A STUDY OF METHODS USED IN

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

REPORT NO. 9

DENSITY OF SEDIMENTS DEPOSITED IN RESERVOIRS

E. W. LANE AND VICTOR A. KOELZER

NOVEMBER, 1943

A Study of Methods Used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

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Office of Indian Affairs, Bureau of Reclamation

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The cooperative study of methods used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

covers phases indicated by the following report titles.

Report No. 1

FIELD PRACTICE AND EQUIPMENT USED IN SAMPLING SUSPENDED SEDIMENT

Report No. 2

EQUIPMENT USED FOR SAMPLING BED-LOAD AND BED MATERIAL

Report No. 3

ANALYTICAL STUDY OF METHODS OF SAMPLING SUSPENDED SEDIMENT

Report No. 4

METHODS OF ANALYZING SEDIMENT SAMPLES

Report No. 5

LABORATORY INVESTIGATIONS OF SUSPENDED SEDIMENT SAMPLERS

Report No. 6

THE DESIGN OF IMPROVED TYPES OF SUSPENDED SEDIMENT SAMPLERS

Report No. 7

A STUDY OF NEW METHODS FOR SIZE ANALYSIS OF SUSPENDED SEDIMENT SAMPLES

Report No. 8

MEASUREMENT OF THE SEDIMENT DISCHARGE OF STREAMS

Report No. 9

DENSITY OF SEDIMENTS DEPOSITED IN RESERVOIRS

SYNOPSIS

In order to determine the rate at which reservoirs will fill with sediment it is often necessary to estimate the weight per unit volume of the deposited sediment, because the quantity of sediment carried by a stream is usually expressed in terms of weight rather than volume. A thorough study of this subject has never been undertaken and consequently the estimated densities used cover a wide and indiscrimate range of values. All available data have been compiled in this report. The results and conclusions drawn from an analysis of the data are summarized in a form applicable to the needs of organizations or individuals interested in reservoir design.

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DENSITY OF SEDIMENTS DEPOSITED IN RESERVOIRS

E. W. Lane and Victor A. Koelzer*

I. INTRODUCTION

1. Scope of project--The measurement of the quantity and character of sediment transported by streams is an important activity common to river maintenance and development, stream discharge measurement, erosion control, irrigation and hydro-electric development. Considerable work in sediment measurement and analysis has been done, but the methods and apparatus used have varied widely and the quality of the results ranges from very good to very poor. In an effort to improve and to standardize the methods and equipment a cooperative project has been undertaken by the federal agencies having problems in this field. Six reports covering the results of these studies, have been issued as follows:

Report No. 1--"Field Practice and Equipment used in Sampling Suspended Sediment", is a detailed review of the equipment and methods used in suspended sediment sampling from the earliest investigation to the present. with discussions of the advantages and disadvantages of the various methods and instruments. The requirements of a sampler which would meet all field conditions satisfactorily are set forth.

Report No. 2--"Equipment Used for Sampling Bed-Load and Bed Material", deals with equipment for sampling bed-load and bed material in a manner similar to that in which Report No. 1 covers suspended load.

Report No. 3--"Analytical Study of Methods of Sampling Suspended Sediment", covers an investigation of the accuracy of various methods of sampling suspended sediment in a vertical section of a stream, based on the latest developments in the application of turbulence theories to sediment transportation.

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Report No. 4 "Methods of Analyzing Sediment Samples", describes and discusses many methods developed for determining the size of small particles in sediment analyses. Detailed instructions are given for many of the common methods in use for determining the particle size and the total concentration of sediment in samples as developed by agencies doing extensive work in these fields.

Report No. 5--"Laboratory Investigations of Suspended Sediment Samplers", describes investigations of the effect of various intake conditions on the representativeness of sediment samples and the filling characteristics of slow filling samplers under various conditions.

Report No. 7--"A Study of New Methods for Size Analysis of Suspended Sediment Samples" gives account of a study to develop methods of size analysis more suitable to the conditions usually met in suspended sediment studies. It describes a simple form of apparatus developed and gives detailed procedures for its use.

Two additional reports now in preparation will be issued shortly on the following subjects:

Report No. 6 "The Design of Improved Types of Suspended Sediment Samplers" describes the development of various types of time integrating samplers suitable for taking vertically integrated samples in flowing streams and others for taking time-integrated samples at a fixed point. Details of the best forms developed are given.

Report No. 8--"Measurement of the Sediment Discharge of Streams", describes the most efficient methods and equipment to be used in making sediment measurements under various conditions encountered in natural streams.

The scope of the project has been broadened somewhat in order to embrace the study of sediment density described in this report, as the subject covered was of considerable importance to the agencies involved and the material was available without further effort.

2. Purpose of this investigation--In determining the economic feasibility of a reservoir project in a sediment bearing stream, one of the most important problems is to make an estimate of the life of the

reservoir, or the length of the period between its construction and the time when it will become so nearly filled with sediment that it will be no longer useful. To a large extent the accuracy of such an estimate depends upon how accurately the weight of a unit volume of sediment as deposited in the reservoir can be predicted The weight of sediment which the stream carries can be determined by observations of sediment concentration and stream flow, and the weight of a unit volume of deposited sediment may be estimated by comparison with the results of observations of sediment density made for similar conditions in other reservoirs.

In the past unit weights varying from 30 to 125 lbs per cu. ft have been used by various engineers but comparatively few quantitative data have been available upon which an engineer could base a reliable estimate for any particular situation under consideration It was the purpose of this investigation report to assemble all available data bearing on this subject and analyze it with a view to providing engineers with information upon which more accurate estimates can be made The original data are given in considerable detail in order that they may be available for further research, if desired

3. Scope of this report This report consists of three phases, the first of which is a comprehensive review of information on this subject found in previously published literature with a bibliography of references to the original sources. The second phase consists of a study of this literature and all available unpublished quantitative data with a view to summarizing them in a form which will be readily available for application to engineering problems. The third phase is the presen

tation in detail of a large amount of hitherto unpublished data on sediment densities and size composition, which should be useful in any further studies which may be made of this subject.

After the original draft of this study was completed, considerable more original detailed data collected by the Soil Conservation Service became available, but, unfortunately, it was impossible to digest these data and compare them with the conclusions reached from the examination of the earlier data. In the time available it was possible only to prepare these data in detail in tabular form, where they will be available for future studies, as given in Tables 11 and 12.

4. Authority and personnel--The Federal agencies participating in the general study of "Methods Used in Measurement and Analysis of Sediment Loads in Streams," are: the Corps of Engineers, the Geological Survey, the Bureau of Reclamation, the Office of Indian Affairs, the Flood Control Coordinating Committee of the Department of Agriculture, and the Tennessee Valley Authority. The work was largely carried on by personnel furnished by these agencies under the direction of Prof. E. W. Lane of the Iowa Institute of Hydraulic Research assisted by the staff of the Iowa City Sub-Office of the Corps of Engineers. Among those engaged on this work were: P. C. Benedict, C. A. Boyll, M. D. Dubrow, C. R. Horne, V. A. Koelzer, P. M. Noble, V. J. Palmer, F. W. Parker, D. E. Rhinehart, and J. W. Stanley. The present report was first assembled as a personal project by the authors, but as the material was of great importance to the agencies involved and, since publication with these studies would preserve a great part of the value of the report by enabling the detailed

data to be published in full, it was decided to incorporate this study as a part of the major investigation.

5. Acknowledgments--Much of the quantitative data on deposited sediment which have been used in this report were obtained from unpublished records of the U. S. Geological Survey, consisting of the results of unit weights and particle size analyses of numerous samples taken from deposits along the Colorado River and its tributaries by W. D. Collins, C. S. Howard, and S. K. Love. Considerable data were furnished also by the Missouri River Division of the Corps of Engineers which had been compiled by Dr. L. G. Straub. An article by Oexle[24], translated for this study by the U. S. Waterways Experiment Station Research Centers, gave a great deal of data from European studies on this subject. A number of samples were collected from the Iowa and Cedar Rivers by the Iowa Institute of Hydraulic Research. These were analyzed by J. C. Kennedy, of the U. S. Engineer Department, who also made a preliminary review of the previous literature on this subject. Samples of the deposits in the Englewood and Germantown retarding basins of the Miami Conservancy District were furnished by C. H. Eiffert, Chief Engineer, and C. S. Bennett, Engineer, of that organization. A large collection of unpublished data was also furnished by the Soil Conservation Service of the U. S. Department of Agriculture. Other data were obtained from the publications of the Soil Conservation Service, and the U. S. Bureau of Reclamation, and from Mr. A. D. Lewis, Director of Irrigation, Union of South Africa. Many valuable suggestions were made by Carl B. Brown, Head of the Reservoir Section, Sedimentation Division of the Soil Conservation Service. The generous cooper-

ation of all these agencies and individuals in making these data available is greatly appreciated.

II. A REVIEW OF PUBLISHED LITERATURE

6. Previously published literature--The first phase in the study consisted of a thorough review of the previously published information dealing with this subject. References were found scattered in engineering literature, and to aid future investigators a bibliography is added at the end of this report. It was found that unit weights varying from 30 to 125 lbs. per cu. ft. have been used by various engineers in estimating rates of reservoir filling. In the following paragraphs the important information from these articles is summarized.

7. Humphreys and Abbott--The earliest record found of any estimate of the density of deposited sediment was made in 1861 by Humphreys and Abbott who, used a value of 120 lbs. per cu. ft. for the unit weight of material deposited by the Mississippi River.

8. Elephant Butte Reservoir--The Elephant Butte Reservoir, which was constructed between 1910 and 1916 on the Rio Grande River in New Mexico, probably has received more study from the standpoint of sedimentation than any other reservoir. Because the sediment load of this stream is extremely heavy, amounting to as much as 22 per cent by weight, it was recognized early that extensive deposition would occur in the reservoir, and studies of sedimentation were therefore part of the investigation and design of the project. The first study seems to have been made by W. W. Follett of the U. S. Geological Survey(5). On the basis of a single sample consisting of a 3-in. cube taken under carefully selected conditions, he concluded that the unit weight of deposited ma-

terial in the proposed Elephant Butte Reservoir would be 53 lbs. per cu. ft. and that an average of 19,739 acre ft. of sediment would be deposited annually.

It is interesting to note that a later survey of the silting of the Elephant Butte Reservoir indicated[8] that it was filling at the rate of 20,000 acre ft. per year. Concerning these results, Hemphill[8] says, "Follett made no estimate of the silt rolled along the bottom of the stream, but stated his belief that it might possibly amount to as much as 25 per cent of that suspended. Accepting this ratio as a maximum, the results of the survey gave a unit value of 65 lbs. of dry silt per cu. ft. of deposit. It is believed that they (the Rio Grande sediment records) were accurate enough to indicate fairly that suspended silt in the Rio Grande will form deposits containing from 55 to 65 lbs. per cu. ft. of silt."

A study of the sediment deposited in the basin was made by R. R. Coughlan and V. E. Leib[40] in 1916, who measured the density of three samples of sediment and found dry weights of 88 to 101 lbs. per cu. ft. with an average of 92 lbs. per cu. ft. Sieve analyses of these samples show sizes ranging from 76 to 88 per cent (average 81 per cent) passing the 200 mesh sieve and practically all passing the 100-mesh sieve.

The water inflow into the Elephant Butte Reservoir has been measured at San Marcial, a short distance above the reservoir since before storage was started in the basin. Continuous sediment observations were made in 1919 and from 1925 to date. Based on the inflow and sediment records, estimates of the density of the sediment were made by the International Boundary Commission from 1925 to 1935 and by the Sedimentation Division of the Soil Conservation Service for the period 1915 to 1935. So far as known, these are the only comparisons of measured sediment volume in a reservoir and sediment inflow measurements, and give the only values for the average density in a reservoir. From the difference of storage space available in the reservoir as shown by surveys in 1925 and 1935 and the weight of sediment inflow computed from the stream discharge and frequent sediment samples taken during the period, the International Boundary Commission found a deposit of 122,075 acre ft. from 186,506,000 tons of sediment, which give a unit weight of deposited sediment of 70.2 lbs. per cu. ft. The estimate of the Soil Conservation Service was based on the difference of storage space available in the reservoir as shown by the surveys before storage started in 1915 and in 1935, with a sediment inflow weight determined from frequent samples for 12 of the 21 years and from sediment rating curves for the remaining 9 years. A deposit of 379,509 acre ft. was found for this period (including the storage above the spillway level but below the gaging station), and a sediment inflow at the gaging station of 428,385,000 tons, giving a sediment density of 51.8 lbs. per cu. ft. Neither of these estimates take into account the inflow of sediment as bed-load, nor that coming into the reservoir below the gaging station, nor the outflow of sediment through the dam (estimated at 5,000 acre ft. for the total period). The first two of these omissions cannot be estimated accurately but tend to produce a computed density less than the true value, and the third tends to give a density greater than the true value. There is good reason to believe that both of the first two omissions cause small errors, and that therefore an assumption that they are offset by the error of about 7.6 per cent from the third omission is probably valid. The International Boundary Commission estimate neglects the storage of sediment above spillway level, estimated by the Soil Conservation Service at 14,323 acre ft. This is 3.8 per cent of the storage used for the total period and 11.8 per cent of the storage used for the 1925 to 1935 period. The error is therefore between 3.8 and 11.8 per cent. It is reasonable to assume that most of the sediment above spillway level was deposited in the latter part of the period, since during much of the early part of the period the reservoir was filling up, and therefore at a low level. Assuming that 10,000 of the 14,323 acre ft. were deposited in the 1925 to 1935 period, the inclusion of this volume in the 1925 to 1935 estimate would lower the sediment density from 70.2 to 64.5 lbs. per cu. ft. Another part of the difference in the densities computed by the two organizations is probably due to the shrinkage in the sediment with time. The assumption is made that the difference in the sediment volume in 1925 and 1935 is the space occupied by the sediment which came in during this period. Actually the sediment occupies not only this space but also the space made available by shrinkage of the sediment deposited before 1925 which took place during the 1925 to 1935 period. The true volume of the 1925 to 1935 sediment is therefore greater than that estimated and the true density is therefore less than estimated. Knowledge of the rate of compaction in reservoirs is insufficient to estimate closely how much difference in density the compaction would make, but it might amount to several lbs. per cu. ft.

9. Colorado River Basin. Considerable data have been collected in

the valley of the Colorado River in Arizona and California. The U. S. Bureau of Reclamation used[7] a unit weight of 100 lbs. per cu. ft. in studying the deposited material in the Imperial Canals. Fortier and Blaney[6] thought this value was too high for material carried in suspension as the material sampled and analyzed in determining this figure was largely transported as bed-load.

Table 1 is a summary proposed by Stevens[16] of a number of samples of sediment deposits taken in the region of the Colorado River by Fortier and Blaney.

TABLE 1

DENSITY OF SEDIMENT DEPOSITS FROM VICINITY OF COLORADO RIVER

Location	Number of Samples	Density lbs. per cu. ft.
Yuma, Arizona	20	85.4
Laguna Dam	10	81.6
Bed Silts, Imperial Canals, 1925	17	102
Bed Silts, Imperial Canals, 1917-18	12	97
Gila River silt bars	15	74.2
Settling basins of following Imperial Valley municipal water systems:		
El Centro, California	12	45.2
Imperial, California	12	37.0
Calexico, California	10	37.7
Experimental basin at Parker City	5	57.5

A large number of samples have been taken from the Colorado River region by the U. S. Geological Survey, the data for which are given in Tables 8 and 9.

10. Texas reservoirs--Table 2 gives data taken from surveys of numerous reservoirs in Texas[4,8] in 1929 by the U. S. Department of Agriculture. This table gives the dry unit weight of the deposited sediment and also the percentage of moisture in the samples as taken. The

TABLE 2

DENSITY OF SEDIMENTS DEPOSITED IN TEXAS RESERVOIRS

Sample Number	Density lbs. per cu. ft.	Moisture Per cent	Remarks
			LAKE AUSTIN, AUSTIN, TEXAS
1	83.5	24.0	Exposed deposit 9 ft. below high water mark. Surface cracked.
2	84.9	22.3	Sample from 6 in. below top of deposit. Surface cracked.
3	84.5	24.0	Sample from 6 in. below top of deposit. Surface cracked.
4	86.9	23.6	Sample from 6 in. below top of deposit. Surface cracked.
5	106	14.7	Probably deposited before dam was built. Surface cracked.
6	64.7	38.0	Sample from 9 ft. below high water mark and 8 in. above water surface.
7	73.1	32.4	Sample from 20 ft. of silt and 35 ft. under high water mark.
8	69.8	31.2	Sample from 20 ft. of silt and 35 ft. under high water mark.
9	67.6	31.9	Sample from 20 ft. of silt and 35 ft. under high water mark.
10	51.9	43.3	2.5 ft. below top of deposit and 2 ft. below high water mark.
11	54.5	40.8	2 ft. below top of deposit and 1 ft. below high water mark.
12	29.6	63.0	300 ft. above dam and under 10 ft. water. All material less than 200-mesh screen.
13	29.9	62.9	
14	30.5	62.4	Fresh deposit.
			MEDINA RESERVOIR
1	36.1	55.4	300 ft. above dam at bottom of channel. All less than 300-mesh.
2	45.0	49.4	3-1/2 mi. above dam at bottom of channel. All less than 300-mesh.
3	46.4	47.3	7 mi. above dam at bottom of channel. All less than 300-mesh.
4	106	23.7	In silt cobbles from bar above backwater. High weight believed to be due to rolling while in plastic state.
5	49.2	47.1	At point of inflow 1 ft. above water surface.
6	91.6	22.4	From bank exposed for long period.
7	72.9	30.6	Exposed bank deposit. Surface cracked.
8	74.4	31.1	Exposed bank deposit. Surface cracked.
			LAKE WORTH, FORT WORTH, TEXAS
1	18.7	74.7	1/4 mi. above dam at middle of reservoir, under 30 to 40 ft. of water. All material less than 300-mesh.
2	21.7	71.4	From reservoir bottom in old channel. All less than 300-mesh.
3	22.6	69.9	4-3/4 mi. above dam in old channel. All less than 300-mesh.
4	29.4	62.8	6 mi. above dam in old channel. All less than 300-mesh.
5	45.3	49.7	8 mi. above dam under 8 in. of water. Exposed during low stages.
6	53.9	42.7	8 mi. above dam under 8 in. of water. Exposed during low stages.
7	47.2	49.2	8 mi. above dam under 8 in. of water. Exposed during low stages.
8	33.4	56.6	9.5 mi. above dam in old channel.
9	99.2	16.6	Old exposed deposit on bank. 73 per cent sand.
10	93.5	18.0	Sand bar 1 ft. above water surface. All sand.
			LAKE KEMP, SEYMOUR, TEXAS
1	37.0	56.4	300 ft. above dam.
2	35.9	57.5	300 ft. above dam.
3	88.8	26.0	Old dry deposit.
			LAKE CISCO, CISCO, TEXAS
1	42		Intermittently exposed deposit.
2	85		Exposed dry deposit.

report on this study gives a great deal of valuable data, of which the following paragraphs summarize the more important findings.

"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 lbs.; 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 lbs.; and in a power reservoir, where the head is maintained practically constant, exposure and the resulting shrinkage do not take place, and the average ultimate weight of the dry material per cubic foot of deposit approximates 30 lbs.

"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 lbs. 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 downstream below the water surface, it is impossible to estimate the volume. Such material will be deposited where it will be preserved indefinitely if kept submerged with water."

Regarding the results of these studies on Texas reservoirs, Hemphill(8) said:

"Exposed bars of coarse silt, such as is found at the head of reservoirs, averaged 92 lbs. of dry material to 1 cu. ft. of deposit, while finer silt in much the same location averaged 82 lbs. Samples from the surface of deposits near the middle of reservoirs averaged 55 lbs. of dry material to each cu. ft. Samples of the finest material taken from the submerged deposits in old river channels in reservoirs averaged 31 lbs. of dry material to 1 cu. ft.

"It is interesting to note that if the average silt yield, in tons per square mile, from the area above this reservoir (Lake Worth) is comparable to that of the nearby

Brazos drainage, as shown by the records at Glenrose, the deposit in the reservoir contains less than 60 lbs. per cu. ft."

H. G. Nickle(16) states that the density of deposits in the Medina Reservoir after 13 years of operation averaged 30 lbs. per cu. ft., but 5 years later, owing to exposure to the sun and atmosphere in this period, had increased to 63.6 lbs. per cu. ft. He estimates that an average value of 70 lbs. per cu. ft. should be used in reservoirs in which the sediment deposits are subject to alternate wetting and drying.

11. <u>Missouri River</u> -Dr. L. G. Straub made a thorough study of the density of sediment carried by the Missouri River for the Missouri River Division of the U. S. Engineer Department. A combination of samples gathered in the course of field operations were separated into various grades ranging from clay to pebble gravel and each grade was allowed to settle in still water under idealized conditions. The following table gives the unit weights and other pertinent data from these studies.

TABLE 3

DENSITY OF DEPOSITS FORMED UNDER

LABORATORY CONDITIONS

	Size Range mm.								
	0-1/256	1/256-1/16	1/16-1/8	1/8-¼	¼-½	½-1	1-2	2-4	4-64
Density, lbs per cu. ft.	37.8	80.9	89.6	99.0	104.9	104.0	104.4	102	102
Voids, Per cent	76.5	50.2	45.6	39.4	35.7	35.7	36.7	37.6	38.2

A number of samples were taken from the settling basins of the Kansas City, Kansas, waterworks and analyzed for unit weights and per cent of voids. The water was pumped from the Missouri River and hence the sediment was definitely suspended. The results are given in the following table.

TABLE 4

CHARACTER OF MISSOURI RIVER SUSPENDED SEDIMENT

DEPOSITED IN SETTLING BASINS

Sample Number	Location of Sample	Density lbs. per cu. ft.	Voids Per cent	Specific Gravity	Per cent in Classification Sand 1/16-1 mm.	Clay 0-1/16 mm.
	1st Basin					
1	upper end	116.0	26.9	2.54	93.5	6.5
2	center	70.0	57.2	2.61	65.7	34.3
3	center	66.7	60.0	2.67	65.4	34.6
4	lower end	34.3	79.6	2.68	17.0	83.0
5	lower end	35.7	78.3	2.63	24.0	76.0
	2nd Basin					
6	upper end	33.8	78.4	2.50	11.6	88.4
7	center	22.7	85.4	2.50	6.8	93.2
8	lower end	25.8	84.2	2.63	11.6	88.4
	3rd Basin					
9	center	25.2	83.3	2.43	4.9	95.1

Regarding the results of these determinations the report states:

"The weight per unit volume varies inversely with the fineness of material.

"A dry weight per unit volume of deposit as low as 22.7 pounds per cubic foot was observed. A corresponding amount of voids was 85.4 per cent, thus indicating the fine mud (silt and clay) to be in a state of what might be considered "semi-suspension".

"The average dry weight per unit volume of deposit material was 47.8 pounds per cubic foot with a corresponding amount of voids of 70.4 per cent of the bulk volume".

A number of samples were taken from natural deposits in the Missouri River in the vicinity of Kansas City. Data on unit weight, size analysis and per cent of moisture of these samples are given in Tables 8 and 9.

12. Miami Conservancy District retarding basins.--In order to determine the densities reached by sediments in retarding basins where the

deposits are covered with water only at rare intervals, two samples each were taken by the engineering department of the Miami Conservancy District from the Englewood and Germantown basins near the dams at the points of deepest deposits, and were analyzed at the Iowa Institute of Hydraulic Research. The deposits from the Englewood Basin were finer than those from the Germantown Basin, probably because the detention period in the former is longer, ranging from 5 to 12 days as compared with 2 1/2 to 4 days in the latter. The two samples from the Englewood basin showed dry weights of 70 and 85 lbs. per cu. ft., and those from the Germantown basin showed 79 and 80 lbs. per cu. ft. From the information available it is not possible to explain the difference in the density of the two samples from the Englewood basin. The size analyses of the Miami samples are shown in Table 8.

13. European investigations. Oexle[24] has given a very extensive review of European literature on this subject, together with the results of a thorough investigation of his own. The following is a summary of the pertinent parts of his review of previous literature: Baumgarten[25] gives 92 lbs. per cu. ft. as the density of suspended material deposited in the Caronne River and Spring and Prost[26] found 81 lbs. per cu. ft. for the Meuse. Heim[27] found a value of 79 lbs. per cu. ft. at a depth of 200 m. in Lake Urn where a depth of 15 mm. of sediment was deposited in a year and in the Nuotta basin, at a depth of 100 m., a value of 99 lbs. per cu. ft. where 80 mm. were deposited per year. Singer[25] was of the opinion that a value of 100 lbs. per cu. ft. should be used and in certain cases 125 lbs. per cu. ft. These values probably applied to bed-

load which was composed of sand or coarser material. Deposits in the Drance were found to have values between 89 and 104 lbs. per cu. ft.

Reisinger[28] gives some interesting data on the variation of density with depth within the marl sediment in Lake Niedersoutholfen in Bavaria, which are shown in Table 5.

TABLE 5

VARIATION OF DENSITY WITH DEPTH OF SEDIMENT IN LAKE NIEDERSOUTHOLFEN

Depth, m.	Upper Layer	1	2	3	4	5	6	7
lbs. per cu. ft.	21.6	39.6	41.5	34.8	42.1	45.1	52.8	53.9
Depth, m.	8	9	10	11	12	13	14	15
lbs. per cu. ft.	56.0	73.6	74.0	80.4	85.2	97.7	92.7	84.0
Depth, m.	16	17	18	19	20			
lbs. per cu. ft.	87.2	85.3	92.8	88.1	89.6			

In a later publication[29] he gives other interesting data on the variation of density with increasing distance from the inflow to the lakes. Five traps on the bottom of Lake Alp arranged progressively further from the inflow, after 8 years gave values of 41, 32, 26, 26, and 25 lbs. per cu. ft. At the site of the fourth trap in 4 years a value of only 13.1 lbs. per cu. ft. was observed. The average rate of deposit per year was 0.84 lb. per sq. ft. In a case at Lake Niedersoutholfen, seven sediment traps similarly arranged, for a period of 3 years gave values of 29.4, 24.4, 21.8, 21.8, 20.6, 20.0, and 13.7 lbs. per cu. ft. The deposits in this case averaged 1.25 lbs. per sq. ft. per year, but the rate of settlement did not vary appreciably with time. In Lake Starnberg, at its maximum depth (117 m.), a deposit of 0.104 lb. per sq. ft. per year gave a density of 10.1 lbs. per cu. ft., and the deposits on the lake bed which were 7 m. deep, had a density of 83 lbs. per cu. ft. The flow in Lake Starnberg is much slower than in Lake Alp. Mulhofer[30] found a density of 92 lbs. per cu. ft. for a sample taken below a spur dike in the Inn River.

Size analyses and density data on samples taken by Oexle are given in Tables 8 and 9.

14. Investigation of coarse sediments in California--A great deal of data on the weight of very coarse sediments such as might be deposited by a mountain stream have been collected in California in connection with ground-water studies. Sonderegger[22] gives the following data on the per cent of voids of coarse deposits in San Gabriel wash in southern California from which the unit weights have been computed, assuming the specific gravity of the particles to be 2.65.

TABLE 6

DENSITY AND POROSITY OF SAN GABRIEL WASH DEPOSITS

Classification	Voids Per cent	Density lbs. per cu. ft.
Boulders, gravel and sand	12	146
Coarse gravel and sand	17	137
Medium gravel and sand	20	132
Fine gravel and sand	28	119

These values indicate substantially higher unit weights for this sort of material than for sands, silts and clays.

A very thorough study of the voids and water retaining capacity of coarse sediments was made by the Division of Water Resources of the State of California[31]. To determine the underground water storage capacity of the south coastal basins in the vicinity of Los Angeles more than 200 samples were analyzed and their voids determined. The amount of water which would drain out of them was also determined. The voids (porosity) and water retention (possible recovery) for coarse material were found to vary with the particle size, as shown in Fig. 1.

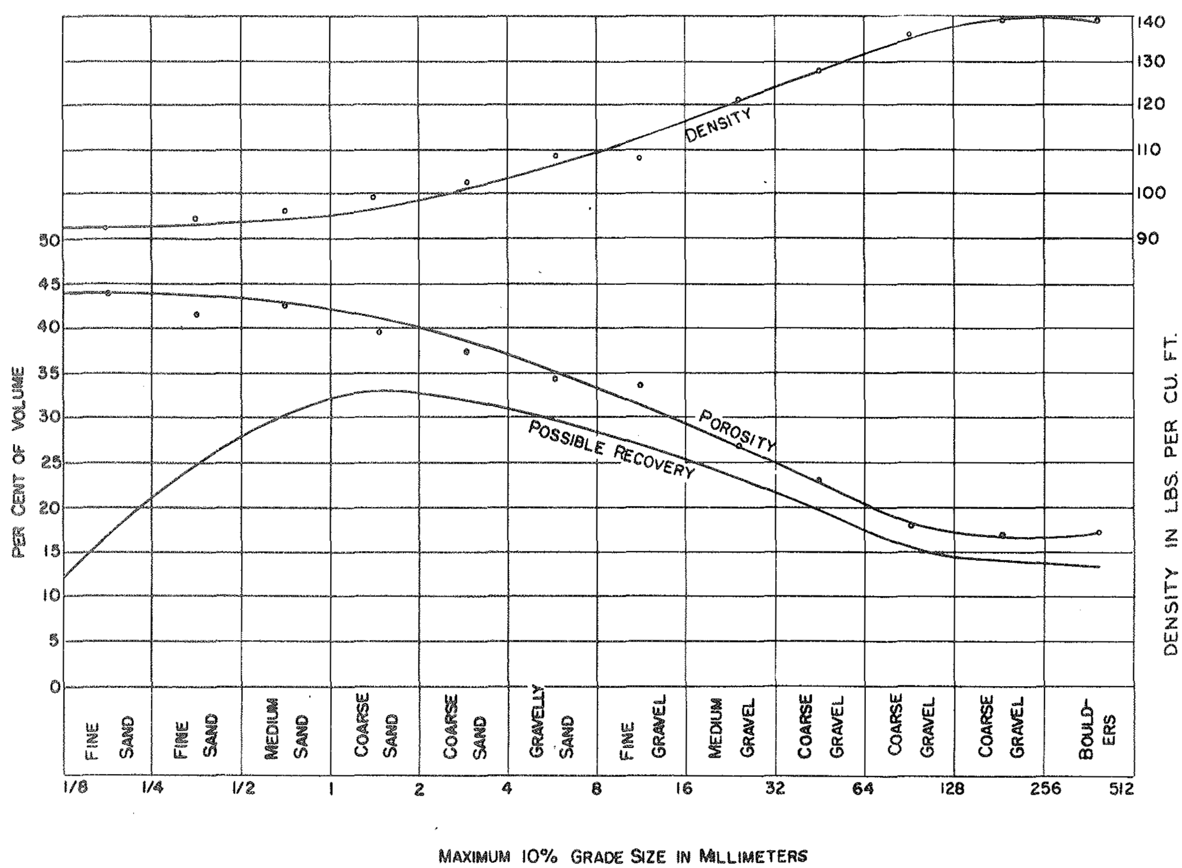

FIG. 1 - POROSITY, DENSITY AND POSSIBLE WATER RECOVERY FOR SEDIMENTS OF THE SOUTH COAST BASIN, CALIFORNIA

Assuming the solid particles to have a specific gravity of 2.65, the densities of the deposits shown on this diagram were also computed. The sizes shown on the abscissa scale are the sizes at which the cumulative total, beginning with the coarsest material, reaches 10 per cent, i.e. the 10 per cent coarser size. It will be seen that the density of the sediments increased as the particle size increased, from 93 lbs. per cu. ft. for fine sand to 139 lbs. per cu. ft. for boulders. These data compare reasonably well with the data given by Sonderegger(22) and check exactly the value, for sand 93 lbs. per cu. ft., obtained independently on Fig. 2. Studies of sediments in the Mokelumne area in California by the U. S. Geological Survey(32) give similar results. The sediments studied by the California Division of Water resources and the Geological Survey were taken from pits and borings sunk into deposits of steep streams and in most cases were probably hundreds or thousands of years old. It is believed, however, that the settlement of coarse material with time and depth is very small, so that the results of these studies can be accepted as being substantially correct. Because the data on which these studies were based are very voluminous and are readily available in detail in the publications, and because of the fact that the materials studied were not recent depositions and that reservoirs filling with such material are relatively rare, the detailed data are not presented in this report.

15. Studies of initial density by Trask--Trask(34) studied the relation of density to particle size of sediments when first deposited. He separated sediments into fractions composed of particles within a given size range and determined their density after a very short settlement period. He found that the initial density increased with the particle size, as shown in Table 7.

TABLE 7

INITIAL DENSITY DETERMINED BY TRASK

Type	Size mm.	Density lbs. per cu. ft.	Average Density lbs. per cu. ft.
Sand	.500 - .250 .250 - .125 .125 - .064	89 89 86	88
Silt	.064 - .016 .016 - .004	79 55	67
Clay	.004 - .001 .001 - .000	23 3	13

16. Other investigations. A board of Army Engineers reporting on the San Carlos Project, Arizona, in 1914(8,10) used a unit weight of 70 lbs. per cu. ft. of deposit.

By studies and measurements on the Kaw River in Kansas, Herman Stabler and H.N. Parker(15) determined the unit weight of the deposited sediment to be 85 lbs. per cu. ft.

Dabney(37) found a density of 60 lbs. per cu. ft. for samples of deposits of sediment from tributaries of the Yazoo River in Mississippi.

Silt in the Indus River, India,(14) was found to weigh approximately 95 lbs. per cu. ft.

Todd and Eliassen(18) found that the weight of dried deposited sediment in the Yellow River, China, averaged 101.5 lbs. per cu. ft. Freeman(19) found Yellow River deposits averaged 90 lbs. per cu. ft.

In estimates for the Martin Reservoir on the Arkansas River, the senior author used unit weights of 95 lbs. per cu. ft. for the coarse material which would be deposited in and above the delta and 60 lbs. per cu. ft. for the fine sediment which would be deposited more or less evenly over the bed of the reservoir.

Happ[42] states that 318 samples have been studied by the Soil Conservation Service, ranging in densities from 20.1 to 101.7 lbs. per cu. ft. The average of all samples was 54 lbs. per cu. ft. For 210 samples from the fine deposits which were continually submerged, the average was 44 lbs. per cu. ft., and for 35 samples of similar deposits which had been exposed and subject to drying and compaction the average was 67 lbs. per cu. ft. The average of the 73 samples from deltas was 75 lbs. per cu. ft.

Apjohn[20] made a number of experiments on the clayey sediment deposited in Bengal, India, rivers and found an average dry weight of 50 lbs. per cu. ft. Col. W. M. Ellis took six samples from the margins of the Kistna River which had an average dry weight of 98 lbs. per cu. ft. The difference is probably due to the larger quantity of sand in the Kistna, the material studied by Apjohn being extremely fine mud. Parker[41] states that values ranging from 140 to 80 lbs. per cu. ft. have been observed, presumably in India.

III. RESULTS OF STUDY OF AVAILABLE DATA

17. Factors influencing sediment density.- A determination of the unit weight which should be used for reservoir sediment in any case is a complicated problem involving a number of variables. Among them are the manner in which the reservoir will be operated, the size of the sediment particles, the rate of compaction of the sediment, and perhaps other factors.

Probably the most important of these is the manner in which the reservoir is to be operated. As has already been pointed out in the review of previous literature on this subject, when a reservoir is operated in such a manner that the level is lowered from time to time, the deposited sediment is exposed to the sun and air, and is dried out and becomes more dense. The most extreme case of this is in detention basins used exclusively for flood control without conservation pools. Here the sediment deposited in one flood usually has ample time to dry out before the next flood comes and a high unit weight is therefore produced. Reservoirs that are frequently drawn down for irrigation supply or power storage form an intermediate condition, and reservoirs which are kept full have the lowest unit weight.

A case tending toward low unit weights is that of a reservoir used for pondage by a "run of river" hydro-electric plant, where the sediment is submerged at frequent intervals and drying out is prevented. Multi-purpose reservoirs offer complicated problems which can only be solved by consideration of the way in which they will operate. Another case which produces low unit weights is a storage reservoir which is drawn down only at long intervals, with a rapid rate of drawdown and quick refill.

As long as all the deposits are below the lowest level that the reservoir is drawn down, they have no adverse effects, but as soon as they accumulate above this level they reduce the maximum effective capacity. As soon as they reach this level, however, in most cases they are dried out to some extent, and therefore the density increases. The amount of drying, however, is not large unless the deposits are uncovered for a considerable period of time. Therefore, normally only the deposits which lie somewhat above the usual drawdown level will be increased considerably in density by drying. The dried sediment does not expand to its original density when it is again covered with water. The growth of plants on the sediment also probably tends to consolidate the sediments by using up moisture in them.

The rate at which sediment deposits consolidate under water is of importance, because if the consolidation is rapid, a higher unit density can be used than if it is slow. Little information on this point is available and the subject is under study by the Sedimentation Division of the Soil Conservation Service. Considerable information along this line is available in the field of soil mechanics, but it is not known exactly how the results of studies of the compaction of the more consolidated sediments used in soil mechanics apply to the conditions of low consolidation usually met with in reservoir sediments. There is reason to believe, however, that coarse sediments, such as sands and gravels, reach their final consolidation in a negligible length of time, and that the rate of consolidation decreases with the fineness of the sediments.

The size of the sediment particles has an important effect on the unit weight. Sand and gravel have a high unit weight, especially if the size of particles is non-uniform so that the voids between the larger particles tend to be filled by the smaller ones. Silts have a lesser weight and clays still less. Where deposits are of coarse material, a higher unit weight should be used than if the deposits are fine.

Reservoirs in which there is a current of water flowing when the sediment is depositing tend to produce heavier sediments than those where the water is not flowing, as the currents carry away more or less of the fine material, thus producing a coarser sediment, and consequently a greater density.

It has been suggested that this condition of flocculation or non-flocculation under which the fine silts or clays are deposited has considerable effect on the density of the sedimentary formation produced. Very probably this is true, but verification could not be made due to lack of pertinent data. It appears to open a fertile field for further study.

18. Analysis of observed densities--In Table 8 are given all available data on size composition of samples of which the density has been measured. A great many different separation points were used by the various agencies in these analyses and in Table 9 they have been reduced, as accurately as possible, to a single basis, by dividing them into the sand, silt, and clay fractions, according to the U. S. Bureau of Soils classification. In this classification clay includes all particles less than 0.005 mm., silt those between 0.005 and 0.05, and sand those between 0.05 and 1.0 mm. On Table 9 are also given brief notes on the locations from which the samples were taken.

Most of the samples on which data were secured are from the Colorado and Missouri Rivers, and therefore probably have more sand content than the average reservoir deposit. Comparatively few data are available on deposits having a high clay content. The results show a distinct tendency for the weight to increase with increase in the proportion of coarser material. An attempt was made to show this graphically on the basis of the per cents in the three classes, sand, silt, and clay, but the data on densities at the higher clay contents were insufficient to permit a reliable graph to be drawn. It was found however (Fig. 2) that the data could conveniently be shown by plotting the dry weight in lbs. per cu. ft. against the per cent of sand, including in sand all material larger than 0.05 mm. It is probable that very few of the samples contained an appreciable amount of material larger than 1.0 mm., the upper limit of sand sizes in the U. S. Bureau of Soils classification.

Most of the samples follow a well defined band, showing a distinct increase in weight with increasing sand content, but a number of them differ considerably from this general trend. A large number of those which differ widely were taken from the beds of shallow chutes through a sand bar in the Missouri River, and were probably very recent deposits which were in a dilated condition. Two were taken from the Iowa River, where the conditions were similar. It is believed that these are not representative of deposits which have accumulated in sufficient quantities to materially reduce the capacity of reservoirs. The equation of the line through the band representing most of the plotted results is $W = 51 (P + 2)^{0.13}$. On Fig. 2 are drawn also the lines showing 5 and 10 per cent deviation from the equation. They show that 50 per cent of the

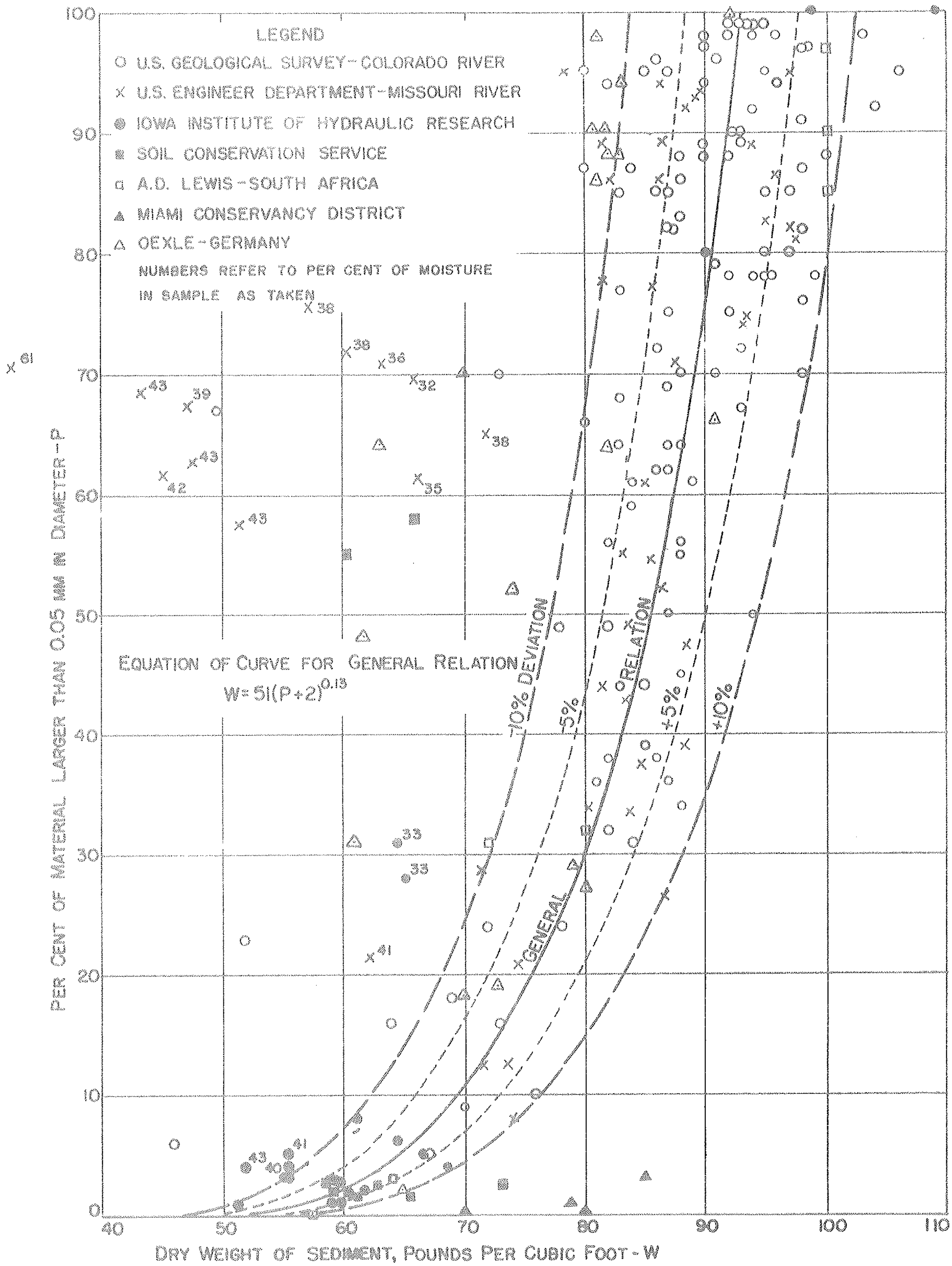

FIG. 2 - RELATION OF UNIT WEIGHT OF DEPOSITED SEDIMENTS TO PER CENT OF SAND

TABLE 8

DENSITY AND SIZE ANALYSIS OF DEPOSITED SEDIMENT

Source	Sample No.	Density lbs. per cu. ft.	Per cent finer than given size in mm.												
			2.0	0.5	.20	.149	.100	.074	.050	.040	.030	.020	.010	.005	.002
Iowa and Cedar Rivers, Iowa Collected by Iowa Institute of Hydraulic Research	1	56	100	100			100		97			82	56	33	
	2	55	100	100			100		97			88	62	37	
	3	56	100	100			100		95			68	38	23	
	4	69	100	100			100		96			79	49	30	
	5	61	100	100			97		92			70	40	20	
	6	59	100	100			100		99			81	54	27	
	7	59	100	100			100		97			74	45	25	
	8	62	100	100			100		98			77	43	21	
	9	56	100	100			100		96			73	41	20	
	10	60	100	100			100		99			73	39	17	
	11	65	100	99			78		72			52	31	15	
	12	65	100	99			76		69			53	32	18	
	13	52	100	100			100		96			88	59	36	
	14	52	100	100			100		99			85	55	13	
	15	67	100	100			100		95			69	39	22	
	16	64	100	100			100		94			71	21	25	
	17	90	100	57			24		20			11	7	4	
	18	50	95	93			38		33			19	12	8	
	19	109	99	40			1		0			0	0	0	
	20	99	98	26			1		0			0	0	0	
Lake Arthur, South Africa Collected by A. D. Lewis	Valves	38			100				100			--		77	64
	A	39			100				100			95		67	49
	A2	58			100				100			91		67	49
	A7	100			77				10			5		4	2
	A10	72			98				69			53		40	29
	B2	64			100				97			84		51	37
	B5	100			97				15			7		3	3
	B7	80			100				68			42		22	15
	B11	100			70				3			2		2	1

Colorado River near Yuma,	Y1	86							15	9	6	4	3	2	--
Arizona	Y2	88							66	46	28	13	7	5	4
Collected in 1928 by W. D.	Y3	69							58	32	21	--	--	--	--
Collins and C. S. Howard.	Y4	93							33	23	16	10	6	4	1
Analyses by U. S. G. S.	Y5	87							18	8	5	4	2	1	1
	Y6	85							56	43	29	18	10	7	2
	Y7	85							61	45	29	22	12	6	5
	Y8	69							82	73	57	41	23	14	6
	Y9	52							77	68	60	48	44	32	20
	Y10	88							12	10	8	7	6	5	--
	Y11	87							16	10	9	8	7	6	--
	Y12	92							12	9	6	5	4	3	--
	Y13	73							30	21	17	15	10	7	--
	Y14	97							15	9	6	5	4	3	--
	Y15	82							68	61	54	46	37	22	14
	Y16	76							90	84	75	65	42	26	13
	Y17	82							51	43	37	32	22	14	--
	Y18	82							44	36	32	26	18	14	--
	Y19	93							10	--	--	--	--	--	--
	Y20	93							10	--	--	--	--	--	--
	Y21	86							38	28	24	20	15	11	--
	Y22	83							15	10	8	7	5	3	--
	Y23	88							14	9	6	5	5	4	--
	Y24	81							64	50	36	25	14	11	--
	Y25	86							32	47	34	24	13	9	6
	Y26	72							76	72	66	56	40	30	--
	Y27	87							5	3	2	--	--	--	--
	Y28	64							84	81	77	67	53	35	16
	Y29	103							2	1	--	--	--	--	--
	Y30	98							3	2	1	--	--	--	--
	Y31	93							11	8	5	4	--	--	--
	Y32	89							39	23	15	11	6	3	--
	Y33	95							20	13	9	7	6	--	--
	Y34	78							51	38	30	23	16	11	--
	Y35	87							31	20	14	11	--	--	--
	Y36	91							21	13	11	9	7	5	--

TABLE 8

DENSITY AND SIZE ANALYSIS OF DEPOSITED SEDIMENT (CONTD.)

Source	Sample No.	Density lbs. per cu. ft.	Per cent finer than given size in mm. 2.0	0.5	.20	.149	.100	.074	.050	.040	.030	.020	.010	.005	.002
Colorado River near Topock	T1	85				89		16	5			--		--	
and Parker, Arizona	T2	83				96		51	32			--		--	
Collected by S. K. Love and	T3	98				84		30	13			--		--	
C. S. Howard.	T4	88				99		83	44			--		--	
Analyses by U. S. G. S.	T5	94				56		26	22			--		--	
	T6	98				99		44	24			--		--	
	T7	73				95		90	84			--		--	
	T8	82				81		69	62			--		--	
	T9	70				99		96	91			--		--	
	T10	98				95		48	30			--		--	
	T11	88				98		71	30			--		--	
	T12	84				99		82	39			--		--	
	T13	87				99		93	50			--		--	
	T14	88				98		74	36			--		--	
	T15	87				99		83	64			--		--	
	T16	83				99		89	56			--		--	
	T17	80				99		76	34			--		--	
	T18	87				95		63	25			--		--	
	T19	83				96		58	23			--		--	
	T20	87				95		50	18			--		--	
	T21	87				93		49	15			--		--	
	T22	88				95		49	17			--		--	
	T23	90				83		12	2			--		--	
	T24	92				90		12	1			--		--	
	T25	83				99		78	36			--		--	
	T26	80				99		77	13			3		1	
	T27	90				90		41	6			1		0	
	T28	82				93		31	6			3		--	
	T29	80				82		23	5			3		--	
	T30	86				93		24	4			2		--	

	T31	90				93		22	3			1		--	
	T32	98				91		20	3			1		--	
	T33	92				91		19	2			1		--	
	T34	78				100		98	76			43		15	
	T35	91				100		80	30			10		4	
	T36	92				95		76	22			5		2	
	T37	96				67		19	2			1		--	
	T38	94				65		13	2			1		--	
	T39	95				71		12	1			0		0	
	T40	94				50		10	1			0		0	
	T41	93				34		5	1			0	--	0	
	T42	94				35		5	1			0	--	0	
	T43	67				--		99	95			70	--	42	
	T44	95				99		76	22			5	--	2	
	T45	98				97		52	9			2	--	1	
	T46	90				90		28	11			8	--	4	
	T47	86				--		92	28			4	--	2	
	T48	94				99		96	50			15	--	5	
	T49	95				94		55	22			9	--	3	
	T50	93				99		87	28			9	--	3	
	T51	46				99		98	94			70	--	35	
Colorado River at Grand Canyon,	GC41	87							38			7	--	3	
Arizona	GC44	88							45			7	--	2	
Collected by S. K. Love.	GC46	87							36			11	--	3	
Analyses by U. S. G. S.	GC48	84							41			8	--	2	
	GC51	96							6			1	--	--	
	GC54	97							20			2	--	1	
Little Colorado River near	GF1	91							4			2	1	0	
Grand Falls, Arizona	GF2	88							55			21	9	5	
Collected by S. K. Love.	GF3	99							22			7	3	2	
Analyses by U. S. G. S.	GF4	95							15			11	8	5	
	GF5	106							8			5	4	2	
	GF6	90							12			6	4	3	
	GF7	94							8			5	4	3	
	GF8	104							8			5	4	3	

TABLE 8

DENSITY AND SIZE ANALYSIS OF DEPOSITED SEDIMENT (CONTD.)

Source	Sample No.	Density lbs. per cu. ft.	Per cent finer than given size in mm. 2.0	0.5	.20	.149	.100	.074	.050	.040	.030	.020	.010	.005	.002
Colorado River at Lees Ferry, Arizona. Collected by S. K. Love. Analyses by U. S. G. S.	LF9	100							12			3	1	0	
	LF10	95							5			1	0	0	
	LF11	92							25			10	4	2	
	LF12	98							18			4	2	0	
Lake Worth, Fort Worth, Texas Collected by U. S. Department of Agriculture.	W1	19							100						
	W2	22							100						
	W3	23							100						
	W4	29							100						
	W5	45							100						
	W9	99				88		17	10						
	W10	94				3		0	0						

Lakes Lee, N. C., Olathe, Kans., and El Dorado, Kans.
(Collected by U. S. Soil Conservation Service)

Source	Mechanical Composition of Sediment Samples: Sample No.	Density lbs.per cu. ft.	Sand (over 0.05 mm.) per cent	Silt (0.05 to 0.005 mm.) per cent	Clay (0.005 mm.) per cent	Median diameter mm.	Less than 0.02 mm. per cent
Lake Lee	S5	63	2.7	33.5	63.8	0.0032	62.8
	S6	60	1.7	30.1	68.2	0.0030	60.5
	S7	54	2.0	40.2	57.8	0.0039	59.2
	S8	59	2.4	53.0	44.6	0.0060	58.9
	S9	60	2.4	48.1	49.5	0.0051	59.9
	S10	61	1.6	49.4	49.0	0.0054	61.2
	S11	66	1.5	50.3	48.2	0.0053	65.7
	S12	73	2.3	63.2	34.5	0.0082	73.1
Lake Olathe	Composite of 4 samples		57.0	16.0	27.0		
Lake El Dorado	Composite of 4 samples		61.0	21.0	18.0		

Miami Conservancy District Reservoirs
(From hydrometer analysis curves)

Reservoir	Sample No.	Density lbs. per cu. ft.	Per cent smaller than mm. 0.0025	.005	0.01	0.02	0.05
Germantown	1	80	23	36	56	80	100
	2	79	23	38	67	88	98
Englewood	1	85	43	69	87	93	97
	2	70	44	68	83	92	100

No.	European Data Collected by Oexle — Sample Taken From	Density lbs. per cu.ft.	Per cent of sediment in given size range: Above 2 mm.	2.0 to 1.0 mm.	1.0 to 0.5 mm.	0.5 to 0.34 mm.	0.34 to 0.25 mm.	0.25 to 0.20 mm.	0.20 to 0.15 mm.	0.15 to 0.10 mm.	0.10 to 0.0 mm.	Approx. per cent larger than 0.05 mm.
4	Lake Saalach at Reichenhall I	73	0	0	0.1	0.3	0.2	0.7	0.5	4.3	93.8	19
5	Lake Saalach at Reichenhall II	65	0	0	0.05	0.05	0.05	0.05	0.1	0.3	99.4	2
6	Lake Saalach at Reichenhall III	92	0	0	0.3	4.1	19.0	34.4	11.5	12.8	17.9	100
7	Lake Saalach at Reichenhall IV	70	0	0	0.2	0.6	0.5	0.3	0.7	3.9	93.8	18
8	Alz Canal at Trostberg I	63	0	0	11.3	4.0	3.9	5.7	8.6	26.0	40.5	64
9	Alz Canal at Trostberg II	70	0	0	5.3	3.3	2.0	3.3	3.7	25.0	57.4	70
10	Iller River above Mooshauser Weir	62	0	0	0.2	0.5	1.1	2.1	4.0	14.5	77.6	48
11	Iller Canal at Hydroel. Plant III	61	0	0	0.2	3.4	3.7	2.3	2.8	5.7	81.9	31
12	Inn River, Km. 170.3	83	0	0	0.1	4.2	9.6	12.5	9.0	14.9	49.7	88
13	Inn River, Km. 168.0	74	0	0	0.3	0.7	0.9	4.1	4.0	17.1	72.9	52
14	Inn River, Km. 163.5	81	0	0	0.1	0.3	2.0	9.3	9.2	23.3	55.8	86
15	Inn River, Km. 159.2	82	0	0	0	0.5	1.5	7.2	7.7	25.8	57.3	88
16	Inn River, Km. 94.6	80	0	0	0	0.4	0.2	0.9	1.7	9.2	87.6	27
17	Inn River, Km. 94.3	81	0	0	0.7	9.0	19.0	26.0	12.0	13.0	20.3	98
18	Inn River, Km. 91.65	79	0	0	0	0.1	0.2	0.5	1.0	7.5	90.7	28
19	Inn River, Km. 91.62	83	0	0	0.2	1.0	5.0	7.2	15.0	31.3	40.3	94
20	Inn River above Jettenbach Weir	91	0	0	0.3	0.5	0.9	5.2	6.2	22.6	64.3	66
21	Settling Basin at Intake Structure, Inn Canal	81	0	0	0.1	0.3	1.7	6.7	16.0	23.3	51.9	90
22	Surge Tank at Toging Hydroel. Plant I	81	0	0	0.2	0.9	2.9	16.4	15.0	18.6	46.0	90
23	Surge Tank at Toging Hydroel. Plant II	82	0	0	0.2	0.2	0.4	2.5	4.5	21.1	71.1	64

TABLE 9 - SAND, SILT, AND CLAY IN DEPOSITED SEDIMENTS

Body of water and location	Sample Number	Density lbs. per cu. ft.	Per cent of Moisture	Per cent of Sand	Silt	Clay	Sample taken by	Remarks
Iowa River near Iowa City, Iowa	1	56	42	3	64	33	Iowa Inst. Hydr. Res.	Fairly soft mud flat about 3 ft. from edge of stream.
	2	55	41	3	60	37		Sample taken below sample No. 1.
	3	56	41	5	72	23		Very soft mud flat near water edge.
Iowa River near North Liberty, Iowa	4	69	34	4	66	30		Sample taken from firm mud about 3 ft. above water level.
	5	61	38	8	72	20		Sample taken from fairly soft mud flat near edge of stream.
Lake McBride near Solon, Iowa (sample numbers progress	6	59	38	1	72	27		Sample taken from bottom of lake.)
from inlet toward center	7	59	39	3	72	25		" " " " " ")
of lake)	8	62	40	2	77	21		" " " " " ") Deposits continually submerged.
	9	56	40	4	76	20		" " " " " ") Not over 4 years old.
	10	60	38	1	82	17		" " " " " ")
Iowa River at Iowa City, Iowa	11	65	34	28	57	15		Sample taken in soft mud flat at edge of stream 150 ft. above dam.
	12	64	33	31	51	18		Sample taken from apparently same material as No. 1 on this date.
	13	52	43	4	60	36		Rather firm mud flat on bank 1200 ft. above dam.
	14	52	44	1	86	13		Rather firm mud flat on bank and near sample No. 3 of this date.
	15	67	34	5	73	22		Firm mud flat shortly above pool effects.
	16	64	35	6	69	25		" " " " " "
Cedar River near Cedar Valley, Iowa	17	90		80	16	4		From bank, 75 ft. back from low water line, surface scum scraped off.
	18	50		67	25	8		From bank, 75 ft. back from low water line, surface scum scraped off.
	19	109		100	0	0		From sand bar.
	20	99		100	0	0		From sand bar.
Miami Conservancy District - Germantown Reservoir	1	80		0	64	36		
	2	79		2	60	38		
Miami Conservancy District - Englewood Reservoir	1	85		3	28	69		
	2	70		0	32	68		
Lake Arthur, South Africa	Valves	38		0	23	77	A. D. Lewis	Material through valves, after 77 days settling.
	A	38		0	33	67		From bore holes, under water, 3000 ft. above dam.
	A2	58		0	33	67		From bore holes, under water, 3000 ft. above dam.
	A7	100		90	6	4		From bore holes, under water, 3000 ft. above dam.
	A10	72		31	29	40		From bore holes, under water, 3000 ft. above dam.
	B2	64		3	46	51		From bore holes, under water, 12,000 ft. above dam.
	B5	100		85	12	3		From bore holes, under water, 12,000 ft. above dam.
	B7	80		32	46	22		From bore holes, under water, 12,000 ft. above dam.
	B11	100		97	1	2		From bore holes, under water, 12,000 ft. above dam.
Lake Lee, Monroe, North Carolina	S5	63		2.7	33.5	63.8	Soil Conservation	Lower basin, water depth 19 ft.)
	S6	60		1.7	30.1	68.2	Service	Lower basin, water depth 16 ft.)
	S7	59		2.0	40.2	57.8		Big Richardson Cr., water depth 14 ft.)
	S8	59		2.4	53.0	44.6		Big Richardson Cr., water depth 9 ft.) Deposits continually submerged.
	S9	60		2.4	48.1	49.5		Big Richardson Cr., water depth 8 ft.) Age not over 11 years.
	S10	61		1.6	49.4	49.0		Little Richardson Cr., water depth 10 ft.)
	S11	66		1.5	50.3	48.2		Little Richardson Cr., water depth 8 ft.)
	S12	73		2.3	63.2	34.5		Little Richardson Cr., water depth 5 ft.)
Lake Olathe, Olathe, Kansas	--	60		55	17	28	Soil Conservation	
Lake El Dorado, El Dorado, Kansas	--	66		58	23	19	Service	
Colorado River at Yuma, Arizona - E. Main Canal	1	86		85	13	2	Collins and Howard,	190 ft. up the canal from 8th St., surface deposit.
	2	88		34	61	5	U. S. Geological	380 ft. up the canal from 8th St., sample from below dry deposit.
	3	84		31	60	9	Survey	Same as No. 2 and about 1 ft. away.
	4	93		67	29	4		530 ft. up the canal from 8th St., deposit at edge of canal.
Colorado River at Yuma, Arizona - Main Canal	5	87		82	17	1		Same as No. 4, sample from about 1 ft. below surface of deposit.
Colorado River at Yuma, Arizona - Main Canal	6	85		44	49	7		Surface sample.
	7	85		39	55	6		Top of sample at water level of canal.
Colorado River at Yuma, Arizona - E. Main Canal	8	69		18	68	14		200 ft. above bridge; sample from canal bottom, 9 in. below water surface.
	9	52		23	45	32		Same location as No. 8, from canal bottom, 1-1/2 ft. below water surface.
Colorado River near Yuma, Arizona - below Laguna Dam	10	88		88	7	5		At point of a bar; top of sample at water level.
	11	87		84	10	6		Same as No. 10.
	12	92		88	9	3		On inner side of same bar; top of sample 5 in. below water surface.
	13	73		70	23	7		On inner side of bar; top of sample about 1 in. below water surface.
	14	97		85	12	3		At edge of pool of water.

	15	82		32	46	22		From bank, about 10 in. above river level.
	16	76		10	64	26		Same as No. 15; top of sample about 1 ft. below top of deposit.
	17	82		49	37	14		Near No. 15; 2 ft. from water edge, top of sample at water level.
	18	82		56	30	14		Same as No. 17.
	19	93		90	9*	1*		Sand dune, 20 ft. above river.
	20	93		90	9*	1*		Same as No. 19.
Colorado River near Yuma, Arizona - above Laguna Dam	21	86		62	27	11		100 ft. above dam, deposit near bank, top of sample 3 in. below river level.
	22	83		85	12	3		100 ft. above dam, top of sample 5 in. below river level.
	23	88		86	10	4		100 ft. above dam, sample from below surface ooze.
	24	81		38	51	11		1 mile above dam, top of sample 1 ft. below surface of deposit, at river level.
	25	86		38	53	9		Same as No. 24.
	26	72		24	46	30		100 yds. above No. 24, top sample 2 ft. below surface of deposit, at river level.
	27	87		95	5*	0*		Same as No. 26, but more uniform material in sample.
	28	64		16	49	35		Same location as No. 26, but at water's edge.
Colorado River at Yuma, Arizona	29	105		98	2*	0*		From edge of deposit.
	30	98		97	3*	0*		From edge of deposit.
	31	93		89	9*	2*		200 ft. below No. 29, top of sample about at river level.
	32	89		61	36	3		300 ft. below No. 29, top of sample about at river level.
	33	95		80	15*	5*		Same as No. 32.
	34	78		49	40	11		3 ft. from water edge, top of sample 1 ft. above water level.
	35	87		69	24*	7*		3 ft. from water edge, top of sample 8 in. above water level.
	36	91		79	116	5		Same as No. 35.
Colorado River near Topock, Arizona	1	85		95	5*	0*	S. K. Love, U. S. Geological Survey	About 1 ft. above water surface and 12 ft. from water's edge.
	2	83		68	29*	3*		About 6 in. above water surface in small bay.
	3	98		87	13*	0*		On edge of river 2 in. above water surface.
	4	88		56	43*	1*		At water's edge in sand bar.
	5	94		78	21*	1*		8 in. above water level. Two distinct sizes, top 1-1/2" fine, lower 5" coarse.
	6	98		76	23*	1*		Fine material in top portion, coarser material in lower portion.
	7	73		16	80*	4*		On low flat next to small channel, 2 in. above water surface.
	8	82		38	60*	2*		Collected a few ft. away from No. 7.
	9	70		9	85*	6*		In mud flats 150 ft. from water's edge.
	10	98		70	29*	1*		About 1 ft. above water surface.
	11	88		70	29*	1*		About 15 in. above water surface.
	12	84		61	35*	4*		About 2-1/2 ft. above water surface.
	13	87		50	40*	10*		About 3-1/2 ft. above water surface.
	14	88		64	32*	4*		About 4-1/2 ft. above water surface.
	15	87		36	*	*		From sandy ledge on river bank, 3 in. above water surface.
	16	83		44	40*	16*		Samples No. 16 to 22 represent a 20-inch section of the bank, each sample representing a vertical 2 inches of the section. This bank appeared to be the high water bank for a period of possibly two years, with considerable vegetation growing on it.
	17	80		66	30*	4*		
	18	87		75	23*	2*		
	19	83		77	20*	1*		
	20	87		82	17*	1*		
	21	87		85	14*	1*		
	22	88		83	16*	1*		
	23	90		98	2*	0*		Samples No. 23 to 32 were taken in a large area of sand flats, mostly covered by sand from sand dunes. Samples represent practically continuous 30-in. vertical section from the edge of the river bank. In high water this bank appears to have been covered by swift water. In the top 6 in. were several layers of fine material; below this was coarser material.
	24	92		99	1*	0*		
	25	83		64	34*	2*		
	26	80		87	12	1		
	27	90		94	6	0		
	28	82		94	5*	1*		
	29	80		95	5*	0*		
	30	86		96	4*	0*		
	31	90		97	3*	0*		
	32	98		97	3*	0*		
	33	92		98	2*	0*		3 in. above water surface.
	34	78		24	61	15		Fine material in slight depression deposited in quiet water.
	35	81		70	26	8		1-1/2 to 2 ft. above water surface.

TABLE 9 - SAND, SILT, AND CLAY IN DEPOSITED SEDIMENTS (CONTD.)

Body of water and location	Sample Number	Density lbs. per cu. ft.	Per cent of Moisture	Per cent of Sand	Per cent of Silt	Per cent of Clay	Sample taken by	Remarks
Colorado River above Needles, California	36	92		78	20	2		Samples No. 36 to 42 were collected on river side of sand bar, next to main channel, and represent a vertical section 18 in. high. In the top 6 in. were several layers of fine material; below this was coarser material.
	37	96		98	2	0		
	38	94		98	2	0		
	39	95		99	1	0		
	40	94		99	1	0		
	41	93		99	1	0		
	42	94		99	1	0		
	43	67		5	53	42		About 45 ft. from the river in a depression about 8 in. above water level.
	44	95		78	20	2	C. S. Howard, U. S. Geological Survey	From small bar at water's edge.
	45	98		91	8	1		From deposit 3 ft. from water's edge, 1-1/2 ft. below water surface.
	46	90		89	7	4		From deposit in cove, about 5 ft. above water surface.
	47	86		72	26	2		From deposit in crevice, about 8 ft. above water surface.
Colorado River near Parker, Arizona	48	94		50	45	5	S. E. Love, U. S. Geological Survey	75 ft. from water's edge, 6 in. above main part of flat, but above high-water mark.
	49	95		78	19	3		From sand bar opposite river, 6-1/2 in. above water surface.
	50	93		72	25	3		From sand bar opposite river, 15 in. above water surface.
Colorado River near Grand Canyon, Arizona	51	46		6	59	35		6 in. above water surface and only a short distance from water's edge.
Colorado River near Grand Canyon, Arizona	41	87		62	35	3		From about 18 in. above the water level.
	44	88		55	43	2		From about 5 in. below the water surface.
	46	87		64	33	3		Same location as No. 46, about 3.5 ft. above the water surface.
	48	84		59	39	2		About 7 in. above water level, where there had been a small eddy current.
	51	96		94	6	0		8 in. above water level, where material must have been deposited in swift water.
	54	97		80	19	1		From about 4 in. above water surface.
Little Colorado River near Grand Falls, Arizona	1	91		96	4	0		From island, probably mostly deposited by swift water.
	2	88		45	50	5		From bottom of river bed, probably deposited by very sluggish water.
	3	99		78	20	2		Above 2 ft. above the water surface, this bank covered with high water.
	4	95		85	10	5		From narrow channel, water about 1 ft. deep.
	5	106		95	3	2		From shallow water, main channel, water about 6 in. deep.
	6	90		88	9	3		From bank above this years high water mark.
	7	94		92	5	3		On bank not covered by high water this year. About 10 ft. above water.
	8	104		92	5	3		In wet sand about 1 ft. above water surface. Covered by high water a few years ago.
Colorado River at Lees Ferry, Arizona	9	100		88	12	0		About 5 ft. from water's edge.
	10	95		95	5	0		Between water's edge and a 2 ft. bank. Left in some previous high water.
	11	92		75	23	2		At edge of 2 ft. bank which had not been covered since the spring runoff.
	12	98		82	18	0		At lower edge of 2 ft. bank between Nos. 10 and 11.
Missouri River near Kansas City, Missouri	1	81	27	77	22	1	U. S. Engineer Dept.	Edge of sand bar--3 ft. from water--4 in. above water surface.
	2	93	10	75	25	0		75 ft. from water edge--3-1/2 ft. above water surface.
	3	97	7	96	4	0		50 ft. from water edge, 4 ft. above water surface.
	4	93	18	14	26	0		50 ft. from water edge, 2 ft. above water surface.
	5	94	24	89	10	1		5 ft. from still water, 4 in. above water surface.

6	88	22	71	29	0	20 ft. from water edge, 2 ft. above water surface.
7	33	61	70	26	4	Surface sediment, soupy material at top of bar.
8	72	38	65	35	0	From same point and below No. 8. Firm material.
9	86	24	77	22	1	15 ft. from water edge, 1 ft. above water surface.
10	84	27	34	59	7	3 ft. above water surface in slack water.
11	62	41	22	74	4	2 ft. above water surface. Material firm and moist.
12	75	33	21	78	1	Same as No. 11.
13	74	32	8	87	5	6 in. above water surface in "gumbo."
14	85	34	38	59	3	6 in. above water surface, coarser material than No. 13.
15	72	34	12	84	4	4 in. above water surface cracked.
16	87	30	27	72	1	1 ft. above water surface, deposited in slack water.
17	72	32	29	70	1	2 ft. above water surface slack water deposit.
18	74	38	13	79	8	2 ft. above water surface in "gumbo."
19	98	19	81	19	0	1 ft. above water surface in sandy, wet deposit.
20	97	26	82	18	0	From a bar 2 ft. above water surface.
21	85	26	82	18	0	From a sand bar and 1.5 ft. above water surface.
22	86	13	55	45	0	
23	82	15	32	67	1	
24	80	18	34	66	0	
25	88	16	39	61	0	At upper end of island, about 20 ft. above water surface, about level of adjacent lowlands.
26	83	14	43	57	0	
27	83	14	55	45	0	
28	84	30	49	51	0	
29	86	13	52	48	0	
30	81	16	44	56	0	
31	85	11	61	39	0	
32	96	20	86	14	0	
33	88	17	92	8	0	
34	89	8	93	7	0	
35	79	6	95	5	0	
36	86	7	94	6	0	From a sand bar formed as a result of an obstruction from a dike. 3 to 4 ft. above water surface.
37	90	6	94	6	0	
38	82	10	86	14	0	
39	86	8	86	14	0	
40	82	7	89	11	0	
41	86	8	89	11	0	
42	52	43	58	38	4	
43	48	43	63	35	2	
44	43	43	69	30	1	
45	45	42	62	35	3	
46	66	32	70	28	2	From the bed of shallow chutes through sand bar. Top surface of all samples at water surface.
47	47	39	67	29	4	
48	57	38	76	23	1	
49	63	36	71	27	2	
50	60	38	72	26	2	
51	66	35	61	38	1	

results fall within 5 per cent of the general relation, and 75 per cent within 10 per cent.

It is believed that the values of density shown graphically in Fig. 1, which were computed using the data on porosities collected by the California Division of Water Resources and an assumed specific gravity of 2.65, is as good information on the density of coarse sediments as can be obtained from the available data.

19. Values of density for use in design.--In order to make this report of value to the practicing engineer, it is desirable to summarize the findings of the study in a form as readily applicable as possible to the problem which the engineer has to meet. In the following paragraphs an attempt is made to formulate a method of predetermining the sediment density in a reservoir from the conditions met in each particular case.

As has been previously pointed out, the most important factors which determine the density of sediment in a reservoir are, the method of operation of the reservoir, the particle size of the sediment, the rate of compaction of the sediment, and possibly the condition of flocculation.

The process developed consists of dividing the methods of operation of the basins into four classes in which; (a) the sediment is always submerged or nearly submerged, (b) normally there is a moderate reservoir drawdown, (c) normally there is considerable reservoir drawdown, and (d) the reservoir is normally empty.

The classification "sediment always submerged or nearly submerged" covers the case of a reservoir normally kept full and emptied only at infrequent intervals, and then only for a short time. This class also includes flood control reservoirs in which considerable conservation storage is allowed. The case "normally a moderate reservoir drawdown" is intended to cover the case where reservoirs store over long periods, with small drawdowns in the normal years. It also covers "run of river" hydro-electric plants, where the basin is used for pondage and the sediment, when deposited above the low water level, is frequently exposed by the changes of water level. The next classification, "normally considerable reservoir drawdown," covers the case of a relatively large drawdown in normal years. The classification "reservoir normally empty" covers retarding basins and reservoirs which are empty in normal years.

In reservoirs of each of these four classes the sediment deposited may consist of four grades -- clay, silt, sand, and sand and coarser material. Of these materials clays, and to a lesser extent silts, are affected by the rate of consolidation of deposits.

The unit weights of sediments composed of sands or finer materials are given in Table 10 for deposits in each class and for each type of reservoir operation.

TABLE 10 - DENSITY VALUES FOR USE IN DESIGN

Reservoir Operation	Sand		Silt		Clay	
	W_1	K.	W_1	K.	W_1	K.
(a) Sediment always submerged or nearly submerged	93	0	65	5.7	30	16.0
(b) Normally a moderate reservoir drawdown	93	0	74	2.7	46	10.7
(c) Normally considerable reservoir drawdown	93	0	79	1.0	60	6.0
(d) Reservoir normally empty	93	0	82	0.0	78	0.0

The time of consolidation of the density values W_1 in lbs. per cu. ft. is taken as one year. A constant, K, is given for each sediment class and operation condition which indicates the effect of sediment consolidation with respect to time. The density is assumed to increase logarithmically, the density after any period of years T being $W = W_1 + K \log_{10} T$. For sediment composed of mixtures of the various classes of material, the weight for each class should be combined in proportion to their respective portions of the total sediment. For example, suppose it is desired to determine the average density of the sediment in a reservoir which will fill in 100 years with sediment composed of 20 per cent sand, 40 per cent silt, and 40 per cent clay, if the sediment in the reservoir is always submerged or nearly submerged. The densities of the three classes of material for this method of reservoir operation at the end of a 100-year period would be: sand 93 + 0 = 93, silt $65 + 5.7 \times \log_{10}100 = 76.4$, and clay $30 + 16.0 \times \log_{10}100 = 62.0$ lbs. per cu. ft. The unit weight of the composite material would then be 20 per cent of 93 + 40 per cent of 76.4 + 40 per cent of 62.0 = 74.0 lbs. per cu. ft. For sediments composed of sand or coarser material, Fig. 1 may be used to estimate the densities, and no consideration need be given to the time factor.

The values in Table 10 have been derived from a study of the results of the observations of other investigators in this field, as given in the review of previous literature and from the data recorded in the tables. The data were not of a nature which would permit a rigid mathematical solution of the problem, and the values given were rather derived by a cut and try synthesizing process, starting with sand at 93 lbs. per cu. ft. as derived independently on Figs. 1 and 2 and obtaining values for the other materials which best agreed with the available data and among themselves. The logarithmic correction for compaction was used to give a rapid consolidation in the first few years with rapidly decreasing rate as time continued. The constants for silt and clay for the first three classes were chosed to give the same density for a 1000 year period as would be reached for that class of material when deposited under condition (d) of "reservoir normally empty", where it would have ample opportunity to dry out. A more exact mathematical form could possibly have been obtained by using a curve which would be asymptotic to a final density value, similar to that used by Krumbein[38] in a study of the effect of abrasion on rock fragments, but the mathematical form would have been more complex than would seem justified by the data at hand. As given in this report the bases for determinations in some case. are very meager, the results cannot be considered as being exact, but are believed to represent the best estimate that can be made from the available data. The uncertainties are particularly great in estimating the rate of consolidation and the densities of sediment in retarding basins, because of the small amount of data available. It will be noted that for sand deposits and for the case of reservoirs normally dry, the time factor has no effect. Since in some cases the time of filling can not be known until the density is also known, a preliminary estimate of the density can be used to determine the time, and the true values determined by successive approximations.

It should be noted that the deposits in the reservoir may not have the same composition as the inflowing sediment since part of the sediment may pass out with the outflowing water. This is particularly true of the pools of "run of river" hydro-electric plants and retarding basins. Reservoirs which are normally kept above the spillway level, such as is frequently the case in recreation reservoirs, usually pass a considerable part of the sediment over their spillways. The amount depends upon the time the water remains in the basin and the magnitude of the turbulence in the stream as it passes through. The length of time the water remains in storage before passing over the spillway depends upon the ratio of the storage capacity of the basin to the inflow; when the storage capacity is large with respect to the inflow, the storage period is long. Larger proportions of clay than of silt, are carried through and most sand will be deposited. Some data on this point have been collected for retarding basins(23) but further study would be desirable.

It will no doubt be found in many cases that the data on the size composition of the sediment carried by the streams on which reservoirs are to be established are not sufficient to enable a density value to be closely estimated. This is unfortunate, but cannot be avoided, since the size composition is such an important factor in determining the density. It serves to emphasize the necessity of obtaining data on particle size as well as sediment concentration in observations on streams. Particle size is also equally important in most other engineering problems dealing with sediment. It is believed however, that in most cases it will be possible to estimate sediment density in this manner more closely using the best available information on sediment composition even though it be very inexact, than can be done by any other method now available.

20. Supplementary Data--Data on density, porosity and mechanical analysis of reservoir sediment deposits furnished by the U. S. Soil Conservation Service are given in Tables 11 and 12. These data, having been received too late to be analysed, are not basic to any conclusions or results of this study.

TABLE 11

SUPPLEMENTARY DATA FURNISHED BY SOIL CONSERVATION SERVICE
DIVISION OF SEDIMENTATION
on Density and Porosity

Source	Density - lbs. per cu. ft. (Porosity in per cent if known, is shown in parentheses before the corresponding value of density.)
Ardmore Club Lake, Ardmore, Oklahoma	83, 37, 42, 28, 24, 37, 34, 40.
Baker Reservoir, Baker, Montana	66, 68, 29, 20, 20.
Burlington Reservoir, Burlington, N. C.	47, 45, 54, 50, 62 63, 55, 58, 83* *Exposed to aeration and compaction.
Castlewood Reservoir, Denver, Colorado	63, bottom set; 95, delta and sandy; 90, delta and sandy; 63, bottom set. All samples compacted by aeration.
Clinton City Reservoir, Clinton, Oklahoma	40, 86, 39, 57, 92, 68, 62.
Lake Dallas, Denton County, Texas	(70) 50, (44) 86, (53) 78, (40) 99, (49) 83, (42) 95, (42) 96, (40) 99, (79) 35, (86) 22, (73) 45, (66) 56, (80) 32, (74) 43, (78) 37, (83) 28, (38) 102, (80) 33, (79) 35, (82) 29, (78) 37, (82) 29, (63) 28, (75) 41, (77) 37, (69) 50, (80) 33, (69) 51, (47) 88, (83) 28, (77) 37.
Doniphan County Desilting Basin, Kansas	86, 83, 84, 83, 83, 68.
Eldorado City Reservoir, Eldorado, Kansas	75, 59, 64, 67.
Franklington Reservoir, Franklington, N. C.	65, 45, 56, 90.
Hayes Lake, Hayes, S. D.	47, old silt; 38, old silt; 41 old silt; 33, new silt.
Hurley Lake, Gettysburg, S. D.	45, 47, 40, 43, 29.
Bartel Stock Pond	50, 50, 61.
Johnson Stock Pond	55, 56, 64.
Kenwood Reservoir*, Denver, Colo.	68, fine-grained, bottom-set; 74, coarse, delta; 72, fine-grained, bottom; 88, coarse, delta. *Flood control reservoir--all samples probably compacted by aeration.
Lexington Reservoir, Lexington, N. C. Pee Dee Flood Control Survey.	(82) 29, very fine silt; (71) 47, very fine silt; (73) 45, very fine silt; (42) 96, sandy silt.
Mission Lake, Horton, Kansas	59, 58, 72, 61, 49, 74. On basis of moisture determinations and an assumed average specific gravity of 2.6 for dry sediment.
Medina Lake, Texas*	49, 46, 50, 54, 46, 65, 67, 54, 72, 53, 77, 50, 79, 83, 48, 82, 75, 46, 80, 52, 88, 49, 67, 48, 48, 48, 51, 48, 48, 48, 47, 47, 47, 44, 53. *As determined from samples as received in original containers (assuming original containers exactly filled at time of sampling).
Lake Nasworthy, Tom Green County, Texas	(66) 57, gray silt, silt and sand; (64) 60, gray silt and fine sand; (69) 50, gray silt and fine sand; (64) 60, gray silt and fine sand; (57) 71, gray and red silt and sand; (38) 102, grey and red silt and sand; (51) 81; (62) 63, gray silt and sand; (43) 95, dark silt and sand; (66) 55, sand, grit and clay; (65) 58, sand and silt; (65) 58, gray silt with red coloration.
Lake Olathe, Olathe, Kansas	50, 67, 60, 65.
Palingtown Reservoir, located at Spring Grove, Pa., on Powder Creek (Codorus Creek Watershed)	32, 28, 40.
Pelham Lake, Pelham, S. C.	37, 39, 29, 33, 34, 30, 53, 41, 41, 30, 29, 35, 39, 39, 49, 35, 31, 39.
Santa Fe Reservoir, Agusta, Kansas	69, 42, 54, 64, 61.
Weatherford Reservoir, Weatherford, Texas	39, clay and silt over sand and gravel; 56, silt; 75, sand, clay and gravel; 112, roots in sample; 115; 120, sand and gravel.
White Manganese Reservoir No. 6, Cartersville, Georgia	(69) 50, pure silt, reddish brown; (60) 66, half new silt, half compacted silt; (56) 72, heavy compacted silt; (66) 56, fine loose silt; (62) 63, heavy silt, reddish brown; (64) 59, light oozy silt; (57) 71, heavy silted, compacted; (51) 64, oozy silt, from old lake bed; (51) 80, heavy silt, little sand; (44) 93, firm silt, from valley fill above lake; (46) 89, firm silt, in valley fill above lake; (56) 73, firm silt, in old stream once part of lake.
White Rock Lake, Dallas, Texas	80, silt and fine sand; 79, silt; 31, silt; 29, clay; 33, clay; 42, clay; 44, lower edge of delta; 56, gray clay; 43.
Lake Williams, near York, Pa. (Codorus Creek Watershed)	69, 54, 46, 35, 47, 48, 53, 59, 38, 45.

TABLE 12 - SUPPLEMENTARY DATA FURNISHED BY SOIL CONSERVATION SERVICE
DIVISION OF SEDIMENTATION

Density and Mechanical Analysis of Sediment Deposits

Body of water and location	Sample No.	Density lbs. per cu. ft.	Porosity per cent	Per Cent Finer than given size in mm.																		
				1.981	1.397	.991	.701	.495	.351	.246	.175	.124	.088	.074	.061	.0312	.0156	.0078	.0039	.00195	.00098	.00049
Lake Claremore, Rogers County, Oklahoma	FC 11-3-39 CM-1	43	74												98.9	95.7	95.1	89.6	76.0	54.6	34.1	18.2
	FC 11-3-39 CM-2	45	73												99.8	97.9	95.8	86.8	72.4	51.6	32.6	18.7
	FC 11-3-39 CM-3	40	76												99.5	97.0	94.5	86.2	71.8	50.6	32.4	17.2
	FC 11-3-39 CM-4	44	73												99.8	96.5	93.8	81.2	61.0	42.7	26.3	14.5
	FC 11-3-39 CM-5	51	69												99.6	92.3	80.4	60.2	41.7	27.5	17.3	09.6
	FC 11-3-39 CM-6	55	67												98.8	91.4	81.8	65.2	[illegible]5.4	29.2	18.8	10.5
	FC 11-3-39 CM-7	54	67												98.9	90.5	73.1	53.6	[illegible].9	26.5	17.8	9.4
	FC 11-3-39 CM-8	63	62						99.8		99.2		98.4		97.2	75.8	56.9	40.8	32.1	24.8	18.3	11.8
	FC 11-3-39 CM-9	51	69												99.6	94.0	82.5	65.6	50.2	34.2	21.8	11.7
	FC 11-3-39 CM-10	65	61						99.7		97.5		82.9		78.4	51.4	39.0	30.7	24.6	19.7	14.1	9.3
Grisham Lake, Washington County, Mo.	FC 7-25-39 GR-1	53	68												96.0	92.8	65.7	42.7	28.6	19.4	13.0	7.7
	FC 7-25-39 GR-2	56	66								98.0	96.4	94.3	92.5	91.9	84.4	57.3	36.1	25.1	17.2	12.1	17.4
	FC 7-25-39 GR-3	117	29	86.2	85.1	83.7	81.7	75.0	55.5	23.2	9.1	4.2	2.9	2.4	2.2							
High Point Reservoir, High Point, North Carolina	FC 10-5-38 HPR-6	59							98.9		90.2		80.5		77.9	56.9	44.2	32.3	24.3	18.6	13.7	9.3
	FC 10-5-38 HPR-9	62							99.7		95.3		83.4		77.0	46.3	37.5	27.1	20.4	15.5	11.9	8.5
	FC 10-5-38 HPR-10	68													99.6	94.3	90.1	81.5	68.6	54.0	40.3	27.0
	FC 10-5-38 HPR-13	41												98.8	99.0	93.0	84.7	69.5	54.0	41.0	30.7	21.2
	FC 10-5-38 HPR-14	60							99.9		99.6		98.7		97.4	72.9	58.9	43.2	31.8	24.6	18.4	12.8
	FC 10-5-38 HPR-16	44							99.9		99.7		96.8		94.6	63.7	54.0	38.9	28.6	22.2	17.5	12.0
	FC 10-5-38 HPR-18	64													99.7	96.6	95.4	89.1	76.7	61.8	44.7	29.8
	FC 10-5-38 HPR-21	45							99.7		99.1		92.8		87.7	63.8	49.0	35.2	25.6	19.9	14.4	10.5
	FC 10-5-38 HPR-22	37													98.6	91.4	78.3	58.4	41.8	29.7	24.8	17.5
	FC 10-5-38 HPR-23	40													98.4	96.4	95.8	87.7	83.1	73.3	57.2	38.7
Kirk Lake, Allen County, Kansas	FC 9-15-39 KR-1	42	75												98.9	94.0	89.9	77.9	63.1	44.8	29.8	17.2
	FC 9-15-39 KR-2	55	70												98.4	84.4	72.3	56.5	44.6	32.2	22.7	13.0
Lancaster Reservoir, Lancaster, South Carolina	FC 10-5-38 LA-1	54													99.9	97.5	93.5	87.1	68.4	48.6	33.0	20.4
	FC 10-5-38 LA-2	70													97.5	88.1	72.5	53.4	41.0	31.4	22.7	15.7
	FC 10-5-38 LA-3	70							99.7		98.0		92.8		91.1	68.6	48.2	31.2	22.5	17.1	13.4	10.0
	FC 10-5-38 LA-4	79							99.8		98.4		93.7		89.8	56.3	36.4	23.0	16.4	12.8	10.3	7.4
	FC 10-5-38 LA-5	68							99.94		99.91		99.51		97.5	75.2	58.2	30.2	[illegible].3	20.7	16.3	12.2
	FC 10-5-38 LA-6	39							99.91		99.71		97.8		95.0	70.3	56.1	40.6	27.8	20.1	15.7	11.0
	FC 10-5-38 LA-7	62							99.93		99.73		99.03		99.6	66.5	48.7	31.2	23.6	18.8	14.8	10.9
	FC 10-5-38 LA-8	--		97.4	93.8	84.1	63.2	31.8	10.4	4.6	3.2	2.6	2.2									
Lake Lee, Monroe, North Carolina	FC 38 LE-1	62													97.29	96.90	92.95	80.30	55.89	34.89	21.02	
	FC 38 LE-2	60													98.29	98.15	93.53	82.73	59.30	37.87	24.02	
	FC 38 LE-3	59													99.2	95.4	88.7	71.4	49.5	32.0	20.4	
	FC 38 LE-4	59													98.09	93.82	81.35	58.11	37.26	24.01	14.88	
	FC 38 LE-5	60													98.1	95.0	88.4	64.8	42.8	29.1	17.8	
	FC 38 LE-6	61													98.6	95.9	85.0	62.2	40.6	26.1	15.1	
	FC 38 LE-7	66													98.9	96.4	86.8	63.6	40.8	26.2	17.4	
	FC 38 LE-8	73													97.95	94.96	74.72	47.63	28.83	19.19	12.03	

Lake Marimika, Galesville, Wisconsin	FC 9-15-39 MA-1	40	76												98.6	96.7	90.4	79.2	63.8	44.1	24.0	11.7
	FC 9-15-39 MA-2	52	69												100.0	100.0	98.4	87.8	67.7	45.2	27.8	15.5
	FC 9-15-39 MA-3	56	66												99.7	98.7	86.9	60.3	40.6	26.1	16.4	9.8
	FC 9-15-39 MA-4	55	67												99.7	97.9	89.1	64.4	39.9	22.7	12.4	6.8
	FC 9-15-39 MA-5	60	63												99.4	95.9	79.2	51.6	30.8	18.5	10.5	5.8
	FC 9-15-39 MA-6	70	58												96.8	92.2	73.7	51.5	35.3	23.3	13.4	7.7
	FC 9-15-39 MA-7	63	62												99.5	97.1	77.3	54.4	36.9	25.1	14.6	8.0
	FC 9-15-39 MA-8	60	64												98.9	91.5	65.2	43.1	29.4	21.0	12.6	7.7
	FC 9-15-39 MA-9	66	60			99.5	99.1	98.6	98.3	98.0	97.5	96.8	96.2	95.9	95.4	81.9	57.2	34.4	23.1	15.0	8.8	5.3
	FC 9-15-39 MA-10	80	51						97.0		95.1	92.3	86.5		82.3	54.7	28.8	16.8	11.7	7.8	4.6	2.9
	FC 9-15-39 MA-11	77	54			99.5	98.8	98.2	97.7	97.1	96.4	94.9	93.4	92.9	92.3	77.8	54.8	33.0	18.8	11.2	6.2	3.0
	FC 9-15-39 MA-12	69	58						96.4		92.9	91.0	85.8		82.9	65.9	47.4	30.7	18.8	10.6	5.8	3.2
	FC 9-15-39 MA-13	85	48						97.2		93.3	87.4	81.3		77.6	52.9	27.6	14.7	9.2	6.3	3.6	2.4
	FC 9-15-39 MA-14	87	46						99.3		98.6	96.6	92.1		88.8	62.0	38.8	24.9	16.5	11.3	6.9	4.5
Moran Reservoir Lake, Allen County, Kansas	FC 9-11-39 MR-1	50	70												99.6	97.6	93.3	81.0	62.8	42.7	26.3	14.7
	FC 9-11-39 MR-2	38	77												99.3	97.0	93.1	83.3	69.0	49.1	32.4	18.7
	FC 9-11-39 MR-3	52	68												98.9	92.0	77.9	60.0	46.5	35.6	23.3	15.6
	FC 9-11-39 MR-4	62	62				99.4		96.4		92.3		84.4		80.7	62.4	45.5	31.6	24.6	17.8	12.4	7.3
	FC 9-11-39 MR-5	49	70												98.9	90.4	73.8	54.7	41.6	29.6	19.3	10.9
	FC 9-11-39 MR-6	43	74												99.7	96.8	91.0	79.2	65.0	45.8	30.0	16.8
Mountain Lake, Wayne County, Missouri.	FC 8-1-39 MO-1	57	65												95.2	93.9	77.6	51.0	33.0	22.3	15.1	9.9
	FC 8-1-39 MO-2	41	75								86.5	79.1	72.6	68.6	67.7	58.6	34.8	20.0	12.9	8.9	6.7	4.9
	FC 8-1-39 MO-3	66	60												96.9	93.8	54.9	28.8	18.7	13.2	9.4	6.0
Neosho County State Lake, Kansas	FC 8-18-39 NE-1	37	77												98.0	94.0	91.4	85.4	74.8	56.9	38.0	21.8
	FC 8-18-39 NE-2	30	82												98.4	93.5	86.8	75.0	64.3	48.1	31.7	17.6
	FC 8-18-39 NE-3	36	78												99.3	90.9	73.9	56.6	43.9	31.2	20.8	12.4
	FC 8-18-39 NE-4	38	77												97.7	91.1	78.3	60.6	47.8	34.3	22.3	12.5
	FC 8-18-39 NE-5	45	73												96.2	82.5	54.4	38.2	27.7	20.2	13.7	8.0
Shepherd Mountain Lake, Iron County, Missouri	FC 8-1-39 SH-1	43	74								91.5	89.4	86.9	85.0	84.8	80.3	57.4	34.2	20.0	11.5	7.1	3.7
	FC 8-1-39 SH-3	85	48	89.4	84.9	77.4	66.0	50.6	28.7	11.3	5.3	2.6	1.8	1.5	1.4							

Body of water and location	Sample No.	Density lbs. Per cu.ft. A	Density lbs. Per cu.ft. B	Per Cent Finer than given size in mm. 2.0	0.25	0.05	0.005	0.001	Remarks
Grand Saline, Austin, Texas	1	40	40	100	99	99	78	34	Density A is determined from samples as received in original containers (assuming exactly filled at time of sampling). Density B is determined from samples obtained by pushing a thin tube into material as received in original container.
	2	35	38	100	100	98	80	32	
	3	47	39	100	98	85	39	15	
	4	30	31	100	99	94	68	35	
	5	34	36	100	100	97	60	36	
	6	34	33	100	100	98	67	30	
	7	47	47	100	100	93	39	18	
	8	43	45	100	98	93	52	17	
Wills Point Reservoir, Wills Point, Texas	1	51	54	100	100	98	57	36	Density A is determined from samples as received in original containers (assuming original containers exactly filled at time of sampling). Density B is determined from samples obtained by pushing a thin tube into material as received in original containers. (Gently packed with a knife whenever deemed necessary.)
	2	53	53	100	100	97	61	35	
	3	53	55	100	100	98	55	34	
	4	59	57	100	100	99	60	35	
	5	54	55	100	100	98	69	31	
	6	86	86	100	99	82	29	16	
	7	85	85	100	99	77	29	18	
	8	45	47	100	100	99	82	45	
	9	52	51	100	100	98	82	39	

IV RELATED CONSIDERATIONS

21 Sediment storage capacity of a basin differs from the water storage capacity Although it is not a factor in the subject of this report but because it is so often overlooked it is probably justifiable here to call attention to the fact that the capacity of a basin to store sediment is greater than its capacity to store water. The water storage capacity is usually measured up to the level plane of a comparatively quiet water surface, but the capacity to hold sediment can be measured up to a plane sloping upstream from the dam, the slope depending on the nature of the sediment deposited, being steeper for coarse sediments. In order that the reservoir may fill down to the dam, there must be a current from the upper end to the lower end of the reservoir to carry the sediment through the reservoir to the dam and, except for very fine sediment, this can exist only if there is a slope in the stream between these points. Very little study seems to have been given to the magnitude of the slopes to which reservoirs fill with sediment. It will, of course, be less than that of the river in its unconfined portions. For rivers which emerge from mountains and spread over a plain, values suitable for reservoirs just above the point of emergence can often be estimated from a slope of the river across the plain. Some ideas applicable to rivers with heavy loads of fine sediment can be obtained from a study of the deposits in the Elephant Butte Reservoir(3).

22 Recovery of water from deposited sediments In some cases where reservoirs are filled with very porous material it may be worth while to consider the amount of water which could be recovered from the pores of

the sediment, as the reservoir is emptied. Fig. 2 indicates that under the most favorable conditions a water volume up to 36 per cent of the volume of sediment could be recovered. Quite similar results were obtained by the U. S. Geological Survey(32). This figure shows that the amount depends upon the size of the sediment particles, being greater for coarser sand. The amount of recovery would also depend upon the magnitude and rapidity of the fluctuations of water level in the reservoir, the steepness of the stream and the shape of the reservoir. Slow fluctuations of water level are favorable to large recoveries as they give time for the sediments to drain out. Large fluctuations of water level are also favorable as they tend to produce steeper ground water gradients through the sediments. A narrow reservoir produces steeper gradients for a given drawdown than a wide one. Considerable study has been given, in connection with underground water problems(31) (32) (33) to the amount of water which is available from deposits of various kinds of material, but little seems to be available in readily usable form for determining the rapidity with which the deposits would drain out. It is believed, however, that where conditions are favorable to recovery of considerable amounts of water from deposits, studies based on the porosity, permeability and available slopes would be justified to determine the probable amounts available. The deposits in most reservoirs are predominately silts or clays. In such cases the rate of outflow would be so slow that it would probably be used up by evaporation and produce insufficient water to justify consideration.

BIBLIOGRAPHY

1. Collins, Howard and Love; "Mechanical Analysis of Material Deposited by the Colorado River", unpublished data on samples collected by above men and analyzed by the U. S. Geological Survey.

2. Davis, A. P. and Wilson, H. M.; "Irrigation Engineering". John Wiley and Sons, Inc., New York, p. 371, 1917.

3. Eakin, H. M.; "Silting of Reservoirs", U. S. Department of Agriculture Tech. Bull. No. 524, 1936. Revised edition by Carl B. Brown, 1939.

4. Faris, Orville A.; "The Silt Load of Texas Streams", U.S. Department of Agriculture Tech. Bull. No. 382, 1933.

5. Follett, W. W.; "Silt in the Rio Grande", Engineering News, Vol. 71, No. 1, 1914.

6. Fortier, S. and Blaney, H. F.; "Silt in the Rio Grande and its Relation to Irrigation", U. S. Department of Agriculture Tech.Bull. No. 67, 1930.

7. Grunsky, C. E.; "Silt Transportation by Sacramento and Colorado Rivers and by the Imperial Canal", Trans. A.S.C.E., Vol. 94, p. 1104-51, 1930.

8. Hemphill, R.G.; "Silting and Life of Southwestern Reservoirs", Trans. A.S.C.E., Vol. 95, p. 1061-74, 1931.

9. Howard, C. S.; "Suspended Matter in the Colorado River in 1925-28", U. S. Geological Survey, Water-Supply Paper No. 636B, p. 27, 1929.

10. Hughes, D. S., "Amount of Silt that would be Deposited in Reservoir at San Carlos", House Doc. 791, 63rd Congress, 2nd Session, San Carlos Irrigation Project, Arizona, Appendix G.

11. International Boundary Commission, United States and Mexico; "Flow of the Rio Grande and Tributary Conditions", Water Bulletin No. 7, 1937.

12. Lewis, A. D.; "Silting of Four Large Reservoirs in South Africa", Second Congress on Large Dams, Communication No. 5, 1936.

13. Missouri River, House Document No. 238, 73rd Congress, 2nd Session, 1935.

14. Punjab Irrigation Branch, Technical Review, p. 104, 1925.

15. Stabler, Herman; "Kaw River Silt" Engineering News, Vol. 63.

16. Stevens, J. C.; "The Silt Problem", Trans. A.S.C.E., Vol. 101, p. 208-88, 1936.

17. Taylor, T. W.; "Silting of Reservoirs", Texas University Bull. No. 3025, 1930.

18. Todd, O. J. and Eliassen, S.; "The Yellow River Problem", Proceedings A.S.C.E., Vol. 64, No. 10, p. 1922-91, 1938.

19. Freeman, J.R., "Flood Problems in China", Trans. A.S.C.E., Vol. 85, 1922, p. 1442.

20. Buckley; "Irrigation Pocket Book", p. 124.

21. Kanthack; "The Principles of Irrigation Engineering", p. 213.

22. Sonderegger, A. L.; "Modifying the Physiographical Balance Conservation Measures", Trans. A.S.C.E., Vol. 100, 1935, p. 284.

23. Lane, E. W. and Kennedy, J.C.; "A Study of Sedimentation in a Miami Conservancy District Reservoir, Trans. Am. Geophysical Union, 1940, Part 2, p. 607.

24. Oexle; "Volumetric Weight of Suspended Sediment (Raumgewicht der Schwemmstoffe (Schlamm)", Wasserkraft und Wasserwirtschaft, Vol. 29, Issue 6, p. 61-67, March 16, 1934, Translated by Engineer Department Research Centers, Vicksburg.

25. Singer; "Computing Bed-Load Quantities (Das Rechnen Mit Geschiebemengen)", Zeitschrift der Gewässerkunde, Vol. XI, issue 4.

26. Spring and Prost; "Study of the Water of the Meuse (Etude sur les eaux de la Meuse)", Anales de la Societe Geologique der Belgique, Vol. II, 1883-1884, p. 123 and following pages.

27. "Geological Study for the Genissiat Dam Project on the French Upper Rhone." (Etude geologique sur le projet de barrage du Haut-Rhone francais a Genissiat), 1912.

28. "Investigations Concerning Lake Niedersoutholfen in the Bavarian Allgäu" (Untersuchungen uber den Niedersoutholfener See im bayerischen Allgäu). Scientific publication of the D. W. Oest. A. V. Innsbruck, 1930.

29. "Quantitative Investigation of the Deposition of Sediment in Lake Alp, Lake Niedersoutholfen, and Lake Starnberg" (Quantitative Untersuchungen über den Schlammabsatz in Alpsu, dem Niedersoutholfener See und dem Starnberger See) Reprint from the Archu fur Hydrobiologie, 1932, vol. XXIV, pp. 535-42.

30. Mühlhofer, C. I.; "Researches Concerning the Transport of Light and

Heavy Material in Suspension by the Inn River", near Kirchbichl, Tyrol (Untersuchen über die Schwemstaff und Schurbstoff Fuhrung des Inn nochst Kirchbichl Tyrol) Die Wasserwertschaft, 1933 Issue 1 6.

31. Division of Water Resources, State of California," Geology and ground Water Storage Capacity of Valley Fill:" Bulletin No 45

32. Piper Thomas and Robinson;"Ground water Hydrology of the Mokelumne Area, Water Supply Paper No. 780, p. 101.

33. Piper A. M.; "Notes on the Relation between the Moisture Equivalent and the Specific Retention of Water-Bearing Materials."Trans. Am. Geophysical Union 1933 p. 481.

34. Trask, Parker, "Compaction of Sediments," Bull. Am. Assn. Petroleum Geologists Vol. 15 pp. 271-76

35. Eliassen, Sig ; "Alluvial loess and the silt carrying capacity of Hopei Rivers." Jour. Assoc. Chinese and Amer. Engin. 17 (5): 267-292 Illus. Sept. Oct. 1936.

36. Anonymous; "Method of estimating the probable volume of silt deposits in river storage reservoirs for the Oklahoma City water supply." Engin & Contract 39(11): 290-293. March 12, 1913.

37. Dabney A. L., "The Tallahatchie drainage district," Ill. Soc. Engin. and Surveyors 25th Ann. Rpt. pp. 187-196, illus Jan. 1910.

38. Krumbein, W. C.; "The Effect of Abrasion on the Size, Shape and Roundness of Rock Fragments" Journal of Geology, Vol. XLIX July-August, 1941.

39. Ortenblad, Alberto; "Mathematical theory of the process of consolidation of mud deposits" Jour. Math. and Physics 9 (2): 73-149, illus. April 1930.

40. "Notes on Silting of Elephant Butte Reservoir," Reclammation Record, September 1916 p. 423.

41. Parker, P. A. M., Control of Water,, p. 767.

42. Happ, S. C., "Sedimentation in Artificial Lakes," A Symposium on Hydrobiology. University of Wisconsin Press p. 35.