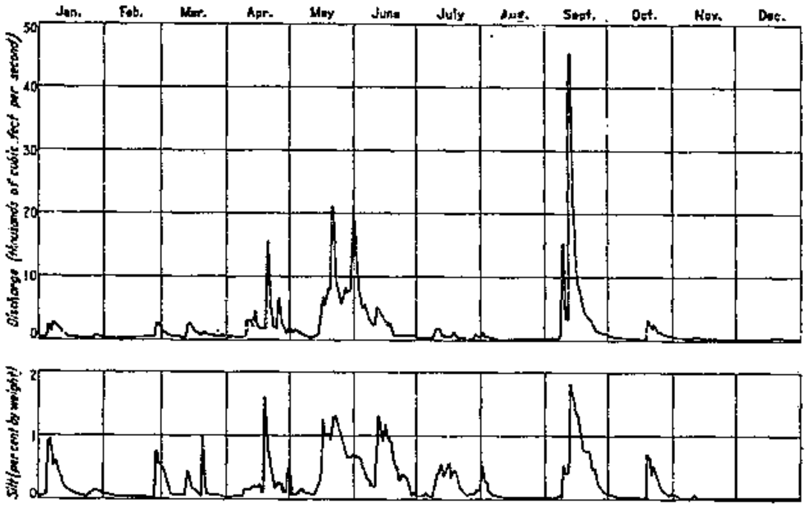

FIGURE 8.—Discharge in second-feet and percentage of silt by weight, Brazos River at Waco, during 1929.

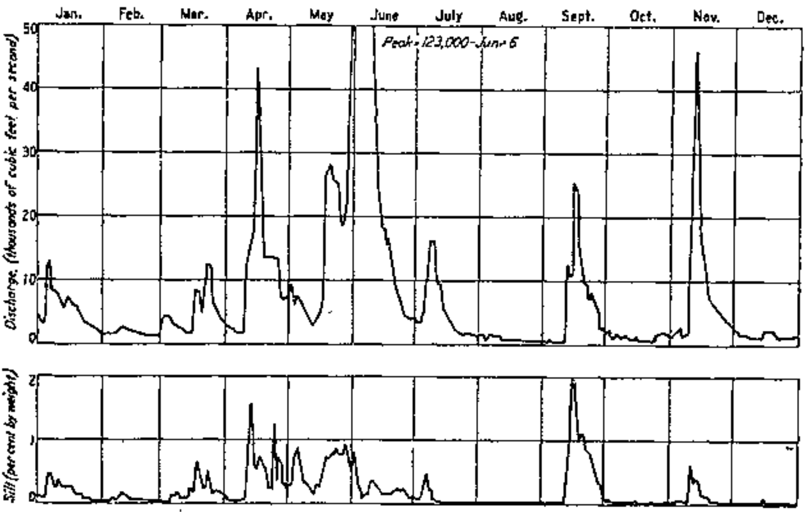

FIGURE 9.—Discharge in second-feet and percentage of silt by weight, Brazos River at Rosenberg, during 1929.

maximum silt percentage was carried November 10, when the discharge was 34,600 second-feet.

Figures 7, 8, and 9 also illustrate the fluctuating character of the stream flow which occurs in sharp rises of comparatively short duration.

MECHANICAL ANALYSES OF SUSPENDED SILT

Mechanical analyses of routine daily samples of muddy water taken at various sampling stations were made from time to time. The results of the analyses of some of the samples are listed in table 10. Material retained on the no. 60 sieve consisted of vegetable matter, shell or mica; that retained on sieves nos. 100, 160, and 200 was composed largely of sand grains; and that passing the no. 200 sieve was impalpable alluvium, having none of the sharp gritty feel to the fingers that is characteristic of sand. The results show that the material is extremely fine, since over 97 percent of the suspended load, on an average, passed the no. 300 sieve.

Table 10.—*Mechanical analyses of suspended load of muddy water from daily sets of routine samples taken at 0.6 depth in midstream*

DOUBLE MOUNTAIN FORK OF THE BRAZOS RIVER NEAR ASPERMONT

Date	Mean discharge for day	Percentages of silt by weight which passed and remained on sieves with specified number of meshes per inch						
		Passed no. 40, retained on no. 60	Passed no. 60, retained on no. 100	Passed no. 100, retained on no. 160	Passed no. 160, retained on no. 200	Passed no. 200, retained on no. 300	Passed no. 300	Total silt content
1928	*Second-feet*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
July 10	996	0.006	0.004	0.012	0.010	0.006	1.282	1.320
July 14	343	.009	.004	.004	.002	.002	1.220	1.241
July 15	162	.016	.012	.008	.004	.004	1.151	1.195
Aug. 5	1,150	.018	.004	.008	.017	.025	1.462	1.534
Aug. 8	186	.032	.013	.002	.004	.005	.603	.659
Aug. 12	279	.004	.002	.002	.011	.008	1.533	1.560
Aug. 13	200	.008	.002	.006	.008	.009	1.534	1.567
Aug. 15	85	.002	.004	.000	.007	.008	.712	.733
Aug. 19	2,030	.038	.010	.027	.058	.134	3.137	3.404
Aug. 20	700	.000	.000	.000	.000	.006	1.622	1.628
Aug. 21	212	.004	.002	.004	.002	.006	1.324	1.342
Aug. 22	121	.002	.000	.002	.004	.007	.538	.603
Aug. 25	53	.000	.000	.000	.000	.001	.056	.057

BRAZOS RIVER AT SEYMOUR

Date	Mean discharge for day	Passed no. 40, retained on no. 60	Passed no. 60, retained on no. 100	Passed no. 100, retained on no. 160	Passed no. 160, retained on no. 200	Passed no. 200, retained on no. 300	Passed no. 300	Total silt content
Aug. 14	162	0.010	0.005	0.006	0.008	0.014	2.212	2.255
Aug. 15	282	.008	.004	.002	.004	.004	2.188	2.210
Aug. 16	499	.012	.008	.002	.002	.004	2.219	2.247
Aug. 17	284	.006	.002	.002	.002	.006	2.187	2.205
Aug. 18	132	.008	.002	.004	.002	.020	2.222	2.258
Aug. 19	74	.008	.002	.002	.002	.018	2.237	2.269

BRAZOS RIVER AT WACO

Date	Mean discharge for day	Passed no. 40, retained on no. 60	Passed no. 60, retained on no. 100	Passed no. 100, retained on no. 160	Passed no. 160, retained on no. 200	Passed no. 200, retained on no. 300	Passed no. 300	Total silt content
Aug. 24	850	0.001	0.001	0.001	0.002	0.004	0.178	0.187

RELATIONSHIP BETWEEN PERCENTAGES OF SILT BY WEIGHT AND BY VOLUME AFTER SETTLEMENT FOR 7 DAYS

In order to arrive at the relationship between the percentage of silt by weight and the percentage by volume in individual samples after settlement for 7 days, many samples containing various charges of suspended matter were placed in glass tubes 42 inches in length with uniform inside diameter of three fourths inch. At the end of 7 days the percentage of silt by volume was determined from the depth of the silt column and the total depth of the sample when placed in the tube. After making the volumetric determination the percentage of silt by weight was determined in the usual manner. Table 11 is a summary of the results of these tests.

TABLE 11.—*Relationship between average silt percentages by volume and weight, in samples of muddy water from various rivers and sampling stations*

River	Locality	Samples involved	Average silt—		Ratio of volume percentage to weight percentage
			Weight	Volume[1]	
		Number	*Percent*	*Percent*	
Brazos:					
Clear Fork	Eliasville	23	0.36	1.16	3.2-1
Salt Fork	Aspermont	22	1.50	4.00	2.7-1
Double Mountain Fork	Aspermont	211	1.72	5.86	3.4-1
Brazos	Seymour	75	1.61	4.80	3.0-1
	Mineral Wells	217	.89	3.15	3.5-1
	Glen Rose	206	1.00	3.26	3.3-1
	Waco	226	.92	3.00	3.3-1
	Rosenberg	168	.76	2.56	3.4-1
Little River	Little River	46	.46	1.40	3.0-1
Colorado of Texas	Tow	11	.68	1.70	2.6-1
Nueces	Three Rivers	7	.37	1.50	4.0-1
San Gabriel	Circleville	2	1.43	3.42	2.4-1
San Antonio	Falls City	3	.40	1.44	3.6-1
West Fork Trinity	Ten Mile Bridge	4	.79	2.11	2.7-1
Rio Grande	Boquillas	12	1.24	3.43	2.8-1
	Roma	13	.73	2.12	2.9-1
Total or average		1,246	1.07	3.52	3.3-1

[1] Percentage by volume after 7 days in glass tubes.

A total of 1,246 samples were tested both gravimetrically and volumetrically. In each instance the water column above the silt was clear within 1 hour after being placed in the tube, the rapid deposition of the silt being due to the action of salts in solution. The percentage of silt by weight varied from 0.09 to 10.28, the percentage of silt by volume after 7 days' settlement from 0.12 to 19.12, and the ratio of volume percentage to weight percentage from 1.1 to 7.7. The wide range of values of the ratio of volume percentage to weight percentage suggests the difficulty encountered in using silt analyses based on the volumetric method.

SILT SURVEY OF MEDINA RESERVOIR

The plans for the investigation included actual measurement of the volumes of silt in a number of reservoirs, but preliminary studies showed that conditions were satisfactory for such surveys at reasonable costs in only a few of them.

To measure a silt deposit under the water surface it is important that a topographic map of the storage basin, as it was before any water was stored in it, with a small contour interval, be available, or that the silt should have been continually submerged since its deposition. A 15-pound window weight attached to a sounding line penetrated such a deposit and came to rest on the original ground surface. Grit brought up on the end of the weight indicated that the lower limit of the silt had been reached. This was checked by excavating to the bottom of silt in exposed deposits. After shrinkage due to exposure of the silt to the atmosphere occurs, the surface sets to such an extent that it may be the limit of penetration of the sounding weight when submergence again takes place.

During September 1925 a survey of Medina Reservoir was made for the purpose of determining the volume of silt after 13 years of actual service. This reservoir is located in Bandera and Medina Counties, about 35 miles northwest of San Antonio. The dam is a concrete structure with a gravity section, across the Medina River Canyon, having a maximum height of 164 feet. The storage capacity at the elevation of the spillway crest is 254,000 acre-feet. The contributing area above the dam is 587 square miles [6] the larger part of which is brush-covered grazing land having a range in elevation above sea level of from 1,000 to 2,500 feet. The average annual rainfall is about 29 inches (*21*).

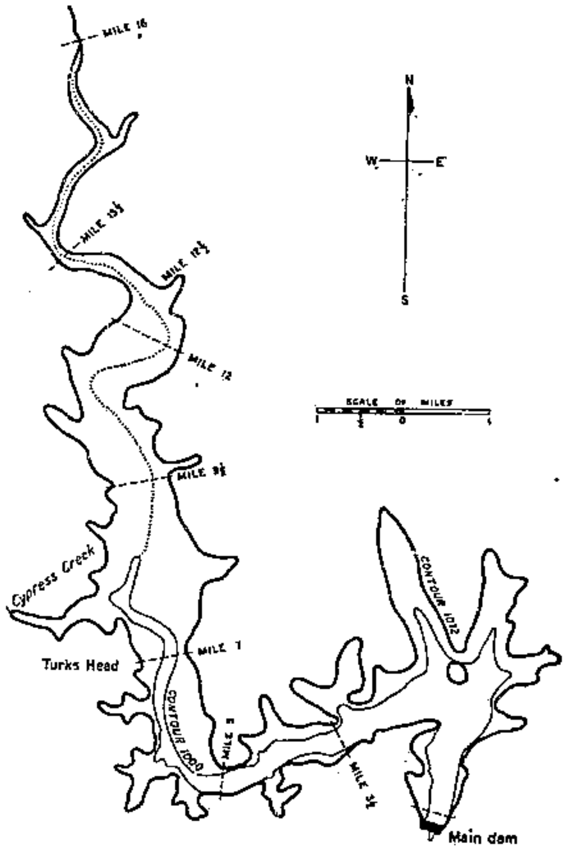

FIGURE 10.—Medina Reservoir, Medina River.

The map of Medina Reservoir (fig. 10) shows roughly, among other features, the contours at the spillway crest—elevation 1,072—at elevation 1,000, the old river channel above elevation 1,000, and approximate distances from the dam in miles. The broken lines indicate the cross sections where soundings were made during the silt survey of 1925.

Silt depths were measured in eight sections between extreme backwater and the dam. Distances from initial points were measured on a one thirty-second inch tinned airplane wire, marked at intervals of 100 feet, stretched from shore to shore where widths did not exceed 1,300 feet. For sections of greater width, one end of the wire was fastened on one shore and distances were measured by unwinding the wire from a hand reel and counting the markers.

[6] Measured on Medina Valley Irrigation Co. and U.S. Army topographic maps.

After sounding from one shore as far as the line permitted, it was taken up and anchored at a point, previously tied in by triangulation, on the opposite shore.

The total silt volume was found to be 2,692 acre-feet, equivalent to a yearly average of 207 acre-feet or 0.35 acre-foot per square mile of drainage area per year. Volume-weight determinations of samples of deposited material indicated that the average weight of the dry material per cubic foot of deposit approached 30 pounds. At this rate of accumulation it would require over 1,200 years for the silt of the nature of that found at the time of the survey to occupy the entire storage capacity.

The silt is gray in color except on the surface of the deposit, where vegetable matter has colored it a bluish black. No grit can be detected in it with the fingers. The liquid mud is extremely fine, 99.5 percent passing a no. 300 sieve.

At and near the elevation of the spillway crest, in the main river channel at the upper end of the reservoir, there were some bars of sand and gravel but not in quantity sufficient to indicate that the reservoir had any influence on its deposition.

In September 1930, owing to scarcity of rainfall and the increased demand for water on the irrigation project, the water surface in the reservoir reached a lower elevation than at any time since the initial filling. All water except that in the main river channel, extending from the dam to a point approximately 4 miles upstream, was drawn out.

While the deposit was exposed to the sun and atmosphere, material consolidation took place rapidly, as indicated by shrinkage cracks, subsidence of the surface, and the growth of weeds upon it. In a depression near mile 5, the original surface of the soft silt was definitely located in the fork of a dead pecan tree left standing in the reservoir. The depth of the deposit had been reduced from 7.2 to 2.7 feet. Since the soft deposit before being exposed contained about 30 pounds of dry material per cubic foot of mud, the corresponding value at the time this measurement was made approached 80 pounds.

From volume-weight determinations of many samples, made over a period of 5 years, and a careful and thorough inspection of the exposed deposits at low-water stages, the average dry weight per cubic foot of deposit following the period of exposure was estimated to be 63.6 pounds. Obviously, the 2,692 acre-feet of material measured in the reservoir during September and October 1925 was reduced in volume to 1,270 acre-feet by the end of 1930, due to the shrinkage caused by exposure to the sun and atmosphere, the kneading and mixing resulting from floods scouring blocks of exposed consolidated silt from place, rolling them down the stream, and finally depositing them on the softer sediment at lower elevations, and the natural shrinkage which takes place in submerged deposits as water is slowly liberated.

There is no way of ascertaining just what the ultimate average dry weight per cubic foot of deposit will be, but it seems rational to expect that it will approximate 74 pounds. (See samples 7 and 8, table 15.) There is a slight probability that the average density, equivalent to that represented by samples 4 and 6, table 15, will exist during the useful life of a reservoir. However, for a reservoir, having a prospective life of several centuries, as Medina Reservoir has, the lower value may be reached.

The exposed silt was confined to the channel and depressions on the reservoir bottom. There was no silt on the hummocks on the large flat areas on each side of the main channel although they had been submerged by water to depths of from 40 to 100 feet for long periods of time. On the other hand, all depressions on the flats contain silt. This condition is due to the movement of silt in the form of liquid mud on the reservoir bottom. The mud, having a greater specific gravity than water, flows on extremely flat slopes. The silt settling on the precipitous slopes of the river channel flows immediately down them and then moves along the bottom of the channel until blocked by the dam.

Streams that frequently overflow their banks during floods build up the adjacent banks, by the deposition of silt, to such an extent that there is a considerable slope away from the channel. When such topography exists in a reservoir, all silt deposited on the side slopes flows obliquely away from the axis of the stream. This accounts for the fact that main river channels in reservoirs retain their identity for a long period of time (*19*) although the volume of the annual silt deposit may exceed the original capacity of the channel within the reservoir.

EFFECT OF A FLOOD ENTERING A RESERVOIR PARTLY FILLED WITH CLEAR WATER

Heavy precipitation occurring April 20, 1926, on the Medina watershed produced run-off which raised the water surface of Medina Reservoir from elevation 1,034.3 feet on April 20 to 1,042.7 feet at 3 p.m. on April 28. According to the storage capacity curve of the Medina Valley Irrigation Co., the volume between these elevations is 26,000 acre-feet.

In order to get information relative to the behavior of muddy flood water entering a reservoir partially filled with clear water, inspections were made from a motor boat, starting from the dam, on April 23 and 29. On April 23, at a point 12.5 miles above the dam, water was running rapidly over a riffle, indicating that the upstream limit of slackwater had been reached. At this point the water had a light color. Owing to the difficulty of holding the boat in the swift current, only a single sample from near the bottom was taken in this section.

At mile 12, where the depth of water was 10 feet, samples were taken at the surface, at one half and three fourths depth, and at the bottom. At all other points of sampling, samples were taken at the surface, one fourth, one half, and three fourths depth, and at the bottom. At mile 9½, where the depth of water was 26 feet, all of the samples were light gray in color. At mile 7, where the depth of water was 54 feet, mud on the weight indicated that the sampling equipment disturbed the soft mud on the bottom. This accounts for the increased percentage of silt in the bottom sample and silt washed from the equipment as the bottom sample was being raised probably increased the percentage in the sample from three fourths depth. All of the samples were light gray in color but an increased intensity of color in samples from the surface to the bottom was apparent.

At mile 5, where the depth of water was 64 feet, the samples from the surface and one fourth depth showed no signs of color, but those from one half and three fourths depth and the bottom had the characteristic light color. At mile 3.5, where the depth of water was 89 feet, the samples from the surface and one fourth depth were clear but the other three were light gray in color. Samples taken at mile 2.75, where the depth of water was 90 feet, were clear from the surface to the bottom.

On April 29, samples from a vertical at mile 7 showed less color than those taken in the same section April 23. At miles 5 and 3.5, the water appeared to be clear on the surface although samples from below were slightly colored. Samples from mile 2.75 were clear from surface to the bottom. A large area of the water surface from mile 2 to mile 7 was covered with vegetable matter consisting of bark, leaves, and decayed wood, moved about by the wind and carrying grains of sand picked up in turbulent water before entering the reservoir. In lowering the sampling equipment through this drift some of the sand load was displaced and taken into the water samples from below.

Upon examination of these samples it became obvious that the bulk of the silt entering the reservoir in suspension had settled previous to the taking of samples on April 23, as only a small part of the extremely fine material remained in suspension. The color was noticed in the samples after standing 2 weeks. The percentages of silt in these samples by weight are given in table 12.

TABLE 12.—*Percentage by weight of silt in samples from Medina Reservoir on 2 days in April 1926*

SAMPLES TAKEN APRIL 23

Portion of depth sample was taken	Mile 12½	Mile 12	Mile 9½	Mile 7	Mile 5	Mile 3½	Mile 2¾
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Surface		0.030	0.021	0.006	0.002	0	0
¼ depth			.022	.004	.002	0	0
½ depth		.032	.021	.013	.019	.026	0
¾ depth		.032	.027	[1].038	.011	.018	0
Bottom	0.026	.029	.028	[1].002	.022	.018	0

SAMPLES TAKEN APRIL 29

Portion of depth sample was taken	Mile 12½	Mile 12	Mile 9½	Mile 7	Mile 5	Mile 3½	Mile 2¾
Surface				0.012	0	0.018	0.003
¼ depth				0	.013	.004	0
½ depth				0	.008	.004	.008
¾ depth				[1].020	.013	.007	0
Bottom				.002	.007	[1].026	[1].020

[1] Bottom disturbed by sampling equipment.

Muddy water entering a reservoir partly filled with clear water does not mix with the clear but forces it down the reservoir toward the dam. This process has been definitely illustrated by samples from stations in the Brazos River drainage. Following long periods of drought, the first water coming downstream due to a flood originating on the upper portion of the watershed is noticeably free from silt, being the clear water forced from pools by the heavier muddy water. No suspended silt will be carried through the reservoir and over the spillway, therefore, until all of the clear water has been discharged.

NATURE OF SILT IN MEDINA RESERVOIR

The storage capacity of Medina Reservoir at elevation 1,072 feet, that of the spillway crest, is 254,000 acre-feet. The 1,072 contour extends up the Medina River 16 miles from the dam. It was reported that no water had passed over the spillway since 1919. Early in May 1929, the water surface had subsided to elevation 997 feet, the lowest stage since the first filling. This stage is 30.5 feet above the invert of the outlet conduit and the available water supply in storage was 22,000 acre-feet or less than one eleventh of the total capacity. Backwater is estimated to have extended to the mouth of Cypress Creek, about 8 miles above the dam. The subsidence of the water surface exposed a considerable area of the silt which had been deposited at higher stages.

Rains on the watershed of the reservoir, May 12 and 13, caused a flood which had practically subsided by May 15 but had raised the water surface to elevation 1,003 feet by adding 7,563 acre-feet of water to the available stored water supply. This combination of conditions offered a good opportunity to secure information of value and May 15 and 16 were spent making an investigation of silt conditions in the reservoir.

The information particularly desired was as to the behavior of silt-laden inflow, scouring of silt deposits, mechanical composition of deposits, and volume-weight of the material.

BEHAVIOR OF INFLOW

With the water surface at elevation 997 feet before the rise the extreme backwater point is estimated to have been about 8 miles above the dam, near the mouth of Cypress Creek. After the rise the water surface stood at elevation 1,003 feet and the extreme backwater point was one fourth mile above Cypress Creek, or approximately 8¼ miles from the dam.

The first floating drift was noted 5¾ miles above the dam and 2½ miles below the extreme backwater. The 2½-mile movement of drift toward the dam was probably due to the current set up by the flood water in the narrow sections of the reservoir at the existing elevation of the water surface. Muddy water at the surface was noted at mile 7¾ or one half mile below extreme backwater. The inflow, which had dropped to 75 second-feet, was very muddy, due to erosion of the silt beds by high-velocity flow, for a distance of approximately 600 feet immediately upstream from the backwater point (pl. 1, A).

The section shown in plate 1, A, is submerged about 67 feet when the surface of the water in the reservoir is at the elevation of the crest of the spillway. As the water lowered, the silt laid down at higher stages was exposed and the surface dried and cracked in blocks. The flood of May 13 to 14, 1929, scoured off these blocks and part of the deposit below them. The part of the deposit remaining was very soft, indicating that the consolidation due to exposure and drying did not extend to a great depth in the deposit. The trees shown were killed by previous submergence.

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To trace the course of the muddy inflow, sets of samples and simultaneous velocities were taken from the surface to the bottom in verticals at three sections. The first of these verticals was the middle of the channel, about 100 feet downstream from the last ripple of the inflow, where the depth was 4.0 feet. The results given in table 13 show a nearly normal distribution of velocity and a very even distribution of silt from the surface to the bottom.

TABLE 13.—*Samples from Medina Reservoir taken at point of inflow and at mouth of Cypress Creek, May 15, 1929*

SAMPLES TAKEN AT POINT OF INFLOW

Depth at which sample was taken	Velocity of water	Silt by weight
Feet	*Feet per second*	*Percent*
0.1	1.32	0.785
1.1	1.35	.880
2.1	1.32	.875
3.1	1.23	.895
[1] 4.0	----------	----------

[1] Bottom.

SAMPLES TAKEN AT THE MOUTH OF CYPRESS CREEK

Depth at which sample was taken	Velocity of water	Silt by weight
0.1	0.20	0.019
1.7	.22	.079
2.7	.40	.066
3.7	.44	.095
4.7	.68	.106
5.7	.72	.320
[1] 6.6	----------	----------

[1] Bottom.

The second of these verticals was the middle of the channel at the mouth of Cypress Creek, about ¼ mile downstream from the point of inflow, where the depth of water was 6.6 feet. The velocities increased from the surface toward the bottom. The samples taken in this vertical show a fairly uniform increase of percentage of silt with the increase in depth, indicating the settling of the silt toward the bottom as the mean velocities are reduced. The results are also given in table 13. The sampling equipment disturbed the deposited material, which probably accounts for the increased percentage of silt in the sample from the depth of 5.7 feet.

The third vertical was in the old river channel at mile 7, where the depth of water was 17.7 feet. So far as could be detected by eye or the current meter, there was no movement of the water in the entire depth. It is possible, however, that near the bottom the silty water was flowing but at too low a velocity to be detected with the meter. The percentage of silt by weight in the samples taken at depths of 12.8, 15.8, and 16.8 feet were 0.004, 0.019, and 0.155, respectively. To a depth of about 12 feet the water was free from silt and below that depth the percentage was insignificant except in the sample taken at 16.8 feet in which the silt observed was probably due to disturbing the deposited mud with the equipment.

On examining the map of the reservoir, it will be noted that with the water surface near elevation 1,000 feet, the greater part of the lake above mile 7 is confined to the channel of the river which is so narrow that the crest of the flood probably caused velocities for some distance below the mouth of Cypress Creek. This accounts for the muddy water at the surface one fourth mile below the point of inflow. The distribution of silt in the verticals seems, however, to support the supposition that the silt load of inflowing water soon settles to the bottom of the reservoir in the form of liquid mud and then flows into depressions or down the valley until blocked by the dam.

SCOURING OF DEPOSITS

Where the water surface in a reservoir fluctuates as it does when water is drawn out for irrigation, the general average weight of the silt deposit will depend largely on the shrinkage which takes place in exposed deposits and the mixture of fine and coarse material, which may be produced by the scouring action of inflow when the water surface is low. The scouring effect of the small flood in Medina Reservoir can be seen in plate 1, A. At the point shown, as the water surface lowered, the deposits in the channel dried out to a depth estimated at 12 inches or more. When the flood came down, this hardened, cracked surface layer and part of the soft but tenacious deposit underneath were scoured off and carried downstream. The depth of the scour could not be determined but in some places it probably exceeded 2 feet, since soundings in this part of the old channel in 1925 showed depths of mud from 2.5 to 2.8 feet, which at that time was under approximately 30 feet of water.

An interesting form of silt was found in the bar shown in the foreground of plate 1, A, and a near view in plate 1, B. The surface of the silt deposit upstream in the old river channel, on being exposed to the atmosphere for some time, had dried and cracked into blocks, the cracks ranging in width up to 4 inches and probably exceeding 12 inches in depth. During the flood stage of the river, the hardened blocks were torn from the softer material below and were rolled downstream by the force of the current. The abrasion and wearing of the blocks as they rolled along the bottom reduced them to the cobble form shown in plate 1, B. The continuation of the flood for a longer period, subjecting the cobbles to further abrasion, would have resulted in complete disintegration.

In plate 1, C, an attempt was made to show the dip of the surface of the deposit. It is believed to indicate that while the surface of the deposit dried out and cracked to depths of from 12 to 18 inches, the material underneath remained soft enough to be squeezed out when the weight of the flood water was added and the channel removed its lateral support. Trees in the background protected this portion of the deposit from the scouring velocities.

Plate 2, A, shows a narrow strip of dried deposit which escaped the scouring action of the flood owing to the protection of the trees and indentations in the bank of the river channel. Had the flood been of greater magnitude or longer duration the remainder of the deposit would have been carried down stream.

Plate 2, B, shows an old silt deposit in Medina Reservoir 7¼ miles above the dam. Wave action prior to the flood of May 13 to 14, 1929, is believed to have been responsible for the erosion of the deposit in the manner shown.

Plate 2, C, is a near view of the deposit shown in B. The width of the cracks gives some idea of the shrinkage which takes place when fine silt dries out. Note also the breaking down of the surface into small blocks.

The data are not sufficient to warrant an estimate of the volume of silt picked up and moved downstream by the flood, but there is no doubt that it was considerable. The inflow of May 16 appeared to be loaded to capacity.

Examination of the deposits indicated that drying and consolidation of a deposit more than a foot below the surface takes place very slowly if below the ground-water surface. The deposit or bar shown in plate 1, A, was very soft. A shovel handle could be pushed into it to a depth of 18 inches with little effort and only the portion covered with the cobblelike material would support a man's weight.

The conditions found indicate that, in selecting a volume-weight factor for silt deposits in reservoirs, any allowances made on the basis of probably shrinkage and consolidation of the deposit should be small unless the deposit is exposed at intervals to the sun and atmosphere.

MECHANICAL COMPOSITION OF SILT

On the trip up the reservoir samples of deposited silt were taken from the bottom of the old river channel for the purpose of determining the mechanical composition and the relation of weight to volume. Sample no. 1 was taken 300 feet above the dam, no. 2 at mile 3½, and no. 3 at mile 7. These samples were taken in a 1-pound size coffee can attached to a 15-pound window weight, raised and lowered by means of a small rope. The weight was sufficient to bury the can in the soft deposit and permit a full-can sample to be taken. These samples consisted of liquid mud in which no grit could be detected with the fingers.

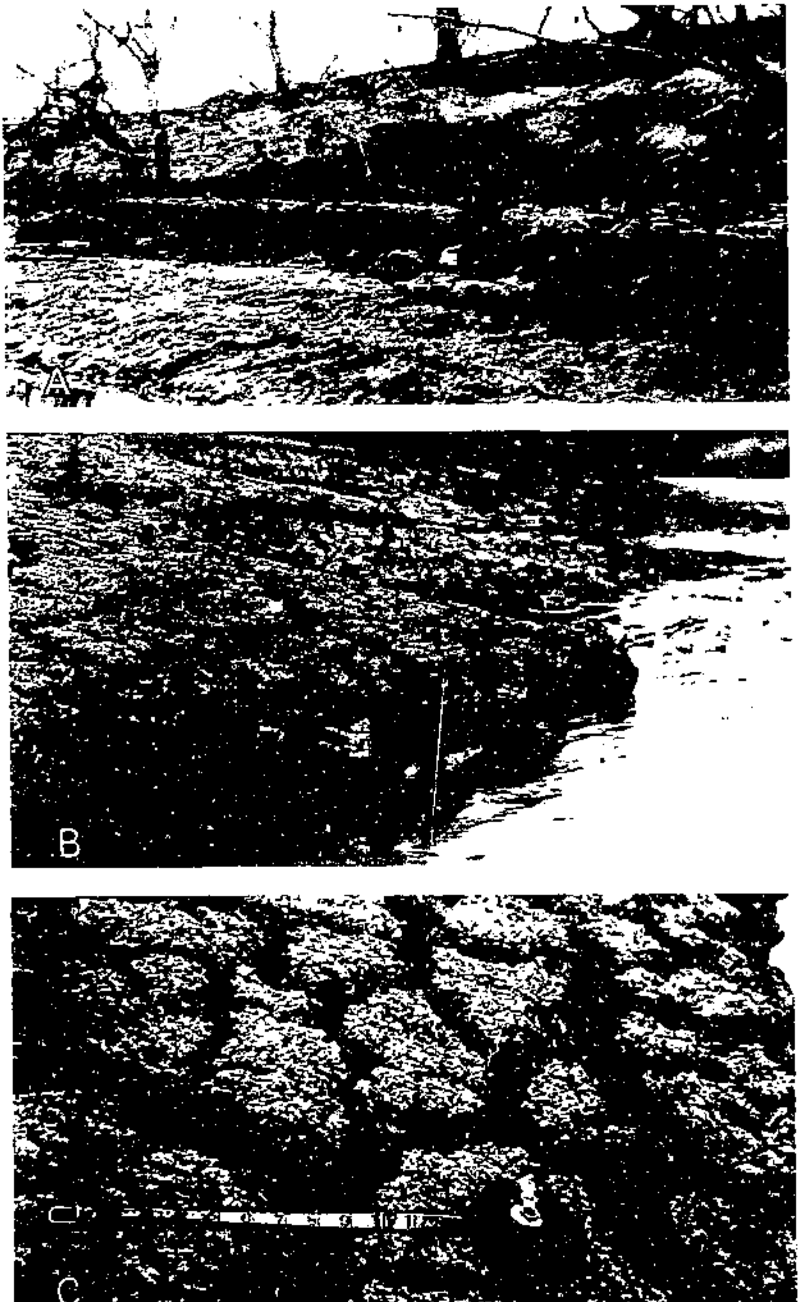
Sample no. 5 was taken at the point of inflow, one fourth mile above the mouth of Cypress Creek, from the bar shown in plate 1, A. The dried, cracked top layer of the original deposit had been scoured off by the flood and the sample was taken from the remaining soft silt by forcing a coffee can into it a few inches below its surface and about 1 foot above the water surface. The softness of the deposit indicated that, on exposure, dehydration and shrinkage of the deposit takes place very slowly.

On testing these four samples with sieves it was found that in each case the entire sample, with the exception of a trace of sand, shell, and vegetable matter, passed a sieve having 300 meshes to the inch. The only coarser material found was coarse sand which was noticed on the surface of the lower end of the bar from which sample no. 5 was taken. This sand was insignificant in quantity and was evidently brought down by the flood of the preceding day.

VOLUME-WEIGHT OF DEPOSITS

In order to determine the relation between the volume and weight of the deposited silt a number of samples were taken. Samples 1, 2, and 3, already noted, consisted of liquid mud taken from the

A, Upstream view of section of Medina River channel one fourth mile above mouth of Cypress Creek and $8\frac{1}{4}$ miles above Medina dam. B, A close view of the cobbles shown in the foreground (pl. 1, A). The cobbles are composed entirely of silt and were evidently produced by wearing and grinding of loosened blocks of dried silt as these blocks were torn from the top of the deposit and rolled along the bottom of the stream by the force of the current during the flood. C, Silt deposit on the right bank of Medina River about one fourth mile above Cypress Creek, which slumped during the flood of May 13, 14, 1929.



A, Remains of silt deposit after scouring effect of flood. B, Silt in Medina reservoir 7¼ miles above dam. C, Near view of the deposit shown in plate 2, B.

bottom, under water from 17 to 40 feet in depth. Sample no. 4 was one of the silt cobbles shown in plate 1, B, taken from the lower end of the bar, immediately above backwater. After being dried in the oven this sample was broken open, disclosing a very dense structure free from cracks and cavities. It is believed that the very dense structure and consequent high ratio of weight to volume was due to compacting caused by rolling of the cobble in a plastic state, along the bed of the channel.

Sample no. 5 was taken in the same location as sample no. 4. A hole was dug in the deposit and a coffee can tapped into the side of the excavation, a few inches below the surface of the mud and at an estimated depth of 2 feet below the original surface of the deposit, before scouring had taken place. It therefore represents the lower portion of a deposit which has been exposed and subjected to shrinkage from partial drying.

Sample no. 6 was a 1-inch cube cut from the surface of the deposit shown in plate 1, C, and was taken to represent the surface of a deposit after a long period of exposure to the atmosphere and the resulting contraction. On breaking this sample open after drying in the oven, it was found to be very dense and free from cavities. This dense structure was confined to the upper 2½ inches of the undisturbed blocks of silt and is probably due to being kneaded, while in a plastic state, by the flood water.

Sample no. 7 was cut in the form of a cube from 2 to 3 inches below the surface of the deposit shown in plate 2, C. This deposit was on the right bank of the old river channel at mile 7 and had been exposed for a sufficient length of time to show pronounced shrinkage. The sample showed a few small cracks on the surface and many small irregular cavities throughout its interior.

Sample no. 8 was also taken at mile 7, about 500 feet from the right bank of the old river channel on a wide flood plain. The deposit in this location was at an elevation from 10 to 15 feet above that from which sample no. 7 was taken. This material also had been exposed for a long time and showed characteristic shrinkage. The sample contained fine cracks and small cavities.

Two months elapsed before time was available for determining the volume-weight relations of these samples. On opening the cans containing samples nos. 1, 2, and 3, which consisted of liquid mud dipped from the bottom of the reservoir, it was found that some settlement had taken place, as evidenced by free water on the surface of the mud. This is thought to be due to the liberation of water held in the mud by virtue of its structure, along the inner surface of the cans at a greater rate than it would be liberated from natural deposits under several feet of water. The free water was siphoned off and the remaining mud was used in determining the volume-weight ratio. By this procedure, the weights obtained for these particular samples are higher than those existing in the undisturbed deposits of the same age.

A sample taken October 7, 1925, at mile 7, from under 50 feet of water, originally weighed 80.75 pounds per cubic foot and the weight of the dry material per cubic foot of deposit was 30.72 pounds. Another sample taken April 29, 1926, from under 53 feet of water in the same section, originally weighed 81.51 pounds per cubic foot and the dry material per cubic foot of deposit weighed 29.86 pounds. The original determinations of the weights of these samples were made soon after the samples were taken and before free water appeared at the surface.

A summary of the results of the volume-weight determinations is given in table 14. It will be observed that the dry weight per cubic foot of deposit varies from 36.1 to 106.1 pounds.

TABLE 14.—*Original weight, percentage of dry silt by weight, and weight of dry material per cubic foot of deposit of samples taken from Medina Reservoir during May 1929*

Sample no.	Original weight per cubic foot of deposit	Weight of dry silt	
		Percentage of original weight	Per cubic foot of deposit
	Pounds	*Percent*	*Pounds*
1	80.553	44.817	36.101
2	88.936	50.632	45.030
3	88.262	52.629	46.451
4	138.749	76.500	106.143
5	92.601	53.175	49.240
6	117.569	77.947	91.641
7	105.203	69.322	72.928
8	108.670	68.493	74.435

SILT IN LAKE WORTH

Lake Worth is formed by an earthen dam with a concrete spillway section across the West Fork of Trinity River about 5 miles northwest of Fort Worth. No topographic surveys from which the original capacity could have been determined were made prior to the filling of the reservoir. Estimates made since the storage of water range from 42,000 (*7*) to 47,177 (*19*) acre-feet.

The drainage area includes 1,870 square miles (*5*), the most of which is classified as rolling. Approximately one third of the area is cultivated farm land and the other two thirds, timber and grassland. The watershed receives an annual rainfall of 32 or 33 inches (*21*).

In April 1925, owing to the regular water demand of the city of Fort Worth and the lack of precipitation on the drainage area, the water surface was drawn down to an elevation 4.5 feet below spillway crest. This was reported to have been the lowest stage since the reservoir was first filled, 11 years before. The receding water surface left large areas of silt exposed and afforded an opportunity to examine the silt deposited under reservoir conditions.

The sketch map of Lake Worth (fig. 11) shows the original flow line at the elevation of spillway crest, highway bridges, and other features, for the purpose of illustrating locations of observations.

At the time of the survey water was in the old channel below Ten Mile Bridge. A narrow arm of shallow backwater extended along the south side of Todd Island for a distance equal to three fourths its length. Water between the lower end of Todd Island and Eagle Club was confined to the old channel, except in two large coves on the north side. Greer Island was completely surrounded by water but the water was so shallow that it was with difficulty that a trip with a small boat of slight draft was made around the island. Below Greer Island the channel was submerged by water.

A 1⅛-inch octagon wooden rod marked in feet and tenths of a foot was used to measure depths of exposed silt deposits which were sufficiently solidified at the surface to support the weight of a man. This rod could be pushed through the silt to the original ground surface with little effort. On the soft areas it was necessary to estimate the silt depths by observing the exposed parts of fence posts in the silted areas. At the edge of the reservoir, where no silt had been deposited, the tops of posts averaged 5 feet above the ground surface, while in the deposits only a few inches were exposed or they were entirely covered.

The silt deposit at Todd Island ranged in depths from 0 at the edge to a maximum of 5 feet which was probably in the channel of the small creek coming in from the northwest. Measured mud depths between this island and Eagle Club ranged from 1 foot to 5 feet, the average of 15 soundings being 3.4 feet. Depths of mud around Greer Island ranged from 3 to 5.8 feet, the average of 16 soundings being 4.4 feet.

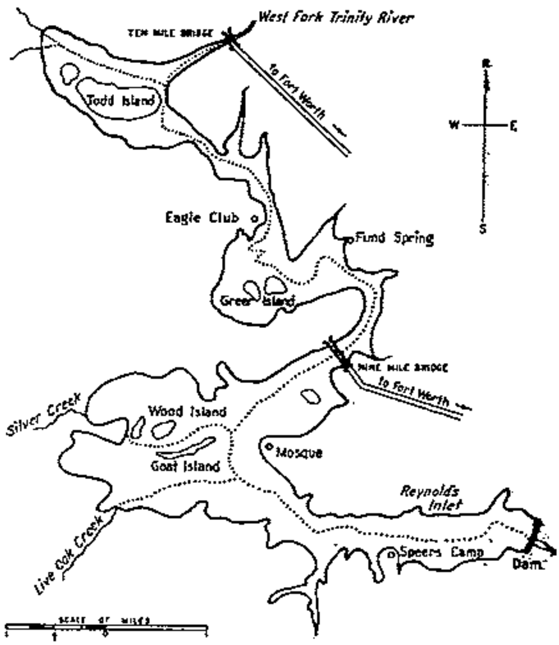


FIGURE 11.—Lake Worth, West Fork of Trinity River.

From Fund Spring down to the dam soundings were made in 20 sections from a boat. The silt depths varied from zero to 5 feet. Soundings in the old river channel showed the deposit to range from 3.9 to 5 feet in depth.

The volume of silt as estimated from these soundings was 10,890 acre-feet, or an average annual accumulation of 1,000 acre-feet over a period slightly less than 11 years. Three years later, in 1928, T. U. Taylor made a silt survey of the lake at a stage which permitted sounding from a boat over the greater part of the area. He found the accumulation of silt to be 13,837 acre-feet (*19*).

The silt deposit one third mile south of the Eagle Club house on the west side of the river channel was 4.8 feet in depth and was so soft in places that it would not bear a man's weight.

Two narrow sections (fig. 11), one between Todd and Greer Islands and the other in the vicinity of the Nine Mile Bridge, practically divide the reservoir into three distinct basins. These act as retarding basins (*19*), offering protection to the dam in case of floods which might otherwise overtax the spillway capacity. They are also effective as settling basins. Observations made during the silt survey of 1925 indicated that 100 percent silting had taken place in parts of the upper basin above Todd Island and was being approached in parts of the middle basin back of Greer Island. Small floods drop practically all of the suspended material in the upper basin, increased inflow carries part of its suspended load into the middle basin, and larger floods do not drop all of the suspended matter until the lower basin is reached.

RESERVOIR EFFECTIVE AS SILT TRAP

For the purpose of determining the relative portion of the suspended silt load deposited in the reservoir, samples of the inflow at Ten Mile Bridge and of the outflow over the crest of the spillway were taken during a period of several months whenever the inflow was of sufficient volume and turbidity to warrant the study. The results for June and July 1928 include maximum silt load for the inflow and are offered in table 15 as the best illustration of the relationship found.

TABLE 15.—*Percentage of silt by weight in samples of water taken at Ten Mile Bridge and on the crest of the spillway of Lake Worth during June and July 1928*

Date	Silt by weight			Date	Silt by weight		
	At Ten Mile Bridge	Over spillway crest	Discharge [1] (*6*)		At Ten Mile Bridge	Over spillway crest	Discharge [1] (*6*)
	Percent	*Percent*	*Second-feet*		*Percent*	*Percent*	*Second-feet*
June 1	0.006		38	July 1	0.119	0.009	2,190
June 2			78	July 2	.131	.006	2,860
June 3			256	July 3	.117	.014	3,140
June 4			513	July 4	.119	.011	2,440
June 5			972	July 5	.055	.011	982
June 6		0.018	1,390	July 6	.022	.005	309
June 7			1,720	July 7	.026	.008	202
June 8	.204		1,650	July 8		.002	156
June 9	.251	.004	1,110	July 9		.001	110
June 10	1.310		999	July 10		.008	78
June 11		.010	972	July 11	.275	.011	80
June 12		.013	664	July 12	.272	.006	256
June 13	.305	.012	972	July 13	.158	.005	437
June 14	.370	.012	1,170	July 14		.003	318
June 15	.344	.006	1,520	July 15	.058	.000	214
June 16	.240	.021	1,950	July 16	.024	.004	133
June 17	.394	.005	2,330	July 17	.002	.008	94
June 18	.128	.020	2,960	July 18		.013	70
June 19	.137	.013	3,100	July 19		.004	38
June 20	.151	.016	2,360	July 20			22
June 21	.086		999	July 21		.000	14
June 22	.040	.012	458	July 22		.004	12
June 23	.012	.000	287	July 23		.008	22
June 24		.008	214	July 24		.000	54
June 25		.006	144	July 25		.000	202
June 26		.005	612	July 26	.055	.008	418
June 27	.297	.008	1,260	July 27	.506	.005	604
June 28	.508	.007	1,360	July 28		.010	1,140
June 29	.457	.006	1,420	July 29	.265	.007	1,620
June 30	.765	.011	1,780	July 30	.162	.000	1,880
				July 31	.178	.003	2,020

[1] Discharge for period, 114,300 acre-feet.

Records of the flow at Ten Mile Bridge are not available, but records of the discharge over the spillway for June and July 1928 show that the total discharge during those 2 months was 114,300 acre-feet (*6*), which is 3.4 times the capacity of the reservoir in July of the same year, as determined by Taylor (*19*).

There are no data from which the time interval for flow between Ten Mile Bridge and the dam can be estimated with accuracy but a comparison of the percentages of silt by weight at the two sections indicates that the reservoir is very effective as a silt trap. Assuming that the water entering the reservoir June 10, with a silt charge of 1.31 percent by weight, passed the spillway June 16, with a load of 0.021 percent by weight, the portion of the load which was deposited within the storage basin was 98.4 percent of the silt which entered the reservoir in suspension. It is probable that the silt which passed the spillway June 16 was of local origin from side drainage immediately above the dam, in which case the effectiveness of the reservoir as a silt trap was in excess of 98.4 percent.

CHARACTER OF SILT IN LAKE WORTH

On April 26, 1929, samples of deposited silt were taken at elevations above the spillway crest, from the bottom of Lake Worth in various sections throughout its length, and from the river channel near Ten Mile Bridge, for the purpose of determining the character, the volume-weight relation, and the variation in mechanical composition of the deposit from the dam to backwater.

The samples were taken in deep water from a boat. A coffee can fastened to a 15-pound window weight, lowered and raised by means of a small rope, was used to take the samples. The silt was so soft that the weight carried the can to the bottom of the deposit, allowing a full-can sample to be taken.

Reference to figure 11 will aid in locating the points at which samples were taken. Sample no. 1 was taken in the middle of the reservoir about one fourth mile above the dam, in what was thought to be the old channel of the river, from under water between 30 and 40 feet in depth. This sample contained 18.7 pounds of dry material per cubic foot of deposit. On the basis of 2.65 for the specific gravity of the dry material, water occupied 88.59 percent of the space and the absolute voids were 88.66 percent, which indicates that the material was colloidal in character and of flocculent structure.

Sample no. 2 was taken from the reservoir bottom, in the old river channel about 1 mile south of the Mosque. The sample contained 21.7 pounds of dry material per cubic foot of deposit. Assuming the specific gravity of the dry material to be 2.65, water occupied 86.30 percent of the space and the absolute voids were 86.87 percent which indicates that the material had colloidal characteristics and a structure combining honeycomb and flocculent characteristics.

Sample no. 3 was taken from the bottom of the reservoir, in the old river channel, 100 feet above Nine Mile Bridge and about 4¾ miles above the dam. This sample contained 22.6 pounds of dry material per cubic foot of deposit. Assuming the specific gravity of the dry material to be 2.65, water occupied 84.48 percent of the space and the absolute voids were 86.31 percent, which indicates that the material had colloidal characteristics and a structure combining honeycomb and flocculent characteristics. The difference in the space occupied by water and the absolute voids was due to gas in the soft mud.

Sample no. 4 was taken in 6 feet of water, 500 feet north of Greer Island and approximately 6 miles above the dam. It contained 29.4 pounds of dry material per cubic foot of deposit. Assuming the specific gravity of the dry material to be 2.65, water occupied 79.82 percent of the space and the absolute voids were 82.16 percent, which indicates a slightly colloidal characteristic and a honeycomb structure.

These samples felt creamy and not the slightest indication of grit could be detected with the fingers. A thin layer at the surface of the deposit had a very dark, almost black, color, which was assumed to be due to coloring by decaying vegetable matter. This material at the surface of the deposit was slightly condensed and had the consistency and "feel" of freshly clotted cream, but the material under the surface skin showed no signs of compacting.

Samples nos. 5, 6, and 7 were taken from a deposit under 8 inches of water in the first narrow section below Todd Island and about 8 miles above the dam. This deposit had been exposed to the atmosphere during lower stages of the water surface and shrinkage, resulting in cracking of the surface to depths of 12 or more inches had taken place. Later, floods had again raised the water level and submerged the deposit, and fresh silt had filled the cracks and formed a layer from 1 to 2 inches in thickness over the old dried surface. The difference between the consistencies of the old and new deposits made it possible for the hand to detect the contraction cracks. They were about 2 inches in width and the hand could be inserted to a depth of 12 inches, the indications being that they were considerably deeper. The new deposit was so soft that it was almost liquid but the old deposit was plastic and showed contraction to the extent of the detected cracks. The surface of the old deposit was fairly firm and tough but was less dense as the depth increased.

Sample no. 5 was taken by forcing a coffee can into the deposit, digging it out with a shovel and shearing the silt off at the plane of the top, making the volume of the same equal to the capacity of the container. Water was permitted to escape from the can as it was being forced into the deposit, through a small nail hole in the bottom. This sample contained 45.3 pounds of dry material per cubic foot of deposit. Assuming the specific gravity of the dry material to be 2.65, water occupied 72.59 percent of the space and the absolute voids were 72.59 percent, showing that it was thoroughly saturated and contained no gas pockets. As a check, sample no. 6 was taken at the same location. An attempt was made to cut a cube of the silt but owing to irregular seams, this could not be accomplished and an irregular-shaped piece was broken out of a block of the deposit and its volume determined immediately, in a rather rough way, by the displacement of water. This sample indicated a weight of 47.2 pounds of dry material per cubic foot of deposit as compared with 45.3 for sample no. 5.

Sample no. 7 was taken at the same location with the object of comparing the weight of the surface layer of the old deposit with the weight of the material taken from a few inches under the surface, indicated by sample no. 5. A lid of a coffee can was forced into the deposit and a sample of the surface about one half inch thick obtained. This sample contained 53.9 pounds of dry material per cubic foot of deposit, which indicates a considerably greater density at the surface of the deposit than a few inches deeper.

Sample no. 8 was taken from the main channel of the river at Ten Mile Bridge, which is about 9½ miles above the dam. There was little or no velocity at this point and the sample, which contained 33.4 pounds of dry material per cubic foot of deposit, was made up almost entirely of fine silt similar to that in the main reservoir, though an occasional trace of grit could be detected with the fingers. Assuming the specific gravity of dry material to be 2.65, water occupied 70.95 percent of the space and the absolute voids were 79.75 percent, which indicates the presence of gas or air.

Sample no. 9 was taken about 250 feet below Ten Mile Bridge, on the left bank of the main channel. The bank had been built up with silt deposited during overflow and sloped away from the channel to a low, swampy area 150 feet from the stream. Through this ridge a small drainage ditch, about 3 feet deep and 18 inches wide, had been dug. The side of the ditch was cleaned off and a can forced laterally into the material at an elevation estimated to be 3 or 4 feet above spillway crest. When the can had been forced in flush with the face of the excavation it was dug out, and the excess material at the top was shaved off level with the top of the can. To the feel, this material appeared to consist of fine sand. It contained 99.2 pounds of dry material per cubic foot of deposit. On the basis of 2.65 for the specific gravity of the dry material, water occupied 31.71 percent of the space and the absolute voids were 39.93 percent, which indicated air space.

It was desirable to procure a sample of the sand, which might be carried into the reservoir during high floods, from the bed of the stream; but at low stages the velocity is so slight that the bed is covered by very fine silt like that illustrated by sample no. 8. As an extreme example of the coarse bed material immediately above the reservoir, a sand bar in the bed of Walnut Creek (a tributary of the West Fork of Trinity River) 3 miles above Ten Mile Bridge, was selected. Sample no. 10 was taken by forcing a can into the side of this bar about 2 feet below the surface and about 1 foot above the water surface in the creek. This sample contained 93.5 pounds of dry material per cubic foot of deposit. The specific gravity of this material in a dry state was found to be 2.658. Water occupied 32.83 percent of the space and the absolute voids were 43.53 percent, indicating the presence of air.

Table 16 is a summary of the results of the volume-weight determinations. The specific gravities of samples nos. 3 and 10 were 2.639 and 2.658, respectively—values within the normal range of those found in other tests of silt. The proportion of vegetable matter in sample no. 3 was found by ignition to be 4.7 percent by weight.

TABLE 16.—*Results of volume-weight determinations of samples of silt deposits from Lake Worth near Fort Worth, taken April 26, 1929*

Sample no.	Original weight of deposit per cubic foot	Dry silt by weight	Weight of dry silt per cubic foot of deposit	Sample no.	Original weight of deposit per cubic foot	Dry silt by weight	Weight of dry silt per cubic foot of deposit
	Pounds	*Percent*	*Pounds*		*Pounds*	*Percent*	*Pounds*
1	73.882	25.327	18.712	6	93.144	50.671	47.195
2	75.413	28.732	21.667	7	94.357	57.160	53.934
3	75.202	30.042	22.592	8	77.625	43.062	33.426
4	79.143	37.191	29.434	9	118.911	83.386	99.155
5	90.507	50.066	45.343	10	114.315	81.828	93.541

Portions of samples nos. 1, 2, 3, 4, 5, 9, and 10, representing the several locations from which samples were taken, were tested with sieves to determine the mechanical composition. The results of the sieve analyses are given in table 17.

TABLE 17.—*Mechanical analysis of samples of silt from Lake Worth near Fort Worth, taken Apr. 26, 1929*

Sample no.	Proportion of silt by weight passing and retained on sieves with specified number of meshes per inch							
	Retained on 10	Passing 10, retained on 20	Passing 20, retained on 35	Passing 35, retained on 65	Passing 65, retained on 100	Passing 100, retained on 200	Passing 200, retained on 300	Passing 300
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	0	0	0	0	0	0	(1)	100.00
2	0	0	0	0	0	0	(1)	100.00
3	0	0	0	0	0	0	(1)	100.00
4	0	0	0	0	0	0	(1)	100.00
5	0	0	0	0	0	0	(1)	100.00
9	0	0	0	.66	10.91	71.21	8.98	10.23
10	0	3.78	14.92	65.70	12.42	2.83	.17	.18

[1] Sample was tested first with the 300 sieve. With the exception of a trace of organic matter, the entire sample passed the sieve.

To get additional information as to whether the bulk of the silt load is carried in suspension to the dams of large reservoirs or whether it settles soon after entering the slack water and, in the form of soft mud, flows along the slope of the reservoir bottom until blocked by the dam, additional tests were made to determine the rate of settling of the material taken from Lake Worth. Portions of the samples from different locations were placed in glass tubes three fourths of an inch in diameter and 40 inches in length. Since Lake Worth water was not available for these tests, water from routine daily samples of Brazos River stations, believed to contain the same kind of salt as Lake Worth water as they are from similar and adjacent watersheds, was added and, after the contents had been thoroughly agitated, the tubes were placed in a rack and the rate of settlement was observed. Readings were made at intervals ranging from 5 minutes to 48 hours. In each instance, the water column above the column of silt was clear within 1 hour.

The rates of shrinkage or settling of the columns of silt after the first hour are given in table 18.

TABLE 18.—*Shrinkage of silt columns throughout 7-day period*

Period	Shrinkage as percentage of 7-day total for sample no.—							
	1	2	3	4	5	8	9	10
1 hour	8.2	19.5	17.5	34.8	23.4	20.2	100.0	99.6
2 hours	56.9	47.3	50.2	66.3	41.7	41.9	100.0	99.6
4 hours	73.9	71.3	75.1	78.9	74.7	66.8	100.0	100.0
10 hours	80.6	78.0	82.2	84.9	83.3	81.7	100.0	100.0
1 day	85.6	84.6	87.9	90.5	89.8	89.1	100.0	100.0
3 days	93.6	94.1	95.1	96.9	96.6	96.1	100.0	100.0
5 days	99.1	99.2	99.1	99.4	99.4	99.5	100.0	100.0
7 days	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

It was not possible to cover minutely the entire area near the head of the reservoir, but the inspection was sufficient to indicate that comparatively little coarse material had been deposited in the reservoir proper and that such coarse material as has been transported down the river has been deposited in the delta within a mile of the head of the lake. Even in this area the greater part of the deposit seemed to be fine material deposited from water which at high stages backed into sloughs or flowed slowly through old channels. Considering the entire reservoir, the inspection at the head and the results of the mechanical analyses of the samples from various locations lead to the conclusion that by far the greater part of the present deposit is made up of very fine silt, and that coarse material in the deposit occurs only in limited areas near the head of the reservoir. There was no material of sufficient size or weight in the delta area to suggest that it had been rolled along the bed of the stream, but all material observed was such that ordinary river velocities would carry it in suspension.

The rapid clearing of the water above the silt columns in the tubes when tests were made to determine the rate of settling indicates that little silt is carried in suspension to such distant points in the reservoir as those at which samples nos. 1 and 2 were taken, and it is believed that the bulk of the deposit in the lower end of the reservoir reached its location by flowing along the bottom in the form of liquid mud. As stated, Brazos River water was used in preparing the tube samples for rate of settlement tests. It is possible, but not probable, that it differed enough from Trinity River water in chemicals in solution to affect the rate of settlement. The possibility is not borne out by observations of samples of muddy water taken at Ten Mile Bridge in which the rate of settlement was found to be comparable to that of the samples with which Brazos River water was used.

LAKE KEMP

Lake Kemp, located about 10 miles north of Seymour, is formed by a hydraulic-fill dam 100 feet high, closing a portion of the wide, eroded valley of Big Wichita River. The dam was completed late in 1923 and storage of water was practically started at the time of completion, although sufficient water had been held to float the dredge during the construction period.

The drainage area of 1,990 square miles[7] is mostly grazing land covered with a sparse growth of mesquite and native grass. The steeper slopes show considerable erosion.

No topographic surveys of the reservoir site were made. Estimates of the capacity range from 550,000 to 640,000 acre-feet. A traverse around the storage basin on contour elevation 1,152 feet, or 2 feet above the spillway crest, includes 22,827 acres. Within the traverse, high land of unknown area rises above elevation 1,152 feet forming islands at high stages of storage. In November 1924 the water surface had been drawn down between 3 and 4 feet below the maximum stage that had been reached. In a depression near the upper end of the reservoir, an exposed silt deposit, 1.5 feet thick in the lowest part of the invert and feathering out to nothing toward the top of the sloping bank, was examined. The deposit was broken by shrinkage cracks up to 2 inches wide into blocks from 8 to 12 inches square. A sample cut from one of these blocks originally weighed 120.14 pounds per cubic foot and had a dry weight per cubic foot of deposit of 88.77 pounds.

Measurements of silt depths were made in several sections between extreme backwater and the dam during November 1925, while the water surface in the lake stood at elevation 1,138 feet, 12 feet lower than the spillway crest. In all of the sections, zero silt depths were found on the tops of hummocks under different depths of water. In the river channel from the upper end of the lake toward the dam, the silt depths were 4.0, 3.2, 2.5, and 6.4 feet in different sections. A depth of 11.3 feet was found immediately above the dam in a borrow pit which had been excavated below the level of the river channel bottom. Apparently, the silt settled soon after entering the slack water of the lake and in the form of liquid mud flowed from higher to lower elevations on the reservoir bottom, finally reaching the borrow pit at the dam where the maximum depth of the deposit was found.

The average surface slope of the soft silt deposit in the river channel was 1.34 feet per mile over a distance of 4.33 miles above the dam. This slope, forming an angle with the horizontal of less than 1′, indicates an angle of repose for such material approaching 0°.

Due to inability to sound sections in the upper third of the reservoir at a reasonable cost (owing to the fact that thick brush had been left standing there and to lack of knowledge of the original topography of the reservoir bottom) no estimate of the volume of silt was attempted.

A sample of the silt dipped from the bottom about 300 feet above the dam, November 21, 1925, weighed 84.88 pounds per cubic foot in its original condition and the dry weight per cubic foot of deposit was 37.05 pounds. Three determinations of the specific gravity of this silt in a dry state gave 2.687, 2.633, and 2.656, the average being 2.6586. Based on the average of these three determinations, the space occupied by water was 76.76 percent and the absolute voids amounted to 77.63 percent.

A sample, from the same location taken November 13, 1930, weighed 84.38 pounds per cubic foot in its orignal condition and

[7] Measured on U.S. Geological Survey map of Texas; scale 1 to 500,000.

the dry material weighed 35.94 pounds per cubic foot of deposit. Based on a specific gravity of 2.6586 for the dry material, the space occupied by water was 77.74 percent and the absolute voids were 78.30 percent.

Water is discharged from the reservoir through a battery of concrete pipes with inverts at or below the elevation of the bed of the river. The control gates are located about midway of the length of the conduits, allowing the upstream half of the pipes to be exposed to the pressure at all times. The liquid mud flows into the pipes until blocked by the gates. On opening the gates, the first rush of water carries a heavy load of silt and after discharging all mud within easy reach of the conduits, the discharge becomes clear. Water discharged from the reservoir flows down the river channel several miles and then is diverted into canals of the irrigation system.

The general arrangement is ideal for the removal of deposited material as the greater part of the silt is deposited on the wide, flat areas within the reservoir site, which usually are lower than the old channel banks. If drainage channels were constructed from these flats into the old river channel and all the vegetation and other obstructions were cleared from the reservoir bottom, a large volume of the deposited silt would flow into the main channel and finally reach the conduits where it would be discharged with the irrigation water.

SILT IN THE OLD RESERVOIR AT CISCO

The first reservoir constructed by the city of Cisco is located on a small creek 1 mile northwest of the business district. The original earthen dam was completed in 1889. Due to leakage through a lignite vein near the east end of this dam, a second dam was constructed of earth 450 feet upstream in 1902. In 1910 the second dam failed and the break was allowed to remain open until 1916 when the dam was rebuilt.[8]

The drainage area consists of soil well mixed with gravel and sand and offers considerable resistance to erosion and weathering. About 60 percent of the area has been cultivated but part of the cultivated area has reverted to pasture or grassland. In July 1927, a survey was made in connection with this reservoir and the drainage area was estimated to be 0.69 square mile, the original capacity 55 acre-feet, and the silt deposit 4.9 acre-feet.

Assuming that none of the silt deposited during the period 1889-1910 was carried from the reservoir during the 6 years when the break remained open and that all of the silt brought down during the 6 years passed through the basin, the 4.9 acre-feet of deposit would be the accumulation of 32 years, with a yearly rate of 0.22 acre-foot per square mile of drainage area.

Owing to the limited drainage area and the comparatively light rainfall, this reservoir has been practically dry for long periods during which the exposed silt deposit was subjected to enormous shrinkage. At the time of the survey only two small pools of water existed and the exposed silt was hard and dry. It was estimated that 75 percent of the deposited material weighed approximately

[8] Data obtained in a personal interview with J. M. Williamson, mayor of Cisco.

85 pounds per cubic foot of dry silt, and the dry material per cubic foot of deposit in the 25 percent submerged by water weighed 42 pounds, giving an average of 74 pounds of dry material per cubic foot of deposit.

Had this deposit been continually submerged by water shrinkage would have been slight, the dry material per cubic foot of deposit would have approached 30 pounds, and the silt volume would have been 12.08 acre-feet or practically 0.55 acre-foot per square mile of drainage area per year.

THE AUSTIN RESERVOIR ON THE COLORADO RIVER OF TEXAS AT AUSTIN

The Austin Dam across the Colorado River of Texas, about 3 miles upstream from the business section of Austin, was constructed by the city, primarily for the creation of head to operate a hydroelectric

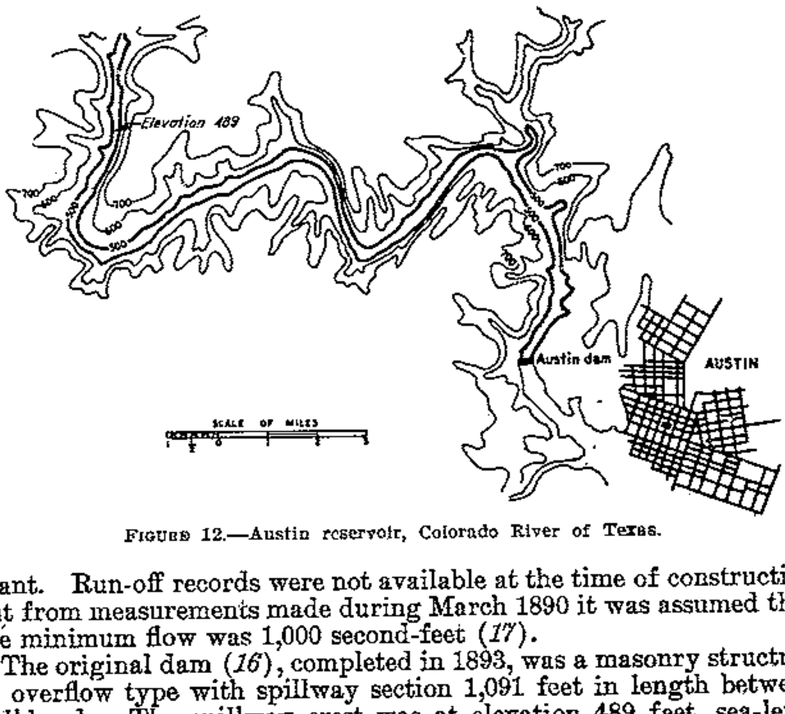


FIGURE 12.—Austin reservoir, Colorado River of Texas.

plant. Run-off records were not available at the time of construction but from measurements made during March 1890 it was assumed that the minimum flow was 1,000 second-feet (*17*).

The original dam (*16*), completed in 1893, was a masonry structure of overflow type with spillway section 1,091 feet in length between bulkheads. The spillway crest was at elevation 489 feet, sea-level datum, and the stream bed elevation was 423 feet.

Contour line 400 crosses the river channel 12 miles downstream and contour 500 crosses it 21.5 miles upstream from the dam (*19*). The 77 feet of fall in 21.5 miles represent an average fall of slightly less than 3.6 feet per mile through the storage basin. The average width of the basin at the elevation of the spillway crest, as determined from 15 cross sections, over a distance of 18.9 miles above the dam, is 807 feet (*17*). The maximum and minimum widths are given as 1,300 and 460 feet, respectively. The original capacity of the reservoir at the elevation of the spillway crest was 49,300 acre-feet (*19*).

Figure 12 shows the limited width of the valley in which the reservoir is located.

The drainage area above the dam is 38,200 square miles (*5*), a part of which is noncontributing. Approximately 13 percent of the drainage area was cultivated in 1930, the remainder being pasture and timber land.

The annual rainfall varies from 15 inches at the headwaters of the drainage basin to 33 inches at Austin (*21*). The average for the entire area above Austin is about 21 inches.

The discharge of the Colorado River of Texas at Austin has been carefully measured by the water resources branch of the United States Geological Survey from February 15, 1898, to the present time. Table 19 is a tabulation of the maximum mean daily discharge in second-feet and the run-off in acre-feet by water years (October 1 to the following September 30, inclusive), covering a 32-year period. The average annual discharge for this period is 1,827,000 acre-feet, equivalent to a volume of more than 37 times the original capacity of the reservoir.

TABLE 19.—*Discharge of the Colorado River of Texas at Austin, Oct. 1, 1898, to Sept. 30, 1930*

Water year	Discharge		Water year	Discharge	
	Maximum mean daily	Total for year		Maximum mean daily	Total for year
	Second-feet	*Acre-feet*		*Second-feet*	*Acre-feet*
1898–99	91,800	1,380,000	1915–16	28,200	874,000
1899–1900	145,000	4,050,000	1916–17	9,750	427,000
1900–1901	28,700	1,570,000	1917–18	38,400	627,000
1901–2	35,900	1,310,000	1918–19	64,700	5,030,000
1902–3	33,700	1,710,000	1919–20	44,600	3,500,000
1903–4	31,500	1,420,000	1920–21	50,200	1,030,000
1904–5	52,900	1,460,000	1921–22	103,000	3,500,000
1905–6	78,500	2,040,000	1922–23	47,500	1,590,000
1906–7	28,100	833,000	1923–24	48,000	2,370,000
1907–8	100,000	2,460,000	1924–25	27,100	1,090,000
1908–9	29,700	1,020,000	1925–26	29,800	2,100,000
1909–10	27,400	905,000	1926–27	26,600	1,340,000
1910–11	27,400	1,290,000	1927–28	36,100	1,620,000
1911–12	17,400	636,000	1928–29	90,400	1,350,000
1912–13	40,300	1,100,000	1929–30	30,700	1,190,000
1913–14	141,000	5,450,000			
1914–15	84,000	2,180,000	Average	52,600	1,827,000

On April 7, 1900, a section of the dam about 500 feet in length failed by sliding. The depth of water on the crest at the time of the failure was 11.07 feet, the discharge being estimated as 151,000 second-feet (*5*). The peak discharge at the gaging station 3 miles downstream was estimated as 236,000 second-feet.

After the failure of the original dam several investigations and reports were made and plans for reconstruction were prepared, but it was not until September 1911 that a franchise was granted for the rehabilitation of the dam and power plant.

The plans for the new part of the dam called for a concrete section of hollow type with crest at elevation 480 feet, or 9 feet lower than the crest of the old dam. They also included gates 14 feet in height on the crest of the concrete section and 5 feet in height on the crest of the old masonry section in order to maintain the water surface at elevation 494 feet. The work under these plans was completed early in 1915, and stored water reached the crest of the old structure February 16, 1915, for the first time since the failure of the original dam (*12*). The city refused acceptance on the ground of alleged defects and the dam and power plant have never been used.

Soon after the original plant was placed in service it was found that the actual minimum flow of the river at Austin fell considerably short of the estimated minimum of 1,000 second-feet, the basis upon which the project was designed. Measurements made in 1899 showed conclusively that the minimum was less than 200 second-feet (*17*). The actual minimum flow of record occurred August 18, 1918, with a discharge of 13 second-feet, which included the flow of springs between the dam and the bridge at Congress Avenue, Austin (*5*).

The silting of this reservoir has been closely observed, and several surveys for the determination of the volume of deposited material have been made by Taylor (*18*) since the completion of the original dam. From May 1893 to January 1900 there was an accumulation of 23,559 acre-feet of deposited material. From the time of completion of the new concrete section in the summer of 1913 to August 1922 there was an accumulation of 26,663 acre-feet (*19*); from August 1922 to August 1924, the accumulation was 2,465 acre-feet; and from August 1924 to August 1926 the accumulation was 1,424 acre-feet. Table 20 shows the rate of accumulation per year.

TABLE 20.—*Rate of accumulation of silt in the reservoir at Austin*

Period		Accumulation of silt	
From	To	For period	Per year
		Acre-feet	*Acre-feet*
May 1893	January 1900	23,559	3,490
Summer 1913	August 1922	26,663	2,963
August 1922	August 1924	2,465	1,232
August 1924	August 1926	1,424	712

The decrease in the annual accumulation is due to the reduction of cross-sectional area of the reservoir by the deposition of silt. As the cross section was reduced, higher velocities were created and more of the silt load was carried through the reservoir and over the spillway.

The river-discharge records for a period of 32 years show maximum mean daily discharges of from 9,750 to 145,000 second-feet, with an average of 52,600 second-feet. In passing floods of such magnitude through the reservoir, the average width of which at the elevation of the crest of the original dam was 807 feet with a minimum width of 460 feet, velocities capable of carrying the major part of the suspended load through the basin and over the spillway were required. In other words, owing to the limited width of the reservoir, stream conditions existed during the passing of the larger floods, and reservoir conditions were not reestablished until the discharge had been so reduced that velocities were slight.

Whenever the discharge was such that reservoir conditions existed suspended matter settled to the bottom soon after entering the slackwater in the storage basin, and in the form of liquid mud flowed toward the dam. Side streams with steep gradients, discharging directly into the reservoir from the adjacent rocky slopes, deposited bars of sand which temporarily retarded the flow of mud. When a rise of sufficient magnitude to create velocities that changed the characteristics from reservoir to stream conditions occurred, some of the heavier particles of suspended matter were deposited throughout the length of the reservoir.

Referring to silt in connection with his survey of 1900, Taylor (*18*) states:

> This silt, from the dam to a point within 3 miles of the head of the lake, was, in 1900, a fine, impalpable, absolutely gritless deposit. At the head of the lake and for about 3 miles down the lake the silt consisted of sand, which readily deposited when the velocity of the stream was checked by the relatively still water of the lake.

According to this statement, slightly less than 7 percent of the material deposited in the reservoir in 6¾ years was sand. This seems to be a low percentage, since the Pedernales River which joins the Colorado 25 or 30 miles above the reservoir is considered a sandy tributary. Observations at the heads of Lake Worth, Lake Kemp, and Medina Reservoir indicate that the volume of sand deposited within the flow line of reservoirs is small in comparison with the total deposit.

> In 1897 this silt * * * was fine, impalpable, absolutely gritless deposit, and where newly exposed would not bear an appreciable weight on its surface. The writer has often tried its resistance all along the lake, and an oar could be driven into it several feet with moderate pressure. Shovelfuls of it placed upon boards in a heaped-up mass would immediately settle and spread so that the upper surface was almost horizontal. A barrel of it, when first taken up at Santa Monica Spring, soon spread out in a flat sheet (*17, p. 41*).

The writer spent considerable time examining and sampling material in this reservoir and in the river channel. The samples include material in many degrees of consolidation.

Sample no. 1 was cut December 12, 1924, from an exposed deposit 1 mile above the dam and 50 feet from the edge of water. The surface of the deposit was about 9 feet below high-water mark and was broken in blocks by shrinkage cracks caused by exposure of the material to the atmosphere.

Sample no. 2 was cut December 12, 1924, from the same bar as no. 1, but 200 feet from the edge of water and 6 inches below the surface of the deposit which was broken by shrinkage cracks up to three fourths inch in width.

Samples nos. 3 and 4 were cut February 13, 1925, from the locality from which no. 2 was taken. They were taken 6 inches below the surface of the deposit and the increase in weight over that of the samples taken December 1924 is due to additional shrinkage, caused by continued exposure to the atmosphere.

Sample no. 5 was cut December 12, 1924, from a bar on the south side of the river, 12.5 miles above the dam. The surface of the deposit was about 9 feet below high-water mark and was broken by shrinkage cracks. The sample, taken 8 inches above the water surface, was black and red in color and was quite sticky.

Sample no. 6 was cut February 4, 1925, from the edge of a wash on the right bank of the river, about 19 miles above the dam. It consisted of a mixture of clay and sand and was probably deposited long before the dam was constructed.

Samples nos. 7, 8, and 9 were cut February 4, 1925, from a deposit on the left bank, about 16 miles above the dam. They had been covered to a depth of 20 feet with silt and the extreme high-water mark was 35 feet above the samples. The material consisted of dark-brown clay with streaks of sand and is thought to have been deposited during the existence of the original dam.

Sample no. 10 was taken April 25, 1925, from the left bank, 1½ miles above the dam. A hole was excavated 2½ feet into the deposit and the sample was taken 2 feet below the water surface by forcing a can into the side of the excavation, digging it out and shearing the silt off at the top of the can. The material had been exposed to the atmosphere at lower stages of the river.

Sample no. 11 was taken April 25, 1925, one third mile above the dam, from a deposit on the left bank. A hole was excavated 2 feet in depth near the edge of the water. The material below was so soft that it flowed into the excavation and prevented going deeper. The sample was taken 1½ feet below the surface of the water by pushing a brass cylinder into the edge of the excavation. This material had been exposed to the atmosphere at lower stages of the river.

Samples nos. 12 and 13 were taken June 9, 1926, 300 feet above the dam, from beneath 10 feet of water. The surface of the deposit was 7½ feet below the crest of the concrete section of the dam and the material sampled is thought to have been under water ever since its deposition. A wooden rod 20 feet in length and slightly over 1 inch in diameter could be pushed 10 feet into the deposit and removed with ease. Silt adhered to that part of the rod which penetrated the deposit and could be removed only by rubbing vigorously. A small amount of very fine grit was noticeable. The samples were taken in a coffee can attached to a 15-pound window weight. The material was so soft that the weight carried the can under the surface, permitting a full-can sample to be taken. A sieve analysis showed that all except particles of shell and vegetable matter passed a sieve having 200 meshes per inch. On ignition the loss in weight was 5.5 percent.

Sample no. 14 was taken from the left bank, 600 feet above the dam. The material sampled had been deposited in slack-water between runways to boat landings, by a flood which had gone down rapidly and left the freshly deposited mud exposed. only a short time before the sample was taken. The sample was dipped with a can. The specific gravity of the silt in the mud state was 1.3 and that of the dried silt was 2.62.

Sample no. 15 was composite, taken from suspension during a flood, at the Congress Avenue bridge at Austin, April 28, 1926. Buckets full of muddy water were drawn up and the water was allowed to stand a few minutes, during which time most of the suspended matter settled to the bottom. The top water was then poured off and the concentrated silt was saved. The material was placed in a 1½-inch glass tube 42 inches long, May 4, 1926, and the height of the mud column was measured from time to time in order to determine the rate of settlement.

It will be seen from the following tabulation that practically one half of the shrinkage of the silt column took place during the first 10 days.

Elapsed time (days) after placing in tube:	Shrinkage (percent)	Elapsed time (days) after placing in tube:	Shrinkage (percent)
10	23.0	100	44.5
20	31.7	530	50.3
30	36.3	642	50.3

As there was no further shrinkage after the five hundred and thirtieth day, this sample was removed from the tube on the six hundred and forty-second day and its volume-weight ratio and specific gravity were determined. Three independent determinations of the specific gravity gave 2.717, 2.741, and 2.730, with an average of 2.729. These results are slightly higher than those for samples of the deposited material from the reservoir, due to the pouring off of the vegetable matter of the composite sample.

Table 21 gives the volume-weight ratios of the samples from the reservoir on the Colorado River of Texas at Austin.

TABLE 21.—*Volume-weight of silt samples from the reservoir on the Colorado River of Texas at Austin*

Sample no.	Original weight per cubic foot	Dry material per cubic foot of deposit	Sample no.	Original weight per cubic foot	Dry material per cubic foot of deposit
	Pounds	*Pounds*		*Pounds*	*Pounds*
1	109.8	83.5	9	99.3	67.6
2	109.2	84.9	10	91.6	51.9
3	111.6	84.5	11	92.0	54.5
4	113.8	86.9	12	79.9	29.6
5	104.3	64.7	13	80.6	29.9
6	124.2	106.0	14	81.2	30.5
7	108.1	73.1	15	82.7	30.7
8	101.5	69.8			

Based on Taylor's description of the material in the reservoir in 1900 and assuming that 5 percent of the deposit described as "fine absolutely gritless" had been exposed to the atmosphere during low stages of the water until considerable shrinkage had taken place, the average weight of the dry material per cubic foot of deposit in 1900 is estimated at 35.9 pounds.

The mean percentage of silt by weight for a 3-year period, in the Colorado River of Texas, at Tow, was 0.36. Applying this percentage to the mean annual discharge at Austin and using 35.9 pounds as the average weight of dry material per cubic foot of deposit, the mean annual volume of silt entering the Austin Reservoir was 11,500 acre-feet. The Llano and Pedernales Rivers discharge into the Colorado between Tow and Austin, but it is believed that they do not materially affect the percentage of silt in the main river.

Had all the silt entering the reservoir been deposited in the storage basin and none carried over the dam, the entire capacity would have been occupied by silt in about 4 years. If storage had been provided for the mean annual flow of the stream, it would have required practically 160 years, at the same rate of filling, for the silt to occupy the entire capacity. When one considers the fact that the mean annual discharge of the river at Austin is 37 times the original capacity of the reservoir it is not surprising that the storage space was occupied by silt in a few years.

DETERMINATION OF THE SILT LOAD

As previously stated, the silt content of daily samples has been determined in terms of percentage of silt by weight. The percentage by weight for each day applied to the river discharge is assumed to give the silt load for that day. Obviously, during changing conditions of run-off and stream flow, with only one sampling daily in a given section, the mean percentage of silt, so determined, may vary considerably from the actual mean, but it is believed that the errors are compensating and will approximate true conditions in an extended period. The monthly silt loads as listed in summaries of silt determinations, tables 25 to 43, inclusive, in the Appendix, are summations of the daily loads.

The volume of material deposited in reservoirs from suspension in flood water is subject to enormous shrinkage, therefore the most accurate and convenient method of determining the suspended load is on the basis of weight. In the study of the silt load of a stream with reference to the probable life of reservoirs, the space which it will ultimately occupy just before the reservoir ceases to serve the purpose for which it was constructed, is required. In other words, for practical application the units in weight must be converted into units by volume.

There is little difficulty in determining with a close degree of accuracy the initial and final volume-weight relation of material deposited under reservoir conditions. In existing reservoirs the initial relation may be determined from samples recently deposited. Where no reservoir exists, the initial relation may be determined from suspended material that has been allowed to settle in convenient containers. The final relation in the case of existing reservoirs may be determined from samples of deposited material which has been subjected to considerable shrinkage, due to exposure to the sun and atmosphere for a long period of time. Where no reservoir exists the final relation may be determined from samples carefully selected in deposits laid down by the stream during floods that overflowed the banks. The proper volume-weight relation to apply in making the conversion is, of course, some value between the initial and final relations. The final value is the limit which is being approached, but it is highly probable that it will not be reached during the average life of a reservoir.

Of all samples tested in connection with this investigation the leanest, containing 18.7 pounds of dry material per cubic foot of deposit, possessed prominent colloidal characteristics. This sample was taken immediately above Lake Worth Dam on the West Fork of Trinity River. The densest sample was the cobblelike formation (pl. 1, A and B) containing 106.1 pounds of dry material per cubic foot of deposit, taken from Medina Reservoir. The lowest values for Lake Worth on the West Fork of Trinity River, Medina Reservoir on Medina River, Austin Reservoir on Colorado River of Texas, Brazos River, and Lake Kemp on Wichita River are 18.7, 28.8, 29.6, 31.2, and 35.1 pounds of dry material per cubic foot of deposit, respectively. The highest values for the same sources of supply are 66.3, 106.1, 86.9, 91.2, and 88.8 pounds of dry material per cubic foot of deposit, respectively. The value of 66.3 pounds of dry material per cubic foot of deposit does not represent the maximum density of the silt in Lake Worth at the time this particular sample was taken. Owing to its peculiar jointed structure, it was impossible to take a satisfactory volume-weight sample of the denser material and the sample taken came from below the effect of prominent shrinkage cracks. It is believed that the dry weight per cubic foot of the denser material approached 85 pounds.

For the samples listed above representing the least weight of dry material per cubic foot of deposit, the space occupied by water varied from 80 to 89 percent. The water capacities, by volume, of undisturbed soils below the water table, range between 31.3 percent for very fine sand and 49.0 percent for marly loam (*11*). Comparing the water capacity of the marly loam with that of the sample which contained 89 percent water by volume, it is seen that the latter has a greater capacity, by 40 percent, than the former. This greater capacity is due to the difference in structure of the mass of soft silt deposited from suspension, under water. The structure of silt so deposited and remaining submerged has been called "honeycomb structure," and in case of particles of colloidal size "flocculent" (*20*).

Excess water held in silt by virtue of structure of the deposit is liberated so slowly upon exposure of the material to the atmosphere that it is all taken up by evaporation and is not available as storage water.

The selection of a dry weight per cubic foot of deposit to apply in converting units by weight to units by volume must be based on an estimate. The estimate should be based on an intimate knowledge of rainfall, drainage area, stream characteristics, and a reasonably accurate prophecy as to the actual operation of the proposed reservoir. If a reservoir is operated in such a manner that the silt surface is continually covered with water, the average dry weight per cubic foot of deposit may approach 30 pounds; but if the silt deposit is exposed at intervals, shrinkage will take place and the volume-weight ratio will be increased.

The latter condition is strikingly illustrated in the operation of Medina Reservoir during the 5-year period ended October 1930. At the beginning of this period the average dry weight per cubic foot of deposit approximated 30 pounds. Increased irrigation demand and subnormal rainfall resulted in a lowering of the water surface, thus exposing the deposited material so that shrinkage increased the average dry weight per cubic foot to approximately 64 pounds. Each subsequent exposure of the deposited material to the atmosphere and sun increases the average dry weight per cubic foot of deposit.

During the initial operation of a reservoir, flood water, with its charge of silt, reaches the dam. As the velocity is overcome the suspended silt settles to the bottom in the form of soft mud. As the reservoir continues to fill with silt-charged inflow and the water surface backs upstream, the suspended material continues to settle to the bottom in the upstream limit of slack-water. Sediment which has a greater specific gravity than water, flows in the form of soft mud down the slopes of the reservoir bottom into pools of the main stream and depressions outside the channel. If the inflow is greater than the sum of seepage, evaporation, and diversions, the process will continue until the water surface reaches the spillway crest. At this stage the average number of pounds of dry material per cubic foot of deposit approaches 30 or less if collodial conditions are present. Shrinkage and the accompanying increase in unit weight can take place only by liberation of the excess water. If the deposit is kept continually covered with water, this shrinkage takes place so slowly that it is believed to be negligible so far as the life of a reservoir is concerned.

In the operation of many reservoirs, however, the demand exceeds the supply and a portion of the floor of the reservoir, with the silt deposits, becomes exposed to the sun and atmosphere for intervals of time, and great shrinkage of the silt deposit takes place through the liberation of water held by virtue of its structure. The shrinkage is manifested in cracks and subsidence of the surface of the deposit. The cracks divide the surface into irregular areas and extend into the mass varying depths, depending on the period of exposure, the character of the material, and the thickness of the deposit.

Although the moisture content of the exposed material increases when the water level rises again, material not actually scoured and agitated by incoming floods until complete separation of the particles takes place does not occupy as much space as it did when originally deposited. Owing to the comparatively short distance that consolidated material is exposed to the eroding effect of inflow in reservoirs, complete separation of the particles does not take place and the resulting structure is denser than it was when originally deposited. In material which is not scoured when again submerged, the shrinkage cracks can be detected by the difference in density of the deposit after they have been filled with freshly deposited material. From observation it is believed that the expansion of the undisturbed consolidated material is slight.

Silt deposited in the reservoir on the Nueces River near Mathis and later exposed to the atmosphere several different times weighed 100.9 pounds per cubic foot and the dry material per cubic foot of deposit weighed 64 pounds. When this material was covered with water again, it expanded to the extent that the wet weight was 96.3 pounds per cubic foot and the dry material per cubic foot of deposit weighed 56 pounds. Each subsequent exposure and submersion results in less expansion and a greater dry weight per cubic foot.

At the inception of this investigation it was expected that the results could be expressed exactly, in units by volume, but the information developed as the study progressed proved this to be impossible, since material deposited under reservoir conditions and remaining submerged contained 30 or less pounds of dry material per cubic foot of deposit, while material similarly deposited and then subjected to shrinkage through exposure contained in excess of 80 pounds of dry material per cubic foot of deposit.

It should be kept in mind that the average ultimate weight of the dry material per cubic foot of deposit depends on the function and operation of the reservoir. In a reservoir used for flood control only, the water is stored temporarily, and the deposited material, subjected to shrinkage during long periods of time, has an average ultimate weight of dry material per cubic foot of deposit approximating 90 pounds; in the average reservoir for storage of water for future use, dry periods and increased demand for water result in lowering of the water surface and the exposure of the silt deposit for periods of time, resulting in an average ultimate weight of dry material per cubic foot of deposit approximating 70 pounds; and in a power reservoir, where the head is maintained practically constant, exposure and the resulting shrinkage does not take place, and the average ultimate weight of the dry material per cubic foot of deposit approximates 30 pounds.

The writer, after carefully considering the volume-weight ratios of silt samples and the measurements of exposed and submerged deposits in reservoirs, has selected 70 pounds as the average ultimate weight of dry material per cubic foot of deposit, for converting units by weight into units by volume. This selection was made with a knowledge of the indeterminable volume of vegetable matter in the form of logs and brush which moves down the streams during rising stages. Since much of this material is waterlogged and travels unobserved down stream below the water surface, it is impossible to estimate the volume. Such material will be deposited in reservoirs where it will be preserved indefinitely if kept submerged with water.

Stream discharge records used in tables 25 to 43, inclusive, were furnished by the water resources branch of the United States Geological Survey and the volume of silt is based on the assumption that the weight of the dry material per cubic foot of mud, deposited under reservoir conditions, will ultimately be 70 pounds.

PREVENTION OF SILTING

As previously stated, the most important factors that control run-off, erosion, and transportation of eroded and weathered material are depth and intensity of rainfall, topographic features, structure and texture of the soil, and the amount and character of surface cover or vegetation.

Man has no control over the depth and intensity of rainfall, both of which vary widely. The records of the United States Weather Bureau show for central Texas, where the average annual rainfall ranges from 20 to 33 inches, a minimum annual precipitation of less than 6 inches and a maximum of 67.94 inches, with a recorded intensity of over 19 inches in 24 hours on a portion of the drainage area. Rainfall of such intensity results in heavy run-off with an accompanying heavy silt load in the aggregate, although the percentage of silt may be low, owing to dilution. Continuous slow easy rains may total several inches during a single storm, but from the fact that the rate of absorption of the soil is not overtaxed, little water and proportionately little suspended matter runs off.

The control of topographic features is possible to a limited extent, by the construction of (1) terraces to retard, spread, and direct the flow of run-off so as to reduce the erosion of the ground surface to a minimum and expose it uniformly to the percolating water; (2) check dams of logs, brush, stones, wire, straw, and other material, to check the velocity of the water and cause the deposition of suspended matter; and (3) dams and levees to store and direct the discharge.

The structure and texture of the soil are controllable only so far as they are affected by vegetation and cultivation. A cover crop of grass, weeds, brush, and forest trees is effective in preventing weathering and excessive run-off with its accompanying load of silt. Decaying vegetable matter affects the structure and texture of the soil by contribution of humus and by the mechanical action of the roots perforating the formation.

The deposition of part of the silt load of a supply stream may be accomplished, to a limited extent, in the main valley above the flow line of the reservoir. A dense growth of tamarisk on the flood plain of the Wichita River above the flow line of Lake Kemp is effective in reducing the velocity of flood water to the extent that considerable silt is deposited outside the reservoir.

By diverting flood water from a stream channel above a reservoir and allowing it to spread over the valley floor, the velocity may be reduced so that much material that would otherwise enter the reservoir is deposited. This is illustrated in the operation of a reservoir near Balmorhea. Water for the reservoir is diverted from Toyah Creek and conducted through a feeder canal which has extravagant gradients. High velocities carry sand, gravel, and cobblestones toward the reservoir. At two points along the canal, contracted sections cause large floods to spread out over the flat land on each side, resulting in the deposition of the coarse material, preventing it from being carried into the reservoir.

REMOVAL OF SILT FROM RESERVOIRS

Various schemes have been proposed for removing deposited silt from reservoirs but no feasible plan has been suggested. The chief objection to the methods proposed is the cost per unit volume. Under present conditions the cost of dredging in reservoirs used for irrigation storage or power purposes is prohibitive. The method may be feasible in connection with municipal water supply where water is sold in units of 1,000 gallons instead of acre-feet.

Proper clearing and grading of reservoir bottoms, to remove obstacles to the free flow of soft mud deposits, will provide for the transmission of a considerable volume to the dams. If the outlet conduits are in the lowest part of the stream channel, the soft material reaching the dams will be discharged with the water. The most feasible method of handling the situation arising from reservoirs filled with silt is to provide additional storage capacity by increasing the height of the controlling works or by the construction of a dam at another site.

SILT PROBLEMS OF THE LOWER RIO GRANDE VALLEY

The handling of the silt in the water of the Rio Grande, the source of irrigation supply of the lower Rio Grande Valley of Texas, has been recognized, since the construction of the first irrigation canal in that part of the valley, as an important maintenance and operation problem.

In order to deliver water to the greater part of the irrigable land, the canals had to be constructed with extremely flat gradients which resulted in large cross-sectional areas and low velocities. As a result of the low velocities, the major part of the suspended load is deposited in the upper reaches of the canals, but thin deposits of very fine material have been observed at the extreme lower end of the distribution system 35 miles or more from the river diversions.

Periodic cleanings of the canals are necessary to maintain the required carrying capacities. As a rule, the intake canals from the river to the pumping plants are cleaned with suction dredges; the larger canals of the distribution system are cleaned with drag-line excavators; canals of medium dimensions are cleaned with ladder-type excavators; and small canals and laterals are cleaned with teams and scrapers or by men with shovels.

On several of the irrigation systems, provision has been made for desilting the water by means of settling basins before it enters the canals. The basins of comparatively large areas receive the silt-laden water directly from the pumps at the river. The canals which draw their supply of practically clear water from the settling basins are noticeably free from silt deposit As the basins become filled with deposited material, it will be necessary to provide others. The area built up in the basins should, with proper treatment, be converted into valuable agricultural land.

The basic fertility of the soil in this part of the valley is doubtless due to a large extent to the plant food contained in the sediment of which it is composed, but it has been observed that land between the river bank and the flood-control levee, with a deposit of fresh silt, does not produce crops equal to those produced just over the levee on land protected from freshly deposited material.

Seepage investigations in connection with irrigation canals indicate that the silt is very effective in sealing the wet area and reducing the rate of percolation. In canals with silt on the sides and bottom, losses as low as 0.091 cubic foot per square foot of wet area in 24 hours were measured. In one canal, which contained no silt deposit, its supply being clear water drawn from the surface of a settling basin, the measured loss was at the rate of 3,884 cubic feet per square foot of wet area in 24 hours.

In canal systems other than those of continuous flow in which the main canal receives its full allotment at its head and each lateral diverting therefrom takes its portion of the discharge, the theory deduced by R. G. Kennedy in his investigation on the Bari Doab canal system in India is not applicable.

Experiments in reaches of canals in which the relation of width, depth, and mean velocity were such that silt was neither picked up nor deposited led Kennedy to conclude that the velocity under such conditions is expressed approximately by the equation (*10*)

$$V_o = cd^{.64}$$

where c has values from 0.82 for light sandy soil to 1.07 for coarse silt, and d is depth in feet.

Many irrigation systems and in fact all those in the lower Rio Grande Valley of Texas provide for the delivery of water to irrigators on demand and by reason of the diversity of crops, canals and laterals seldom carry water to their full capacity. A canal with a capacity of 25 cubic feet per second may on account of lack of demand be discharging 2 cubic feet per second, and in order to deliver this amount to the land being irrigated it is often necessary to check the water to freeboard limit. Under such circumstances velocities that will prevent deposition of the suspended matter cannot be maintained.

CHEMICAL COMPOSITION OF BRAZOS RIVER WATER

During April 1926 samples of muddy water were taken from Brazos River at Seymour, Waco, and Rosenberg for the purpose of determining the chemical composition of the material in solution and suspension.

The Seymour sample was taken at 8 a.m., April 21, when the discharge was 2,370 second-feet and the stage was increasing rapidly. Two routine samples taken at 6 p.m. the same day, at a discharge of 7,772 second-feet and falling stage, contained 2.37 percent of suspended matter by weight and 4.92 percent by volume after 7 days' settlement.

The Waco sample was taken at 4 p.m., April 22, during a falling stage when the discharge was 17,500 second-feet. Three routine samples, taken at the same time, contained 0.43 percent suspended matter by weight.

The Rosenberg sample was taken at 8 a.m., April 24, during a rising stage when the discharge was 66,190 second-feet. Three routine samples taken about the same time contained 0.76 percent suspended matter by weight and 3.04 percent by volume after 7 days' settlement.

The chemical analyses were made by A. E. Mix, analyst in the water and beverage laboratory of the Bureau of Chemistry and Soils, United States Department of Agriculture. The results are given in tables 22 to 24, inclusive.

Part of the Brazos River drainage basin above Seymour contains extensive salt deposits. During periods of low or no flow the water standing in pools along the channel becomes saturated with alkali salts. The high salt content of the sample from Seymour is due to a quick rise, following a period of low flow. Contributions of water containing less salt in solution, from streams discharging into Brazos River below Seymour, resulted in dilution as indicated by the decrease in total salts in samples from Waco and Rosenberg.

SUMMARY AND CONCLUSIONS

The Brazos River Basin is representative, in its various sections, of conditions prevailing in other drainage areas in Texas. The upper end of the basin is in New Mexico, about 4,900 feet above sea level. There the average annual rainfall is approximately 15 inches. Thence Brazos River flows southeasterly, discharging into the Gulf of Mexico at a point where the average annual rainfall is about 42 inches.

TABLE 22.—*Potash, phosphorus, and nitrogen in suspended silt of Brazos River water from Seymour, Waco, and Rosenberg*

Location	K_2O	P_2O_5	N
	Percent	*Percent*	*Percent*
Seymour	0	0.08	0.098
Waco	0	.08	.224
Rosenberg	0	.08	.112

TABLE 23.—*Radicals with their reacting values in filtered supernatant water from samples from Brazos River*

Radical	Values for sample from—					
	Seymour		Waco		Rosenberg	
	Quantity	Reacting value	Quantity	Reacting value	Quantity	Reacting value
	Milligrams per liter	*Percent*	*Milligrams per liter*	*Percent*	*Milligrams per liter*	*Percent*
Na (calc.)	253.0	21.58	1.0	0.49	20.9	12.33
Ca	246.5	24.13	73.3	42.05	44.7	30.30
Mg	26.6	4.29	7.9	7.46	6.6	7.37
Fe_2O_3, Al_2O_3	27.0	----------	3.0	----------	0	----------
SiO_2	9.0	----------	4.0	----------	8.0	----------
NO_3	.4	.01	.4	.07	1.4	.31
BO_2	.7	.03	.7	.10	.7	.22
Cl	400.0	25.45	18.0	5.83	24.0	9.19
SO_4	210.7	8.61	35.8	8.57	20.2	5.71
HCO_3	492.4	15.83	182.4	34.36	152.0	33.84
PO_4	1.2	.07	2.7	.98	1.7	.73
Total	1,727.5	100.00	329.2	100.00	280.2	100.00

TABLE 24.—*Anhydrous salts in filtered supernatant water from samples from Brazos River*

Anhydrous salt	Values for sample from—			Anhydrous salt	Values for sample from—		
	Seymour	Waco	Rosenberg		Seymour	Waco	Rosenberg
	Milligrams per liter	*Milligrams per liter*	*Milligrams per liter*		*Milligrams per liter*	*Milligrams per liter*	*Milligrams per liter*
$NaBO_2$	1.1	1.1	1.1	$CaSO_4$	285.5	39.7	0
$NaNO_3$	.6	.6	1.9	$Ca(HCO_3)_2$	654.0	242.3	176.4
NaCl	641.7	1.2	39.7	$Ca_3(PO_4)_2$	2.0	4.4	2.8
Na_2SO_4	0	0	13.6	Fe_2O_3, Al_2O_3	27.0	3.0	0
$MgCl_2$	95.0	23.2	0	SiO_2	9.0	4.0	8.0
$MgSO_4$	11.6	9.7	13.7				
$Mg(HCO_3)_2$	9	0	23.0	Total	1,727.5	329.2	280.2

The mean percentage of silt by weight in samples taken at six tenths of the depths in verticals at one sixth, one half and five sixths the width very closely approximates the mean silt percentage for the section.

While it is known that steep mountain streams transport considerable coarse material by rolling it along the stream bed, it is believed that the solids conveyed by the streams studied, at the sections under consideration, are held in suspension and subject to sampling at velocities existing during periods when silt is being transported in significant quantities.

There is no evidence at the river stations under consideration of any direct relation between the suspended load and the velocity of the water. The higher the velocity, the greater is the capacity to carry; but since the capacity load is not even approximately approached, the magnitude of the silt charge becomes, in effect, a function of loading rather than of capacity to carry.

The greater part of the silt load of a stream is due to previous weathering. Following a dry period, the first run-off picks up the weathered material and carries it into the stream. After the first flush from the area upon which the precipitation falls, the stream must depend upon erosion for its silt load, but since the portion of a large drainage basin subject to excessive erosion or scour is small in comparison with the entire area, the silt load becomes comparatively light.

The maximum silt percentage by weight occurs prior to the maximum stream discharge. There are two distinct peaks in the silt percentage curves for each flood. The first peak occurs on a rising stage at a point above which the volume of water increases much faster than the available silt load, resulting in dilution. The second peak occurs on a falling stage and is due to the caving of banks and the sloughing into the channel of material deposited on the slopes at higher stream stages.

The greater part of the suspended silt load of streams and of most of the material deposited in reservoirs is of such fineness that it will pass a Tyler standard no. 300 sieve.

After 7 days' settlement, the average ratio of the percentage of silt by volume to the percentage by weight is 3.3 to 1. The mud column of samples kept in tubes for 7 days is comparable to freshly deposited material in reservoirs, but being taken from suspension, it contains a mixture of different sized grains, while material deposited in reservoirs has been subjected to more complete sorting.

After 13 years of use Medina Reservoir contained 2,692 acre-feet of deposited silt having an average of 30 pounds of dry material per cubic foot of deposit. Five years later, owing to exposure to the sun and atmosphere at various times, the average weight of the dry material per cubic foot of deposit was 63.6 pounds. The 2,692 acre-feet of material measured in the reservoir in 1925, therefore, had been reduced to 1,270 acre-feet in 1930, through shrinkage due to exposure.

Suspended silt settles to the reservoir bottom soon after entering the slack water and, having a greater specific gravity than water, flows, in the form of liquid mud, down the slopes into depressions and along the main channel until blocked by the dam.

Owing to its greater density, silt-charged water entering a reservoir partly filled with clear water does not mingle with the clear, but forces it downstream toward the dam. No suspended silt is carried through the reservoir and over the spillway until all of the clear water has been discharged.

Silt had accumulated in Lake Worth at the rate of about 1,000 acre-feet per year from the time when water was first stored until

1925, and the same rate of deposition was still continuing in 1928, when the total volume deposited was estimated at 13,837 acre-feet.

Silt deposited from suspension in reservoirs and kept continually submerged contains from 18.7 to 37 pounds of dry material per cubic foot of deposit.

The average weight of the dry material per cubic foot of deposit in reservoirs in which a practically constant head is maintained, approaches 30 pounds.

The average weight of the dry material per cubic foot of deposit in reservoirs that are emptied occasionally, ultimately approaches 70 pounds.

The average weight of dry material per cubic foot of deposit in reservoirs used exclusively for flood control and therefore standing empty most of the time, approaches 90 pounds.

The greater part of the silt deposited from suspension in reservoirs and kept continually submerged has an angle of repose approaching 0°.

The specific gravity of dried silt from reservoir deposits is generally about 2.65. Samples taken from suspension and from which vegetable matter was excluded had an average specific gravity of 2.73.

The average annual discharge of the Colorado River of Texas at Austin, during a period of 32 years, was 1,827,000 acre-feet, or more than 27 times the original capacity of Austin Reservoir. The rapid filling of this reservoir with sediment was due to its relatively small capacity and the large average annual discharge of the stream. Owing to the narrowness of the reservoir, stream conditions existed throughout its length during the discharge of the larger floods. Less than 7 percent of the material deposited within the flow line during the first 6¾ years of operation of this reservoir was sand.

Excess water held in silt by virtue of the structure of the deposit is not available as storage water. On exposure of such deposits to the air, the water is liberated so slowly that all of it is evaporated.

Although the moisture content of exposed silt deposits increases when resubmergence occurs, silt that is not actually scoured and agitated by incoming floods until complete separation of the particles takes place does not occupy as much space as when it was deposited. Each subsequent exposure and submersion results in a greater degree of consolidation.

The density of silt deposited in reservoirs is not increased by the depth of water on its surface. Actual tests of material submerged from only a few to over 100 feet indicate no difference in density. Since the individual silt particles are completely surrounded with water the resultant pressure is zero.

At the beginning of the investigation, it was expected that the results that would be obtained could be expressed exactly in units of volume, but information developed as the study progressed has proved this to be impossible. After considering carefully the volume-weight ratios of silt samples in different degrees of consolidation together with the fact that an indeterminable volume of vegetable matter in the form of logs and brush deposited in reservoirs becomes water-logged and lasts indefinitely, 70 pounds was selected as the average ultimate weight of the dry material per cubic foot of deposit in reservoirs where the deposits are subjected to alternate wetting and drying.

The best method of preventing the deposition of silt in reservoirs is to keep it from being carried into the supply streams. This may be accomplished in part through extensive run-off control projects combining forestation, planting of grass cover crops, terracing of cultivated land, and constructing of check dams and other velocity-reducing structures.

The diversion and spreading of flood water in stream valleys above reservoirs is effective in causing the deposition of heavier grades of material outside the flow line. A dense growth of tamarisk on the flood plains above reservoirs reduces the velocity of flood water to such an extent that considerable material even of the finer grades is deposited before it reaches the reservoir.

The removal of silt by dredging from reservoirs used for irrigation and power purposes is not feasible, owing to the prohibitive cost. In reservoirs with outlet conduits in the old channel of the stream, a considerable volume of soft mud may be discharged with the water. The most feasible method of providing storage to take the place of that occupied by deposited material is to provide further capacity, either by raising the controlling works or by constructing another dam at a new site.

Silt in irrigation water in the lower Rio Grande Valley is effective in reducing percolating losses of earthen canals but frequent cleanings of canals are necessary to maintain the required carrying capacities. On several systems the water is desilted by passing it through settling basins near the diversion points.

LITERATURE CITED

(1) Darton, N. H.
1928. GEOLOGIC ATLAS OF THE UNITED STATES.

(2) Etcheverry, B. A.
1915–16. IRRIGATION PRACTICE AND ENGINEERING. 3 v., illus. New York.

(3) Follett, W. W.
1913. SILT IN THE RIO GRANDE. 102 p. U.S. Dept. State.

(4) Fortier, S., and Blaney, H. F.
1928. SILT IN THE COLORADO RIVER AND ITS RELATION TO IRRIGATION. U.S. Dept. Agr. Tech. Bul. 67, 95 p., illus.

(5) Grover, N. C.
1930. SURFACE WATER SUPPLY OF THE UNITED STATES, 1926. PART VIII, WESTERN GULF OF MEXICO BASINS. U.S. Geol. Survey Water Supply Paper 628, 207 p., illus.

(6) ———
1931. SURFACE WATER SUPPLY OF THE UNITED STATES, 1928. PART VIII, WESTERN GULF OF MEXICO BASINS. U.S. Geol. Survey Water Supply Paper 668, 123 p., illus.

(7) Hawley, J. B.
1923. SILTATION OF AUSTIN AND LAKE WORTH IN TEXAS. Engin. News-Rec. 91: 811.

(8) Hemphill, R. G.
1930. SILTING AND LIFE OF SOUTHWESTERN RESERVOIRS. Amer. Soc. Civ. Engin. Proc. 56: 967–979.

(9) Humphreys, A. G., and Abbot, H. L.
1861. REPORT UPON THE PHYSICS AND HYDRAULICS OF THE MISSISSIPPI RIVER; UPON THE PROTECTION OF THE ALLUVIAL REGION AGAINST OVERFLOW; AND UPON DEEPENING THE MOUTHS. U.S. War Dept., Engin. Corps Pubs. 456 p. Philadelphia.

(10) KENNEDY, R. G.
1895. THE PREVENTION OF SILTING IN IRRIGATION CANALS. Inst. Civ. Engin. Minutes Proc. 119: 281–290, illus.

(11) KING, F. H.
1899. PRINCIPLES AND CONDITIONS OF THE MOVEMENT OF GROUND WATER. U.S. Geol. Survey Ann. Rpt. (1897/98) 19 (pt. 2): 67–294, illus.

(12) MEAD, D. W.
[1917]. REPORT ON THE DAM AND WATER POWER DEVELOPMENT AT AUSTIN, TEXAS. 205 p., illus. Madison, Wis.

(13) NAGLE, J. C.
1902. PROGRESS REPORT ON SILT MEASUREMENTS. U.S. Dept. Agr., Off. Expt. Stas. Bul. 104: 293–324, illus.

(14) ———
1902. SECOND PROGRESS REPORT ON SILT MEASUREMENTS. U.S. Dept. Agr., Off. Expt. Stas. Bul. 119: 365–392, illus.

(15) ———
1903. THIRD PROGRESS REPORT ON DISCHARGE AND SILT MEASUREMENTS ON TEXAS STREAMS. U.S. Dept. Agr., Off. Expt. Stas. Bul. 133: 196–217, illus.

(16) TAYLOR, T. U.
1904. THE WATER POWERS OF TEXAS. U.S. Geol. Survey Water Supply and Irrig. Paper 105, 116 p., illus.

(17) ———
1910. THE AUSTIN DAM. Tex. Univ. Bul. 164 (Sci. Ser. 16), 85 p., illus.

(18) ———
1924. SILTING OF THE LAKE AT AUSTIN, TEXAS. Tex. Univ. Bul. 2439, 23 p., illus.

(19) ———
1930. SILTING OF RESERVOIRS. Tex. Univ. Bul. 3025, 170 p., illus.

(20) TERZAGHI, C.
1925. MODERN CONCEPTIONS CONCERNING FOUNDATION ENGINEERING. Jour. Boston Soc. Civ. Engin. 12: 397–439, illus.

(21) WILLIAMS, B. F., and LOWRY, R. L., JR.
1929. A STUDY OF RAINFALL IN TEXAS. Tex. Dept. Reclam. Bul. 18, 169 p., illus.

APPENDIX

SILT CARRIED BY VARIOUS TEXAS STREAMS BASED ON DISCHARGE RECORDS OF THE UNITED STATES GEOLOGICAL SURVEY

TABLE 25.—*Silt determinations, Double Mountain Fork of the Brazos River, Aspermont, 1924–30*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June (4–30)	235	600	0	November	0	0	0
July	704	34,980	23	December	0	0	0
August	0	0	0				
September	7,470	226,000	148				
October	2,470	60,900	40	Total for period	10,939	322,480	211

1925

Month	Discharge	Silt		Month	Discharge	Silt	
January	22	0	0	August	27,600	1,902,120	1,248
February	0	0	0	September	37,400	1,251,100	821
March	0	0	0	October	5,910	56,050	37
April	40,000	1,379,610	905	November	1,980	4,440	3
May	14,800	392,000	258	December	45	0	0
June	1,040	12,010	8				
July	1,060	22,130	15	Total	130,457	5,029,360	3,295

TABLE 25.—*Silt determinations, Double Mountain Fork of the Brazos River, Aspermont, 1924–30*—Continued

1926

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	30	0	0	August	55,800	2,064,920	1,354
February	25	0	0	September	25,700	437,930	287
March	916	3,160	2	October	162,000	3,812,690	2,501
April	14,700	728,440	478	November	4,310	0	0
May	8,320	186,360	122	December	11,000	43,170	28
June	14,700	457,250	300				
July	17,400	610,860	401	Total	314,901	8,344,780	5,473

1927

Month	Discharge	Silt (tons)	Silt (acre-feet)	Month	Discharge	Silt (tons)	Silt (acre-feet)
January	1,770	0	0	August	8,310	236,270	155
February	2,980	17,090	12	September	4,470	133,500	88
March	1,380	2,470	2	October	2,370	35,870	23
April	3,990	41,260	27	November	4	0	0
May	688	7,100	5	December	11	0	0
June	16,200	463,850	304				
July	22,400	668,720	439	Total	64,573	1,606,730	1,055

1928

Month	Discharge	Silt (tons)	Silt (acre-feet)	Month	Discharge	Silt (tons)	Silt (acre-feet)
January	85	1,190	1	August	19,500	475,860	312
February	1	0	0	September	237	0	0
March	158	460	0	October	232	4,050	3
April	9	0	0	November	545	7,490	5
May	44,800	1,930,490	1,266	December	74	0	0
June	3,840	16,450	11				
July	50,300	1,729,470	1,134	Total	119,781	4,165,490	2,732

1929

Month	Discharge	Silt (tons)	Silt (acre-feet)	Month	Discharge	Silt (tons)	Silt (acre-feet)
January	25	0	0	August	6	0	0
February	71	0	0	September	54,800	1,874,150	1,229
March	664	14,490	9	October	898	4,990	3
April	1,070	16,580	11	November	52	0	0
May	23,700	714,310	468	December	4	0	0
June	19,100	564,280	370				
July	12,600	253,510	166	Total	112,990	3,442,310	2,256

1930

Month	Discharge	Silt (tons)	Silt (acre-feet)	Month	Discharge	Silt (tons)	Silt (acre-feet)
January	2	0	0	August	111	230	0
February	3	0	0	September	5,950	72,660	48
March	4	0	0	October	11,400	318,500	209
April	25,000	820,670	538	November	1,370	5,960	4
May	97,200	5,090,370	3,339	December	12,200	716,110	470
June	19,300	531,180	348				
July	554	3,140	2	Total	176,094	7,558,820	4,958

TABLE 26.—*Silt determinations, Salt Fork of the Brazos River, Aspermont, 1924–25*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June (4–30)	21,800	423,060	278	November	7	0	0
July	1,370	8,950	6	December	25	0	0
August	157	210	0				
September	8,590	256,280	168	Total	33,189	699,960	459
October	1,240	11,460	7				

TABLE 26.—*Silt determinations, Salt Fork of the Brazos River, Aspermont, 1924–25*—Continued

1925

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	199	650	0	June	4,510	84,250	55
February	38	0	0	July	5,300	350,820	230
March	5	0	0	August (1-29)	21,200	705,530	463
April	59,900	3,203,290	2,101				
May	13,200	275,700	181	Total	104,352	4,620,240	3,030

TABLE 27.—*Silt determinations, Clear Fork of the Brazos River, Eliasville, 1924–25*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June (3-30)	6,630	2,360	1	November	95	11	0
July	4	0	0	December	354	0	0
August	131	0	0				
September	89,900	398,280	261	Total	98,484	400,911	262
October	1,370	260	0				

1925

January	417	0	0	June	4,830	710	0
February	93	0	0	July	3,240	700	0
March	18	0	0	August	12,900	12,030	8
April	16,800	53,170	35				
May	83,700	538,420	353	Total	121,998	605,030	396

TABLE 28.—*Silt determinations, Clear Fork of the Brazos River, Crystal Falls, 1925–28*

1925

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
September	78,000	295,540	194	December	695	63	0
October	24,200	35,610	23				
November	3,030	260	0	Total	105,925	331,473	217

1926

January	577	35	0	August	7,680	7,110	5
February	189	7	0	September	10,500	15,350	10
March	5,930	3,150	2	October	16,600	29,880	20
April	28,600	84,130	55	November	353	38	0
May	18,100	34,170	22	December	38,900	144,300	95
June [1]	----------	----------	----------				
July	12,200	13,460	9	Total	139,629	331,630	218

1927

January	1,390	110	0	August	927	150	0
February	3,460	420	0	September	12,400	49,110	32
March	5,670	1,220	1	October	4,610	3,150	2
April	63,700	365,830	240	November	333	1	0
May	495	44	0	December	155	0	0
June	6,870	4,720	3				
July	25,000	48,250	32	Total	125,010	473,014	310

[1] Stage beyond limit of rating curve 3 days during the month, hence discharge not determined.

TABLE 28.—*Silt determinations, Clear Fork of the Brazos River, Crystal Falls, 1925–28*—Continued

1928

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	164	200	0	August	47,600	179,200	117
February	0	0	0	September	1,540	1,760	1
March	0	0	0	October	315	0	0
April	0	0	0	November	3,610	2,120	1
May	197,000	1,196,760	785	December	861	58	0
June	33,700	130,080	85				
July	53,800	217,620	143	Total	338,590	1,727,798	1,132

TABLE 29.—*Silt determinations, Brazos River at Seymour, 1924–30*

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
1924							
June (5–30)	43,000	1,114,020	731	November	0	0	0
July	546	1,270	1	December	0	0	0
August	737	4,420	3				
September	27,400	782,350	513	Total	78,329	1,961,420	1,287
October	6,640	59,360	39				
1925							
January	282	0	0	August	64,800	2,315,930	1,519
February	208	0	0	September	185,000	5,376,530	3,526
March	0	0	0	October	18,000	227,990	150
April	92,800	4,009,630	2,630	November	3,960	13,530	9
May	22,300	477,660	313	December	309	27	0
June	6,810	98,540	65				
July	3,840	34,300	22	Total	398,309	12,554,137	8,234
1926							
January	797	750	0	August	161,000	3,597,770	2,360
February	22	0	0	September	42,500	874,110	573
March	6,910	117,570	77	October	212,000	4,253,520	2,790
April	50,100	1,442,310	946	November	8,960	47,350	31
May	34,000	999,210	655	December	9,760	47,890	31
June	44,600	1,156,170	758				
July	34,700	739,860	485	Total	605,349	13,275,510	8,706
1927							
January	9,770	77,790	51	August	1,340	4,760	3
February	6,830	57,990	38	September	4,120	30,550	24
March	1,910	1,760	1	October	1,250	1,680	1
April	3,010	6,900	5	November	80	0	0
May	8,700	96,810	63	December	197	0	0
June	31,700	534,900	351				
July	31,700	583,070	383	Total	100,607	1,402,810	920
1928							
January	405	65	0	August	34,400	552,400	362
February	293	100	0	September	857	430	0
March	1,180	3,080	2	October	0	0	0
April	0	0	0	November	708	600	1
May	103,000	3,152,500	2,068	December	135	9	0
June	11,200	43,000	28				
July	73,200	2,468,330	1,619	Total	225,378	6,220,574	4,080

Table 29.—*Silt determinations, Brazos River at Seymour, 1924–30*—Continued

1929

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	0	0	0	August	31	8	0
February	338	79	0	September	121,000	3,361,910	2,205
March	2,340	2,420	2	October	8,300	52,560	34
April	2,060	5,040	3	November	1,450	1,670	1
May	31,300	403,190	265	December	126	28	0
June	35,400	820,890	538				
July	29,100	448,910	294	Total	231,445	5,096,605	3,342

1930

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	204	80	0	June	107,000	2,660,980	1,751
February	344	190	0	July (1–13)	806	660	0
March	111	23	0				
April	128,000	2,342,980	1,537	Total	423,465	10,234,273	6,712
May	187,000	5,220,300	3,424				

Table 30.—*Silt determinations, Brazos River near Mineral Wells, 1924–30*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June (2-30)	50,100	366,330	240	November	275	47	0
July	1,060	210	0	December	66	0	0
August	113	25	0				
September	144,000	1,502,690	986	Total	201,014	1,870,702	1,227
October	5,400	1,400	1				

1925

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	461	56	0	August	66,200	1,691,730	1,110
February	308	0	0	September	435,000	8,487,120	5,567
March	6	0	0	October	68,700	187,930	123
April	165,000	5,282,960	3,465	November	12,700	10,560	7
May	372,000	4,238,100	2,780	December	1,560	450	0
June	20,500	28,170	18				
July	7,020	970	1	Total	1,149,455	19,928,136	13,071

1926

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	5,070	2,060	2	August	220,000	3,828,560	2,511
February	1,160	150	0	September	116,000	1,020,210	669
March	20,400	89,290	59	October	343,000	6,649,990	4,362
April	115,000	1,557,080	1,021	November	20,500	8,230	5
May	67,200	453,200	297	December	124,000	681,390	447
June	233,000	2,390,720	1,568				
July	104,000	1,026,440	673	Total	1,368,330	17,707,920	11,614

1927

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	18,000	7,070	5	August	13,100	51,800	34
February	25,200	14,460	10	September	12,300	33,660	22
March	43,700	119,420	78	October	41,300	237,080	156
April	120,000	805,220	528	November	1,310	89	0
May	10,100	2,960	2	December	621	82	0
June	82,900	953,140	625				
July	66,100	437,050	287	Total	443,631	2,662,031	1,747

TABLE 30.—*Silt determinations, Brazos River near Mineral Wells, 1924–30*—Continued

1928

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	1,600	190	0	August	156,000	1,228,170	806
February	828	110	0	September	26,400	110,730	73
March	738	110	0	October	781	450	0
April	3,060	930	1	November	13,200	15,390	10
May	373,000	4,709,370	3,089	December	3,070	300	0
June	190,000	1,541,560	1,011				
July	196,000	2,821,340	1,850	Total	964,677	10,428,650	6,840

1929

January	11,600	49,310	32	August	1,310	140	0
February	983	110	0	September	325,000	5,053,340	3,314
March	7,010	1,570	1	October	46,900	163,270	107
April	15,700	36,840	24	November	7,140	970	1
May	224,000	2,734,920	1,794	December	3,480	1,020	1
June	64,900	809,800	531				
July	48,100	286,470	188	Total	756,123	9,137,760	5,993

1930

January	1,060	120	0	August	6,820	900	1
February	1,420	160	0	September	39,200	211,120	139
March	812	66	0	October	450,000	3,861,610	2,533
April	60,700	1,411,620	926	November	18,800	37,640	25
May	604,000	8,516,250	5,586	December	125,000	1,161,510	762
June	369,000	2,801,300	1,837				
July	20,800	21,170	14	Total	1,697,612	18,023,660	11,823

TABLE 31.—*Silt determinations, Brazos River, Glen Rose, 1924–29*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June	86,300	570,240	374	November	3,040	0	0
July	1,660	0	0	December	1,440	0	0
August	1,110	0	0				
September	122,000	1,373,110	901	Total	227,950	1,940,420	1,279
October	12,400	6,070	4				

1925

January	1,680	0	0	August	46,300	1,228,960	806
February	1,220	0	0	September	357,000	6,247,740	4,098
March	368	0	0	October	119,000	901,610	591
April	127,000	3,082,670	2,022	November	26,500	39,100	26
May	412,000	5,348,960	3,508	December	4,130	560	0
June	16,800	650	0				
July	7,780	0	0	Total	1,119,778	16,850,250	11,051

1926

January	19,200	87,060	57	August	239,000	3,829,520	2,512
February	2,680	370	0	September	218,000	2,843,710	1,865
March	24,100	108,980	71	October	354,000	6,262,690	4,108
April	168,000	2,672,510	1,753	November	40,100	22,090	15
May	113,000	1,108,670	727	December	143,000	1,689,600	1,108
June	314,000	4,667,450	3,061				
July	137,000	1,309,200	859	Total	1,772,080	24,802,450	16,136

TABLE 31.—*Silt determinations, Brazos River, Glen Rose, 1924–29*—Continued

1927

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	24,900	8,940	6	August	24,700	79,570	52
February	32,800	17,300	11	September	19,000	25,770	17
March	71,300	329,870	216	October	87,900	728,830	478
April	175,000	2,413,990	1,583	November	3,350	0	0
May	30,000	197,260	129	December	10,200	4,990	3
June	102,000	1,518,980	996				
July	72,400	659,770	433	Total	653,560	5,985,070	3,924

1928

Month	Discharge	Silt (Tons)	Silt (Acre-feet)	Month	Discharge	Silt (Tons)	Silt (Acre-feet)
January	3,710	(1)	----------	August	201,000	1,083,460	711
February	11,800	(1)	----------	September	52,500	117,490	77
March	3,440	(1)	----------	October	1,790	0	0
April	33,600	(1)	----------	November	14,400	(1)	----------
May	338,000	(1)	----------	December	41,600	(1)	----------
June	231,000	(1)	----------				
July	107,000	2,286,630	1,500	Total	1,129,840	3,487,580	2,288

[1] Silt record incomplete.

1929

Month	Discharge	Silt (Tons)	Silt (Acre-feet)	Month	Discharge	Silt (Tons)	Silt (Acre-feet)
January	36,600	283,330	186	June	114,000	1,299,110	852
February	16,400	76,720	50	July	44,100	220,160	144
March	20,800	14,960	10	August	4,700	3,310	2
April	44,300	393,060	258				
May	236,000	3,440,840	2,257	Total	516,900	5,731,490	3,759

TABLE 32.—*Silt determinations, Brazos River, Waco, 1924–30*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June	130,000	776,880	510	November	10,400	2,420	2
July	5,610	460	0	December	9,070	1,010	1
August	4,590	2,000	1				
September	116,000	1,164,760	757	Total	293,270	1,959,600	1,285
October	18,600	21,960	14				

1925

Month	Discharge	Silt (Tons)	Silt (Acre-feet)	Month	Discharge	Silt (Tons)	Silt (Acre-feet)
January	8,960	0	0	August	43,200	876,980	575
February	3,500	0	0	September	360,000	7,001,770	4,592
March	2,080	0	0	October	166,000	1,265,840	830
April	79,300	1,843,960	1,210	November	74,200	205,570	135
May	499,000	7,657,020	5,022	December	9,390	1,390	1
June	18,500	5,530	4				
July	4,080	860	1	Total	1,268,810	18,858,920	12,370

1926

Month	Discharge	Silt (Tons)	Silt (Acre-feet)	Month	Discharge	Silt (Tons)	Silt (Acre-feet)
January	94,800	387,950	255	August	166,000	3,189,260	2,092
February	19,800	3,920	3	September	286,000	3,985,940	2,614
March	111,000	660,550	439	October	332,000	6,979,080	4,578
April	407,000	4,418,040	2,898	November	38,700	53,460	35
May	184,000	1,768,300	1,160	December	102,000	690,600	453
June	346,000	4,384,480	2,876				
July	220,000	2,019,260	1,324	Total	2,307,160	28,550,340	18,727

TABLE 32.—*Silt determinations, Brazos River, Waco, 1924–30*—Continued

1927

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	34,100	22,620	15	August	39,100	134,690	88
February	68,400	74,240	49	September	19,700	16,210	11
March	112,000	509,300	334	October	142,000	1,096,550	719
April	271,000	1,998,030	1,311	November	7,910	510	0
May	126,000	772,190	506	December	12,700	9,470	6
June	508,000	5,719,080	3,751				
July	105,000	477,370	313	Total	1,445,910	10,830,260	7,103

1928

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	11,200	4,280	3	August	209,000	1,882,270	1,235
February	57,500	181,670	119	September	61,300	308,970	203
March	25,000	18,600	12	October	5,140	630	0
April	111,000	970,920	637	November	9,940	4,690	3
May	347,000	6,140,810	4,028	December	46,100	167,760	110
June	330,000	3,400,330	2,230				
July	162,000	2,522,830	1,655	Total	1,375,180	15,603,760	10,235

1929

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	45,700	251,310	165	August	10,100	28,540	19
February	24,700	113,320	74	September	389,000	6,432,940	4,219
March	52,200	134,280	88	October	60,500	220,670	145
April	138,000	703,070	461	November	24,500	10,290	7
May	361,000	4,208,230	2,760	December	16,000	3,980	3
June	177,000	1,429,230	937				
July	41,600	163,120	107	Total	1,330,300	13,698,980	8,985

1930

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	7,620	680	0	August	14,400	6,680	4
February	28,800	89,180	58	September	63,100	164,940	108
March	16,500	42,850	28	October	633,000	6,188,480	4,066
April	26,400	250,180	164	November	70,200	170,060	112
May	922,000	12,511,440	8,206	December	278,000	1,953,460	1,281
June	359,000	2,752,210	1,805				
July	41,100	8,360	6	Total	2,460,120	24,147,530	15,838

TABLE 33.—*Silt determinations, Brazos River, Rosenberg, 1924–30*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June (11-30)	252,000	343,300	225	November	41,000	4,450	3
July	88,800	26,360	17	December	45,100	2,970	2
August	46,100	2,240	1				
September	106,000	342,320	225	Total	664,800	926,680	607
October	83,800	205,040	134				

1925

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	44,100	4,500	3	August	42,400	158,600	104
February	34,400	1,370	1	September	290,000	3,848,840	2,524
March	30,900	2,300	2	October	991,000	6,236,050	4,000
April	27,000	2,740	2	November	1,120,000	4,019,620	2,637
May	514,000	8,427,090	5,527	December	95,800	20,020	14
June	52,700	15,330	10				
July	31,900	3,390	2	Total	3,274,200	22,740,840	14,916

Table 33.—*Silt determinations, Brazos River, Rosenberg, 1924–30*—Continued

1926

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	539,000	2,110,080	1,384	August	272,000	1,527,250	1,002
February	186,000	106,740	70	September	340,000	4,703,610	3,085
March	955,000	3,603,110	2,363	October	383,000	6,133,660	4,023
April	2,190,000	13,300,030	8,724	November	203,000	706,870	464
May	1,240,000	3,676,190	2,411	December	701,000	2,899,910	1,092
June	462,000	3,596,730	2,359				
July	372,000	2,039,020	1,337	Total	7,843,000	44,403,200	29,124

1927

January	292,000	625,210	410	August	104,000	39,080	26
February	544,000	2,167,930	1,422	September	58,600	9,640	6
March	679,000	2,459,250	1,613	October	599,000	4,953,910	3,249
April	961,000	7,965,830	5,225	November	81,500	8,440	6
May	421,000	1,528,830	1,003	December	82,400	27,970	18
June	838,000	8,801,100	5,773				
July	378,000	1,040,010	682	Total	5,038,500	29,627,200	19,432

1928

January	85,500	32,100	21	August	264,000	3,423,140	2,245
February	318,000	3,278,570	2,150	September	105,000	341,570	224
March	208,000	423,230	278	October	37,600	5,160	3
April	214,000	562,750	369	November	40,800	5,480	4
May	295,000	5,009,890	3,286	December	231,000	700,140	459
June	815,000	9,028,140	5,922				
July	161,000	1,074,180	705	Total	2,804,000	23,884,350	15,668

1929

January	328,000	948,760	622	August	57,500	5,340	4
February	96,100	60,540	40	September	393,000	5,668,710	3,718
March	296,000	933,750	612	October	86,100	31,800	21
April	708,000	5,458,680	3,580	November	555,000	1,978,010	1,297
May	1,130,000	9,950,970	6,527	December	97,800	31,270	20
June	2,360,000	8,074,860	5,296				
July	322,000	471,810	309	Total	6,429,500	33,614,500	22,046

1930

January	214,000	423,770	278	August	58,000	3,120	2
February	468,000	877,950	576	September	118,000	38,360	25
March	238,000	318,600	209	October	916,000	8,317,770	5,456
April	134,000	72,880	48	November	212,000	540,620	355
May	2,600,000	30,476,030	19,989	December	935,000	6,314,890	4,142
June	582,000	4,357,970	2,858				
July	128,000	76,570	50	Total	6,543,000	51,818,530	33,988

Table 34.—*Silt determinations, Little River, Little River, 1924–29*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June (8-30)	23,100	1,970	1	November	3,620	170	0
July	8,560	180	0	December	4,410	170	0
August	4,150	0	0				
September	16,500	21,190	14	Total	64,340	24,160	15
October	4,000	480	0				

TABLE 34.—*Silt determinations, Little River, Little River, 1924–29*—Continued

1925

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	4,000	170	0	August	1,380	94	0
February	3,200	15	0	September	16,500	151,400	99
March	2,970	78	0	October	50,700	309,830	203
April	5,010	2,810	2	November	93,200	418,770	275
May	40,700	189,480	124	December	5,820	410	0
June	2,220	110	0				
July	1,310	57	0	Total	227,010	1,073,224	703

1926

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	38,700	30,610	20	August	11,400	1,650	1
February	16,300	970	1	September	8,230	720	0
March	99,900	339,740	223	October	21,900	20,890	14
April	304,000	1,303,880	855	November	6,790	430	0
May	125,000	171,880	113	December	11,300	750	0
June	55,500	96,740	64				
July	74,700	240,260	158	Total	773,720	2,208,520	1,449

1927

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	9,980	240	0	August	5,760	320	0
February	99,300	208,610	137	September	3,910	190	0
March	68,500	21,650	14	October	139,000	324,130	213
April	98,800	359,930	236	November	12,600	4,150	3
May	65,000	128,270	84	December	14,700	850	1
June	135,000	524,570	344				
July	27,900	18,540	12	Total	660,450	1,591,450	1,044

1928

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	9,840	590	0	August	16,800	8,910	6
February	32,700	16,780	11	September	6,130	590	0
March	27,100	1,890	1	October	1,760	77	0
April	20,000	2,190	1	November	1,850	120	0
May	32,200	77,600	51	December	8,670	2,550	2
June	78,600	415,800	273				
July	8,120	4,210	3	Total	243,770	531,367	348

1929

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	13,500	20,320	13	April	38,300	121,930	80
February	6,220	670	0	May (1–27)	39,100	110,320	72
March	17,000	10,390	7				
				Total	114,120	263,630	172

TABLE 35.—*Silt determinations, San Gabriel River, Circleville, 1924–29*

1924

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
June (7–30)	8,930	420	0	November	1,350	130	0
July	5,480	0	0	December	1,420	39	0
August	2,210	210	0				
September	2,040	1,490	1	Total	22,500	2,419	1
October	1,070	130	0				

TABLE 35.—*Silt determinations, San Gabriel River, Circleville, 1924–29*—Contd.

1925

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	1,510	150	0	August	2,310	1,260	1
February	968	0	0	September	4,240	3,470	2
March	982	17	0	October	20,500	117,760	77
April	1,500	290	0	November	16,400	47,460	31
May	10,300	63,140	41	December	2,870	94	0
June	252	20	0				
July	221	18	0	Total	62,033	233,589	152

1926

Month	Discharge	Silt		Month	Discharge	Silt	
January	23,100	6,000	4	August	3,000	370	0
February	10,800	290	0	September	1,580	130	0
March	27,100	78,840	52	October	6,270	2,890	2
April	48,900	415,770	273	November	2,070	110	0
May	49,700	179,890	118	December	3,700	230	0
June	11,800	1,500	1				
July	10,000	16,980	11	Total	198,020	703,000	461

1927

Month	Discharge	Silt		Month	Discharge	Silt	
January	3,900	110	0	August	707	50	0
February	28,300	152,370	100	September	543	11	0
March	23,100	22,290	15	October	43,300	126,040	83
April	31,100	40,340	30	November	3,340	43	0
May	9,500	1,630	1	December	2,100	82	0
June	17,900	20,220	13				
July	2,630	330	0	Total	166,510	369,516	242

1928

Month	Discharge	Silt		Month	Discharge	Silt	
January	2,000	45	0	August	474	24	0
February	8,340	4,090	3	September	415	14	0
March	8,180	460	0	October	389	24	0
April	3,860	360	0	November	613	28	0
May	4,190	2,920	2	December	1,050	56	0
June	5,680	5,780	4				
July	1,330	1,140	1	Total	36,521	14,941	10

1929

Month	Discharge	Silt		Month	Discharge	Silt	
January	1,060	81	0	July	4,330	380	0
February	922	70	0	August	1,460	25	0
March	2,470	11,830	8	September	750	16	0
April	8,930	40,520	27	October	744	7	0
May	80,600	457,230	300				
June	11,500	1,180	1	Total	112,760	511,339	336

TABLE 36.—*Silt determinations, San Antonio River, Falls City,[1] 1927–30*

1927

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
September (13–30)	2,940	1,060	1	November	4,090	36	0
October	10,700	14,700	10	December	7,190	530	0
				Total	24,920	16,340	11

[1] Samples were taken at San Antonio and Aransas Pass R.R. bridge in Fall City, about 3½ miles northeast of the gaging station.

TABLE 36.—*Silt determination, San Antonio River, Falls City, 1927–30*—Contd.

1928

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	7,440	790	1	August	3,190	150	0
February	5,810	530	0	September	10,200	15,700	10
March	9,960	10,160	7	October	7,690	6,780	4
April	8,090	9,940	7	November	12,400	25,730	17
May	20,500	107,360	70	December	9,650	5,710	4
June	17,000	105,380	69				
July	5,400	830	1	Total	117,330	289,120	190

1929

Month	Discharge	Silt		Month	Discharge	Silt	
January	7,930	2,270	1	August	4,590	370	0
February	6,660	390	0	September	6,430	680	0
March	10,000	21,050	14	October	8,120	3,820	3
April	11,800	39,340	26	November	6,720	1,000	1
May	81,800	398,150	261	December	9,220	2,480	2
June	13,800	27,320	18				
July	14,100	10,890	7	Total	181,170	507,760	333

1930

Month	Discharge	Silt		Month	Discharge	Silt	
January	8,670	200	0	August	3,540	69	0
February	7,160	1,240	1	September	3,430	400	0
March	8,120	490	0	October	6,050	1,770	1
April	7,740	960	1	November	6,070	550	0
May	12,100	25,520	17	December	5,260	81	0
June	12,600	23,060	15				
July	6,460	1,400	1	Total	87,200	55,740	36

TABLE 37.—*Silt determinations, Nueces River, Three Rivers, 1927–30*

1927

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
October	118,000	178,670	117	December	713	1,630	1
November	362	34	0	Total	119,075	180,334	118

1928

Month	Discharge	Silt		Month	Discharge	Silt	
January	251	43	0	August	14,800	25,440	17
February	771	350	0	September	20,600	75,610	50
March	2,810	14,250	9	October	30,900	22,370	15
April	2,230	11,140	7	November	8,630	36,280	24
May	103,000	199,840	131	December	5,730	14,920	10
June	48,100	105,000	69				
July	2,290	5,910	4	Total	245,112	511,153	336

1929

Month	Discharge	Silt		Month	Discharge	Silt	
January	4,950	23,490	15	August	3,310	3,420	2
February	179	15	0	September	17,500	30,340	20
March	82,400	333,400	219	October	36,800	18,880	12
April	50,800	173,710	114	November	2,760	2,260	1
May	225,000	524,440	344	December	14,800	40,580	27
June	280,000	69,120	45				
July	25,900	72,100	47	Total	770,399	1,291,755	846

TABLE 37.—*Silt determinations, Nueces River, Three Rivers, 1927–30*—Contd.

1930

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
January	873	82	0	August	46	4	0
February	475	97	0	September	363	360	0
March	7,690	11,760	8	October	28,500	39,980	26
April	50,800	168,730	111	November	21,200	25,830	17
May	210,900	314,510	206	December	539	45	0
June	209,000	129,500	85				
July	42,900	34,680	23	Total	572,386	725,578	476

TABLE 38.—*Silt determinations, Colorado River of Texas near San Saba, 1930*

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
Sept. (11-30)	24,000	143,140	94	December	75,000	343,220	225
October	941,000	4,204,830	2,758				
November	31,100	3,290	2	Total	1,071,100	4,694,480	3,079

TABLE 39.—*Silt determinations, Colorado River of Texas, Tow, 1927–30*

1927

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
October	189,000	804,380	528	December	13,800	490	0
November	15,400	640	0	Total	218,200	805,510	528

1928

January	11,400	330	0	August	133,000	433,350	284
February	15,900	1,540	1	September	70,200	155,430	102
March	12,000	830	1	October	19,100	3,760	2
April	21,100	9,410	6	November	16,400	2,560	2
May	248,000	1,855,970	1,217	December	16,900	3,000	2
June	159,000	870,560	571				
July	173,000	1,087,460	713	Total	896,000	4,424,200	2,901

1929

January	15,200	2,620	2	August	4,720	56	0
February	10,100	670	0	September	111,000	671,770	441
March	35,000	14,550	10	October	94,100	470,170	308
April	61,300	124,860	82	November	10,900	1,320	1
May	322,000	2,445,390	1,604	December	8,550	430	0
June	66,000	148,830	98				
July	22,500	4,010	3	Total	761,970	3,884,676	2,549

1930

January	7,500	250	0	August	13,600	1,870	1
February	6,280	580	0	September	28,300	102,990	68
March	9,780	1,080	1	October	910,000	3,495,620	2,293
April	5,630	220	0	November	34,600	3,050	2
May	406,000	2,290,470	1,502	December	95,300	275,600	181
June	233,000	1,285,130	843				
July	7,500	13	0	Total	1,763,490	7,456,073	4,891

TABLE 40.—*Silt determinations, Colorado River of Texas, Columbus, 1930*

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
August (3-31)	19,200	660	0	November [1]	168,000	560,870	368
September	50,300	19,360	13	December	274,000	825,410	541
October	1,160,000	7,231,960	4,744	Total	1,671,500	8,638,260	5,666

[1] Beginning Nov. 24, discharge records at Eagle Lake, Tex., used.

TABLE 41.—*Silt determinations, Rio Grande, Roma, 1929–30*

1929

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
March (26-31)	32,200	17,080	11	September	338,000	2,802,470	1,838
April	185,000	405,340	266	October	252,000	553,060	363
May	326,000	1,594,050	1,046	November	171,000	294,590	193
June	184,000	321,660	211	December	192,000	467,050	306
July	240,000	1,169,860	767				
August	276,000	1,392,130	913	Total	2,196,200	9,017,290	5,914

1930

Month	Discharge	Silt		Month	Discharge	Silt	
January	140,000	24,560	16	August	246,000	2,293,620	1,504
February	138,000	176,740	116	September	117,000	231,880	152
March	99,000	26,810	18	October	732,000	4,573,880	3,000
April	223,000	1,947,290	1,277	November	336,000	409,650	269
May	406,000	3,578,820	2,347	December	213,000	42,950	28
June	595,000	3,940,640	2,585				
July	131,000	71,260	47	Total	3,382,000	17,318,120	11,359

TABLE 42.—*Silt determinations, Neches River, Rockland, 1930*

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
August (8-31)	3,600	160	0	November	40,900	9,030	6
September	7,020	140	0	December	230,000	26,050	17
October	56,900	27,160	18	Total	338,420	62,530	41

TABLE 43.—*Silt determinations, Red River, Denison, 1930*

Month	Discharge	Silt		Month	Discharge	Silt	
	Acre-feet	*Tons*	*Acre-feet*		*Acre-feet*	*Tons*	*Acre-feet*
August (13-31)	35,700	1,810	1	November	104,000	215,100	141
September	55,900	37,540	25	December	498,000	4,010,860	2,630
October	602,000	5,503,630	3,610	Total	1,295,600	9,768,940	6,407

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