Sedimentation in Upper Stony Creek Basin, Eastern Flank of the Coast Ranges of Northern California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1798-F

Prepared in cooperation with the California Department of Water Resources

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By J. M. KNOTT *and* C. A. DUNNAM

SEDIMENTATION IN SMALL DRAINAGE BASINS

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SEDIMENTATION IN UPPER STONY CREEK BASIN EASTERN FLANK OF THE COAST RANGES OF NORTHERN CALIFORNIA

By J. M. KNOTT and C. A. DUNNAM

ABSTRACT

Sediment surveys in 1960 and 1962 indicated that the average annual rate of accumulation in East Park Reservoir during the period 1910–62 was 0.37 acre-foot per square mile of drainage area and that in Stony Gorge Reservoir during the period 1928–62 it was 0.27 acre-foot per square mile of drainage area. Maximum deposition occurred in the deeper parts of the reservoirs along prereservoir stream channels. Storage capacity of both reservoirs has been depleted approximately 0.1 percent per year by sediment deposition.

Estimates of suspended-sediment discharge were made from periodic measurements on Stony Creek at Black Butte Dam. Annual sediment yield at this site averaged 0.93 acre-foot per square mile during the 6-year period 1957–62. Most of the sediment load of Stony Creek and its tributaries is transported during periods of storm runoff. The sediment is predominantly of silt and clay size (less than 0.062 mm). Bedload discharge is a minor part of the Stony Creek sediment discharge. The bedload, as computed by three procedures (Einstein, Meyer-Peter and Muller, and Schoklitsch), was 1–6 percent of the suspended load.

INTRODUCTION

This report summarizes the results of a study of the sedimentation in the upper Stony Creek basin (fig. 1) during the 6-year period 1957–62. The study was made to provide information for the evaluation of sedimentation in this basin and adjacent areas. Fieldwork and basic-data collection included sediment surveys of East Park and Stony Gorge Reservoirs in 1960 and 1962 and periodic measurements of suspended sediment in Stony Creek at Black Butte Dam during the 6-year period.

The report was prepared by the U.S. Geological Survey, in cooperation with the California Department of Water Resources. The work was done under the general supervision of R. Stanley Lord, of the Survey's Water Resources Division, California District, and under

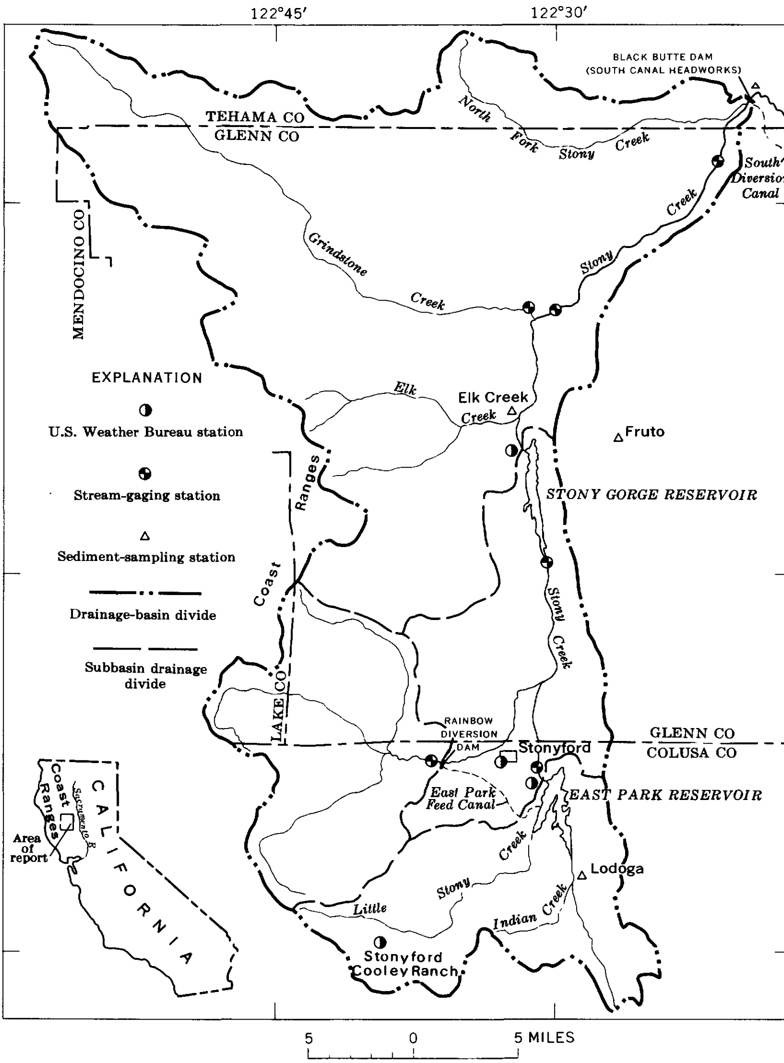

FIGURE 1. — Upper Stony Creek drainage basin.

the immediate supervision of W. W. Dean, chief of the Sacramento subdistrict office. George Porterfield, hydraulic engineer in the Sacramento subdistrict office, assisted in planning the project and interpreting the data.

The U.S. Department of Agriculture, Soil Conservation Service, provided maps and sediment data from previous reservoir surveys. Information on operation and use of reservoirs was given by R. W.

Hollis, Manager of the Orland Water Users Association, and by the U.S. Bureau of Reclamation, Sacramento, Calif.

The only known report on sedimentation in the upper Stony Creek basin is by Brown and Thorp (1947, p. 16–61). It summarizes the results of the sediment surveys of East Park and Stony Gorge Reservoirs made in 1946 by the U.S. Department of Agriculture, Soil Conservation Service. The results were revised by the Department of Agriculture in 1962. Table 1 gives a summary of the results and revisions.

TABLE 1.—*Summary of results of 1946 sediment survey of East Park and Stony Gorge Reservoirs*

[After Brown and Thorp (1947, p. 16) except as noted]

Reservoir	Period (yr)	Drainage area (sq mi)	Sediment volume (acre-ft)	Average annual sediment accumulation per square mile of drainage area (acre-ft)
East Park	1910–46	102	[1]693	[1]0.19
Stony Gorge	1928–46	[2]199	[1]674	.20

1 Values are revisions made by the U.S. Dept. Agriculture, Soil Conserv. Service, 1962.
2 Excluding the area upstream from East Park Dam.

DESCRIPTION OF AREA

GENERAL FEATURES

The upper Stony Creek basin, on the eastern flank of the Coast Ranges of northern California (fig. 1), extends from Colusa County northward through parts of Glenn, Lake, and Tehama Counties. Topography of the 741-square-mile area ranges from steep, rugged mountains on the western boundary to gentle foothills on the eastern boundary. Elevations within the basin range from 370 feet above mean sea level at Black Butte Dam to approximately 7,000 feet at several peaks along the western boundary.

Stony Creek, a tributary to the Sacramento River, flows northward through the foothills. Most of the runoff is from the western part of the basin. The gradient of Stony Creek ranges from less than 2 feet per mile near the Black Butte Dam to approximately 400 feet per mile in the headwaters.

East Park and Stony Gorge Reservoirs provide most of the storage of runoff from the basin. This water is stored for only a few winter months, then is released for irrigation in the spring and summer. Another dam constructed at Black Butte in 1963, subsequent to collection of data for this study, provides for additional storage.

VEGETATION AND SOILS

Vegetation in the semiarid lower and intermediate elevations of the upper Stony Creek drainage basin consists mostly of native grasses and scrub brush; the generally sparse vegetation contrasts with the luxuriant growth of marketable timber at higher elevations. Only during the winter and early spring is the soil moisture adequate to produce a growth of range grasses sufficient for grazing. Soils in the area range from shallow soils unsuitable for agriculture that are on the foothill slopes to thick soils of gravelly loam in the valley.

In the humid areas of the basin, mixed stands of fir, pine, and oak provide a good soil cover, except where logging, road building and other activities of man have affected the natural vegetation.

CLIMATE

Climate of the upper Stony Creek basin is typical of the Coast Ranges in northern California. Summers are characterized by long periods of hot, dry weather with little or no precipitation, and winters are mild and humid. Frequently, more than 65 percent of the annual rainfall occurs during the 4-month period, December–March.

Four climatological stations within the basin are maintained by the U.S. Weather Bureau (table 2 and fig. 1). Long-term records are

TABLE 2. — *Summary of climatological data in the upper Stony Creek drainage basin*

[Records from annual summaries of U.S. Weather Bur.]

U.S. Weather Bureau station location	Period of record (yr)	Elevation above mean sea level (ft)	Average annual precipitation (in.)	Range in annual precipitation (in.)
Stonyford Cooley Ranch	1960–62	3,015	57.27	--
Stonyford Ranger Station	1930–62	1,168	20.63	8.84–44.98
East Park Reservoir	1910–62	1,205	18.94	7.86–39.40
Stony Gorge Reservoir	1927–62	800	19.21	6.97–40.59

U.S. Weather Bureau station location	Period of record (yr)	Range in monthly precipitation (in.)	Average annual temperature (°F)	Minimum and maximum temperature recorded (°F)
Stonyford Cooley Ranch	1960–62	0.00–16.94	--	--
Stonyford Ranger Station	1930–62	.00–13.54	--	--
East Park Reservoir	1910–62	.00–10.60	59	3–117
Stony Gorge Reservoir	1927–62	.00–14.31	60	5–119

available for three stations near East Park and Stony Gorge Reservoirs at elevations of approximately 1,000 feet. The fourth station, Stonyford Cooley Ranch, has been in operation since May 1959. This station is near the headwaters of Little Stony Creek at an elevation of about 3,000 feet.

Long-term records indicate that precipitation at elevations ranging from about 800 to 1,200 feet is uniformly distributed areally and averages about 19 inches per year. Monthly mean precipitation at East Park Reservoir, the oldest climatological station of the four, ranges from 0.02 inch in July to 4.03 inches in January. Monthly mean temperatures at this station range from 43°F in January to 77°F in July. Daily extremes are more variable, with temperatures as low as 3°F and as high as 117°F.

The short-term record at Stonyford Cooley Ranch for the 3-year period 1960–62 indicates that the average precipitation is almost 60 inches per year.

WATER DISCHARGE

Streamflow within the upper Stony Creek basin is regulated. Flow from Little Stony Creek, Indian Creek, and flow diverted from Stony Creek through the East Park Feed Canal (fig. 1) is often stored in East Park Reservoir during the winter months. Outflow from East Park Reservoir and flow of Stony Creek are impounded in Stony Gorge Reservoir for varying periods.

Table 3 shows the water discharge obtained from the stream-gage

TABLE 3. — *Water discharge of Stony Creek at Black Butte Dam, near Orland*

Water year (Oct. 1–Sept. 30)	Water discharge (acre-ft)	
	At gaging station	Adjusted[1]
1948[2]		86,900
1949		170,800
1950		106,200
1951		341,800
1952		538,200
1953		418,300
1954		305,700
1955[3]		162,100
1956		679,100
1957	143,800	228,000
1958	991,100	1,060,000
1959	156,000	238,400
1960	179,800	264,100
1961	146,900	223,500
1962	183,900	267,800
Average		346,300

1 Includes diversion to South Diversion Canal.
2 Water-discharge records began in February 1948.
3 Water-discharge records for the year prior to January 1955 were furnished by U.S. Bur. Reclamation; records for January–July 1955, by the California Dept. Water Resources; records for July 1955–September 1962, by the U.S. Geol. Survey.

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rating curve and the adjusted water discharge at the gaging station at Black Butte Dam. The adjusted water discharge was calculated by adding the quantity of water diverted by the South Diversion Canal and the quantity discharged 0.6 mile downstream from the dam. The average adjusted water discharge was 380,300 acre-feet per year for 1957–62 compared with 346,300 acre-feet per year for the period 1948–62.

Streamflow records for several other locations (fig. 1) within the upper Stony Creek basin are available in annual water-supply papers of the U.S. Geological Survey and in the files of the U.S. Bureau of Reclamation, Sacramento, Calif. Most of these discharge records are fragmentary; however, some provide valuable data on reservoir inflow and streamflow.

Water-discharge records of Stony Creek above Stony Gorge Reservoir for the period 1919–41 include both outflow from East Park Reservoir and streamflow of Stony Creek upstream from the reservoir. Discharge records from 1919 to 1928 are representative of the period before the completion of Stony Gorge Reservoir.

The water-discharge record of Little Stony Creek near Lodoga (1908–34) is probably representative of natural streamflow. After construction of East Park Reservoir in 1910, the records for this station were calculated as the sum of outflow, change in storage, and evaporation less diversion into the reservoir.

Water discharge of Stony Creek near Stonyford (1913–14, 1918–34) is equivalent to the streamflow of Stony Creek above the East Park Feed Canal. Water diverted by the feed canal flows into East Park Reservoir.

Table 4 gives the average annual inflow to East Park and Stony Gorge Reservoirs.

TABLE 4. —*Inflow to East Park and Stony Gorge Reservoirs*

Reservoir	Drainage area upstream from dam (sq mi)	Water years	Average annual inflow[1] (acre-ft)
East Park	102	1920–61	61,130
Stony Gorge	301	1929–62	[2]166,100

[1] From U.S. Bur. Reclamation.
[2] Calculated from change in storage and includes outflow from East Park Reservoir in addition to flow from Stony Creek.

SEDIMENT SURVEYS

METHODS OF SURVEY

Fluvial sediment is deposited in the basin in many catchments, such as stock ponds and small dams, but most of it is trapped in two reservoirs, East Park and Stony Gorge. These reservoirs were surveyed to determine the quantity of sediment accumulation. Each reservoir was observed when the water surface was near spillway elevation and again when the water surface was near maximum drawdown.

The first surveys of East Park and Stony Gorge Reservoirs were made in May 1960, while water levels were near spillway elevation. These surveys were made to reestablish reference points used in the 1946 surveys (Brown and Thorp, 1947) and to determine the accumulation of sediment since 1946. Evaluation of the survey data indicated that some of the 1946 ranges could not be accurately identified; therefore, in November 1962, while the reservoirs were near maximum drawdown, a resurvey was made to determine the total sediment accumulation at the unidentifiable ranges. The total sediment accumulation since 1946 was determined at identified ranges (figs. 2, 7).

The 1962 surveys of the reservoirs were made by transit-stadia traverse at ranges that were above the water level and by sonic depth sounding at submerged ranges.

Sediment depths at locations that could not be reestablished from the 1946 survey were measured by probing. This method consisted of pushing a ½-inch steel rod into the sediment until the original hard surface of the reservoir bed was reached. The thickness of the sediment was also determined at several locations by using an auger. The auger measurements confirmed that the probe measurements of sediment thickness were generally satisfactory.

Samples of lake sediment were obtained at several ranges by using a split-core sampler suspended from a boat. The sampler, similar to the device described by Porterfield and Dunnam (1964, p. 29), penetrates the sediment deposit by the force of its own weight. Penetration is limited by the properties of the sediment deposit, such as cohesiveness, grain size, and compaction. Samples obtained with the core sampler are representative of sediment deposited in the top 18 inches of the reservoir bed.

LABORATORY ANALYSIS

Sediment samples collected from both reservoirs were analyzed for specific weight, specific gravity, and particle-size distribution.

Specific weight is defined here as the dry weight per unit volume. When applied to sediment deposits in reservoirs, it refers to the ratio of ovendried weight to undisturbed volume of the water-sediment mixture and is expressed in pounds per cubic foot. Specific weight is used for converting the volume of sediment deposits to total weight. This conversion is needed to compare the average rate of sedimentation in a reservoir to sediment-discharge data of related streams.

Specific gravity refers to the ratio of the dry weight of sediment to the weight of an equal volume of water at 4°C. Samples were analyzed by using the pycnometer method described by Krumbein and Pettijohn (1938, p. 501).

An analysis of particle-size distribution was made for each of the sediment samples. Sand (0.062–2.00 mm) was analyzed by dry or wet sieving. Silt and clay (less than 0.062 mm) were analyzed by the pipet method.

COMPUTATION OF SEDIMENT VOLUME

The volume of accumulated sediment was determined by dividing each reservoir into segments bounded on two sides by parallel sediment ranges. The volume of each segment was computed from a prismoidal formula described by Eakin and Brown (1939, p. 158–161). The general formula is:

$$V=\frac{A^1}{3}\,\frac{(E_1+E_2)}{W_1+W_2}+\frac{A}{3}\left(\frac{E_1}{W_1}+\frac{E_2}{W_2}\right)+\frac{h_3E_3+h_4E_4}{130{,}680}+\cdots$$

where

V = volume of sediment, in acre-feet.

A^1 = area of the quadrilateral formed between two ranges by connecting the points of range intersection with maximum reservoir level, in acres.

A = actual surface area of the reservoir between ranges, in acres.

E = cross-sectional area of sediment in each of two adjacent parallel ranges, in square feet.

W = width of each range at maximum reservoir level, in feet.

h = the perpendicular distance from the range on a tributary to the junction of the tributary with the main stream, in feet.

EAST PARK RESERVOIR

DESCRIPTION OF RESERVOIR

East Park Reservoir (fig. 2), about 35 miles upstream from Black Butte Dam, provides storage for runoff of Little Stony and Indian Creeks. Water is also diverted into the reservoir from Stony Creek through East Park Feed Canal.

East Park Dam, completed in 1910 by the U.S. Bureau of Reclamation, is a concrete arch-type structure about 190 feet high. The spillway, a separate structure near the dam, has an elevation of 1,198.18 feet above mean sea level. During most years, 1.5-foot-high flashboards are placed in the spillway to increase the storage capacity of East Park Reservoir. Its initial capacity of 46,000 acre-feet can

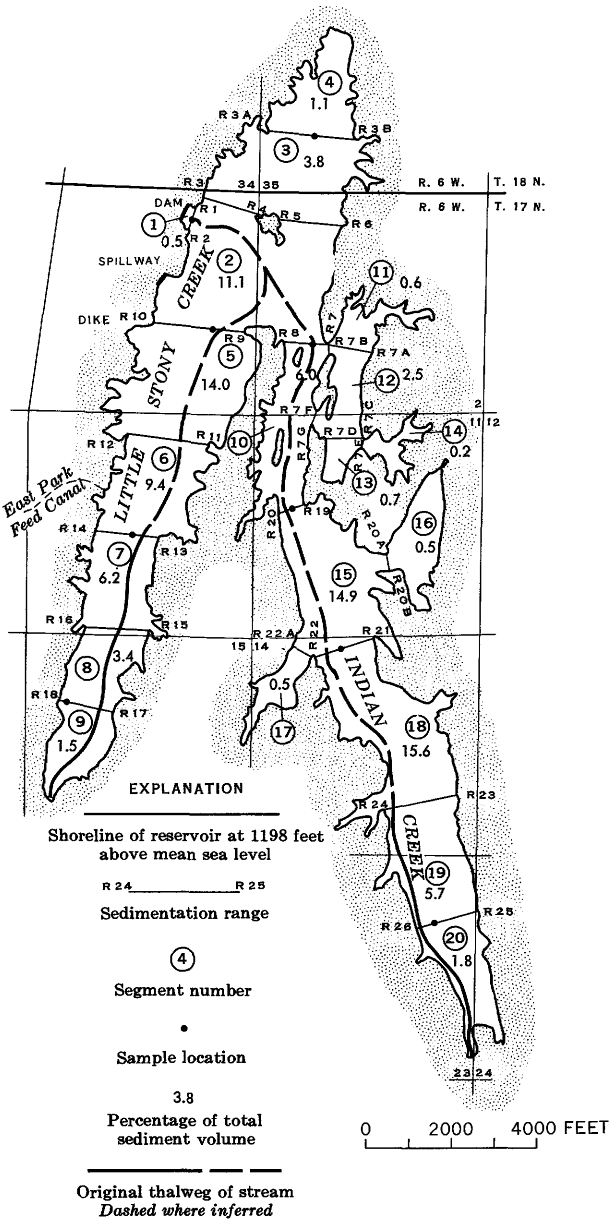

FIGURE 2. — East Park Reservoir, Colusa County. Base from unpublished design drawings of U.S. Reclamation Service, 1908.

thereby be increased to 50,900 acre-feet (U.S. Bur. Reclamation, 1961).

Most of the sediment deposited in East Park Reservoir is from Little Stony and Indian Creek basins, which together drain an area of 102 square miles. Although a small quantity of water is contributed from the Stony Creek drainage basin upstream from the Rainbow Diversion Dam, which is the headworks of the East Park Feed Canal (fig. 1), the quantity of sediment transported through this canal to East Park Reservoir is probably negligible. The flow carried by the canal is small, and coarse sediment is trapped by sediment barriers at the Rainbow Diversion Dam (fig. 1) and must be removed periodically from these barriers.

DISTRIBUTION OF SEDIMENT

An inspection of the reservoir while the water level was low showed that most of the sediment was deposited in the deeper parts of the reservoir in and along the main stream channels; only thin deposits are evident on the former valley slopes. Sediment thickness increases in the downstream direction in both principal arms of the reservoir (figs. 2 and 3).

The channel of Little Stony Creek is well defined between range R13–R14 and the upstream end of the reservoir. Downstream from range R13–R14 the banks of the stream channel gradually become obscured and finally are buried under lake sediment. Sediment thickness increases downstream to a maximum of 5.5 feet at range R9–R10.

The channel of Indian Creek is well defined upstream from range R23–R24. Significant quantities of sediment, however, are evident east of the channel. Downstream the stream channel is obscured by gently sloping sediment deposits that increase in thickness to a maximum of 8.5 feet at range R21–R22. Most of the sediment in the Indian Creek arm is deposited between ranges R19–R20 and R23–R24. It is deposited here probably because of a natural constriction in the reservoir and the damming effect of sediment deposits derived from several tributaries emptying into the main channel at right angles.

The percentage of sediment volume by segments is shown in figure 2. Sediment entering the reservoir during the early part of the runoff season, while the water level is low, is transported to the lower reaches before it is deposited. Also, sediment deposits in upper and intermediate segments of the reservoir probably are washed farther downstream. A comparison of the 1962 longitudinal profile with the 1946 profile (fig. 3) indicates that degradation is taking place at the thalwegs at the upstream end of each arm.

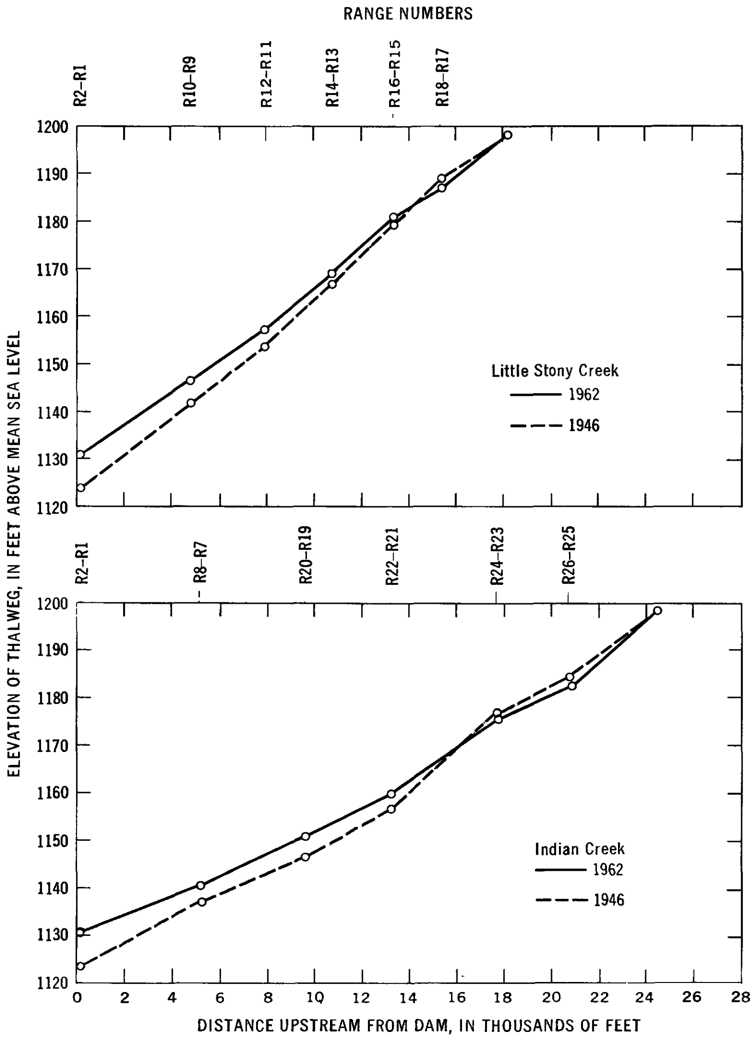

FIGURE 3. — Longitudinal profiles of Little Stony and Indian Creeks upstream from East Park Dam.

PROPERTIES OF SEDIMENT

During the 1960 survey, nine samples of reservoir sediment were collected with a split-core sampler in both the Little Stony and the Indian Creek arms. Analyses of specific weight, specific gravity, and particle-size distribution of the samples are given in table 5.

Specific weight of the samples ranged from 36.2 to 66.2 pounds per cubic foot. The lowest specific weight was for a sample collected at range R1–R2 near the dam. Higher specific weights occurred in the upper parts of the reservoir where coarser material was deposited.

TABLE 5.—*Specific weight, specific gravity, and particle size distribution of core samples from East Park Reservoir*

[Method of analysis: S, sieve; P, pipet; W, distilled water; C, chemically dispersed]

Sample location (range)	Specific weight (lb per cu ft)	Specific gravity	Particle-size distribution (percent finer than indicated size in millimeters)											Median particle size (mm)	Method of analysis
			0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.00	2.00		
R1 –R2	36.2	2.69	70	90	98	99	100	--	--	--	--	--	--	[1]0.0012	SPWC
R3A–R3B	66.2	2.65	44	57	69	84	95	97	98	99	100	--	--	.0028	SPWC
R7 –R8	59.3	2.65	64	79	92	97	99	100	--	--	--	--	--	[1].0011	SPWC
R9 –R10	44.9	2.70	47	58	76	89	97	99	100	--	--	--	--	.0024	SPWC
R13 –R14	65.6	2.72	15	15	20	28	41	48	72	92	96	98	99	.0660	SPWC
R17 –R18	47.4	2.72	19	20	39	73	92	97	99	100	--	--	--	.0100	SPWC
R19 –R20	51.8	2.67	61	73	85	90	96	98	100	--	--	--	--	[1].0011	SPWC
R21 –R22	58.1	2.68	44	50	63	77	91	98	100	--	--	--	--	.0040	SPWC
R25 –R26	62.4	2.68	29	38	52	70	90	98	100	--	--	--	--	.0072	SPWC
Mean			44	53	66	79	89	93	97	99	100	--	--	--	

1 Estimated.

The average specific weight of sediment in East Park Reservoir was 55 pounds per cubic foot. This average was computed by adjusting the specific weight of individual reservoir segments to the volume of sediment deposited therein.

The specific gravity of material in the core samples ranged from 2.65 to 2.72 (table 5). This narrow range of values indicates that specific gravity of mineral grains in the reservoir sediment was uniform throughout and comparable to that of many other reservoirs. Particle-size analyses of nine core samples (table 5) indicated that sediment deposited in East Park Reservoir was predominantly of silt and clay sizes. The average size distribution of the nine samples was 7 percent sand, 40 percent silt, and 53 percent clay.

Specific weight and particle-size of samples related to distance of the sampling location upstream from East Park Dam are given in figures 4 and 5.

Median particle size of sediment in both arms of the reservoir, in general, decreases in the downstream direction; however, the sample from R13–R14 (table 5) has an abnormally large amount of sand in proportion to silt and clay. A comparison of figures 4 and 5 indicates that sediment deposits are generally coarser in the Little Stony Creek arm than in the Indian Creek arm.

The specific weight and the median particle size of deposited sediment in East Park Reservoir were compared with similar data for several other reservoirs in the United States (fig. 6). The data for other reservoirs, compiled by Welborn (1967, p. 106), are representative of conditions where deposited sediments were relatively uncompacted. Although the plotted points are widely scattered, points representing data from East Park Reservoir plot close to the average curve.

VOLUME OF SEDIMENT

The volume of sediment deposited in East Park Reservoir during the 52-year period, December 1910–November 1962, as determined by the 1962 survey, was 1,960 acre-feet (table 6). This figure does not

TABLE 6.—*Sediment accumulation as measured in November 1962 in East Park and Stony Gorge Reservoirs*

Reservoir	Period (yr)	Sediment accumulation		
		Total (acre-ft)	Average	
			Acre-ft per year	Acre-ft per year per square mile
East Park	52.0	1,960	38	0.37
Stony Gorge	34.1	1,840	54	[1].27

[1] Excluding drainage area upstream from East Park Dam.

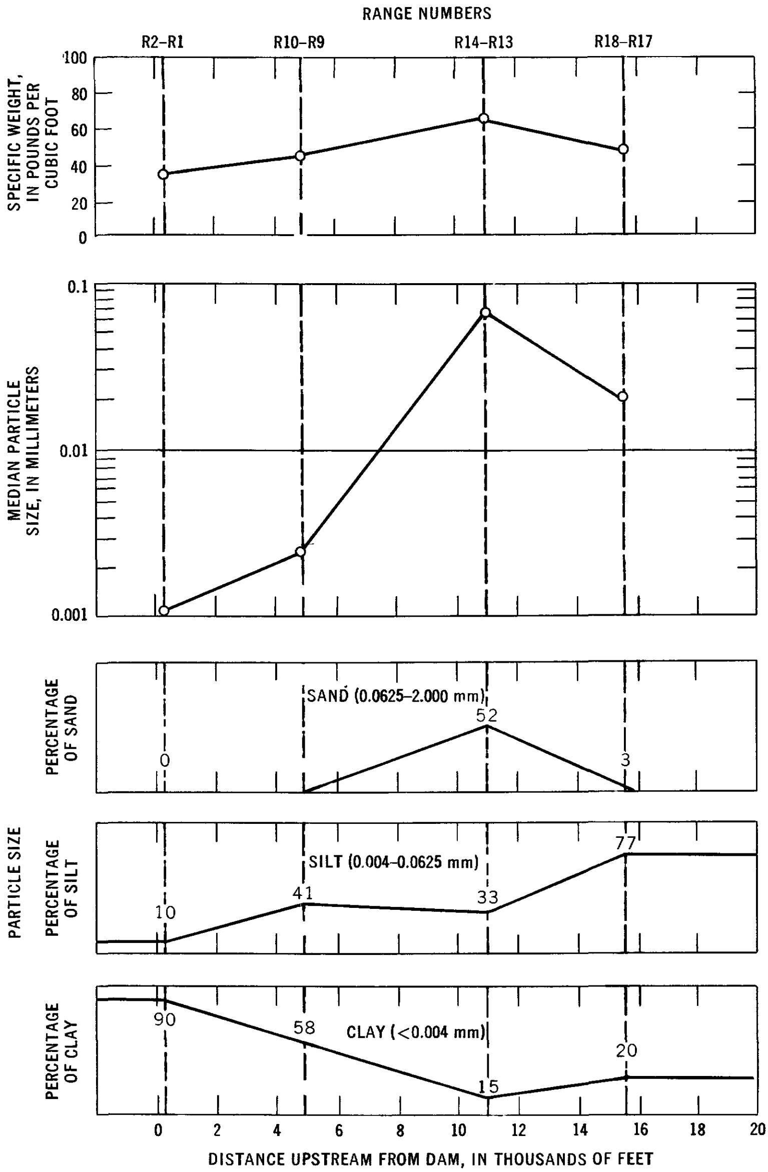

FIGURE 4. — Variation of specific weight and particle size of deposited sediment in Little Stony Creek arm of East Park Reservoir.

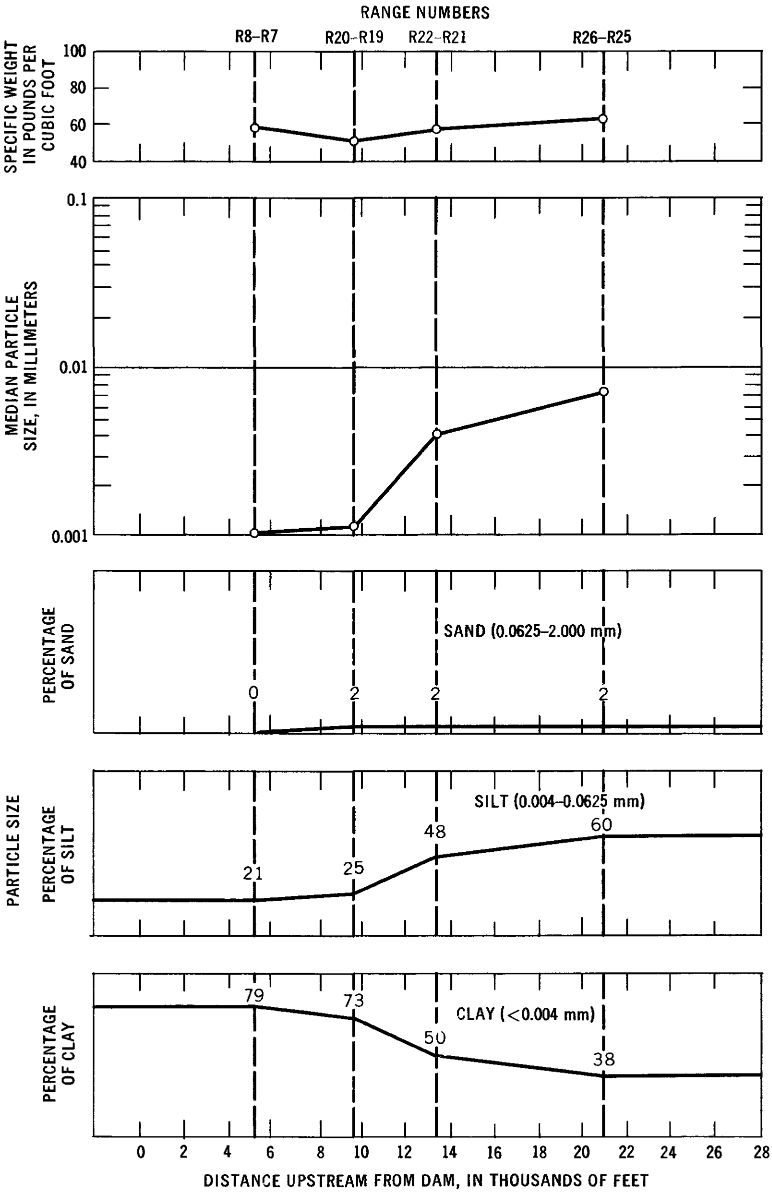

Figure 5. — Variation of specific weight and particle size of deposited sediment in Indian Creek arm of East Park Reservoir.

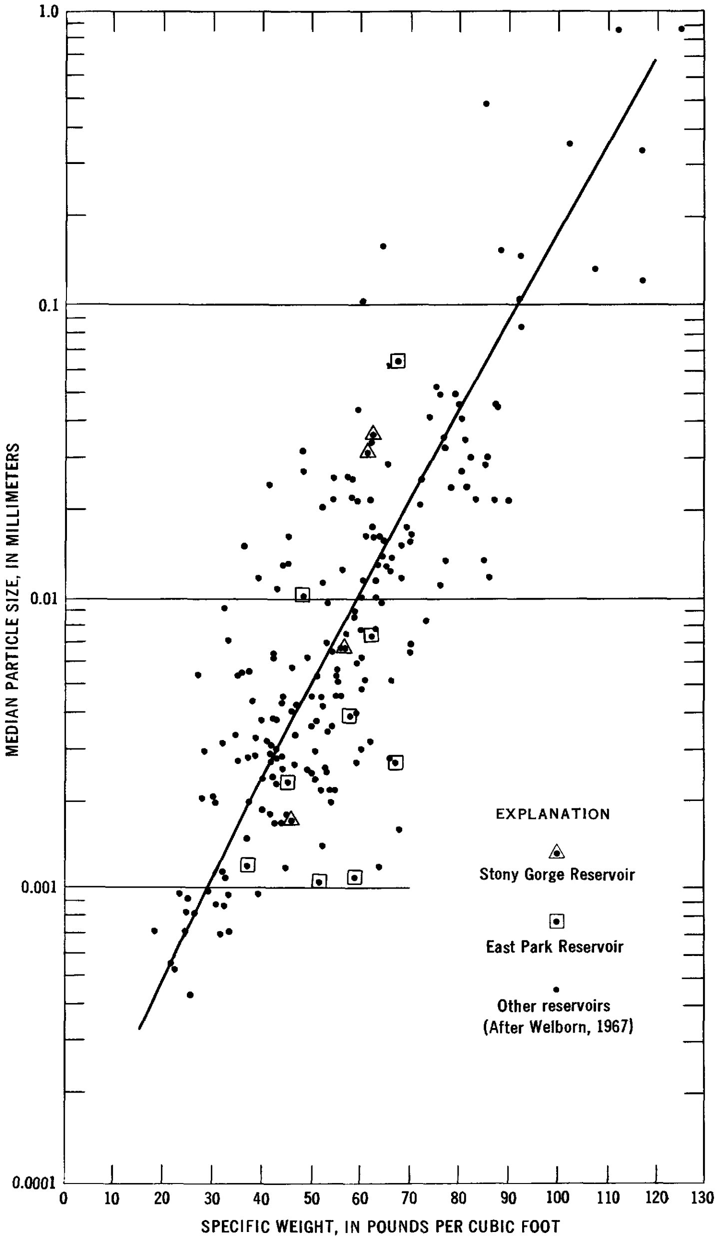

FIGURE 6. — Relation of specific weight of deposited sediment in reservoirs to median particle size.

include the quantity of the sediment that passed through the reservoir.

The ability of a reservoir, or catchment, to retain sediment is the trap efficiency and is expressed as a percentage of the sediment inflow. The trap efficiency of reservoirs is affected by many factors, such as the ratio of reservoir storage capacity to inflow, channel slope, sediment properties, water chemistry, turbidity currents, and reservoir operation. A trap efficiency of 96 percent was estimated for East Park Reservoir by comparing its capacity-inflow ratio with that of other reservoirs in the United States. These data, compiled by Brune (1953, p. 407–418), were for reservoirs where the trap efficiency had been measured directly.

Because the estimate of trap efficiency of East Park Reservoir was nearly 100 percent, no compensating adjustment was made in the determination of sediment yield from the area upstream from the dam. Average sediment yield from the area upstream from the dam was 38 acre-feet per year, or 0.37 acre-foot per year per square mile.

STONY GORGE RESERVOIR

DESCRIPTION OF RESERVOIR

Stony Gorge Dam is near Elk Creek, Calif., and is about 16 miles downstream from East Park Dam. The dam, constructed by the U.S. Bureau of Reclamation in 1928, is a concrete slab-and-buttress structure having a spillway gate elevation of 841 feet above mean sea level. The reservoir behind the dam is narrow and about 5.5 miles long (fig. 7); initial storage capacity was 50,000 acre-feet (U.S. Bureau of Reclamation, 1961).

Most of the sediment inflow to Stony Gorge Reservoir is from a 199-square-mile area that includes the Little Stony Creek drainage downstream from East Park Dam and the adjacent Stony Creek watershed. A negligible quantity of fine sediment is diverted from Stony Creek at the Rainbow Diversion Dam.

Outflow from East Park Reservoir contributes some sediment to Stony Gorge Reservoir. This outflow contains mostly suspended material that is too fine grained to be deposited in East Park Reservoir. The quantity of this fine sediment deposited in the Stony Gorge Reservoir is probably small in relation to the quantity produced from the Stony Creek watershed.

DISTRIBUTION OF SEDIMENT

Most of the sediment in Stony Gorge Reservoir is deposited in and along the old channel of Stony Creek. Only thin deposits of sediment occur on the former valley slopes. The lack of major tributaries to

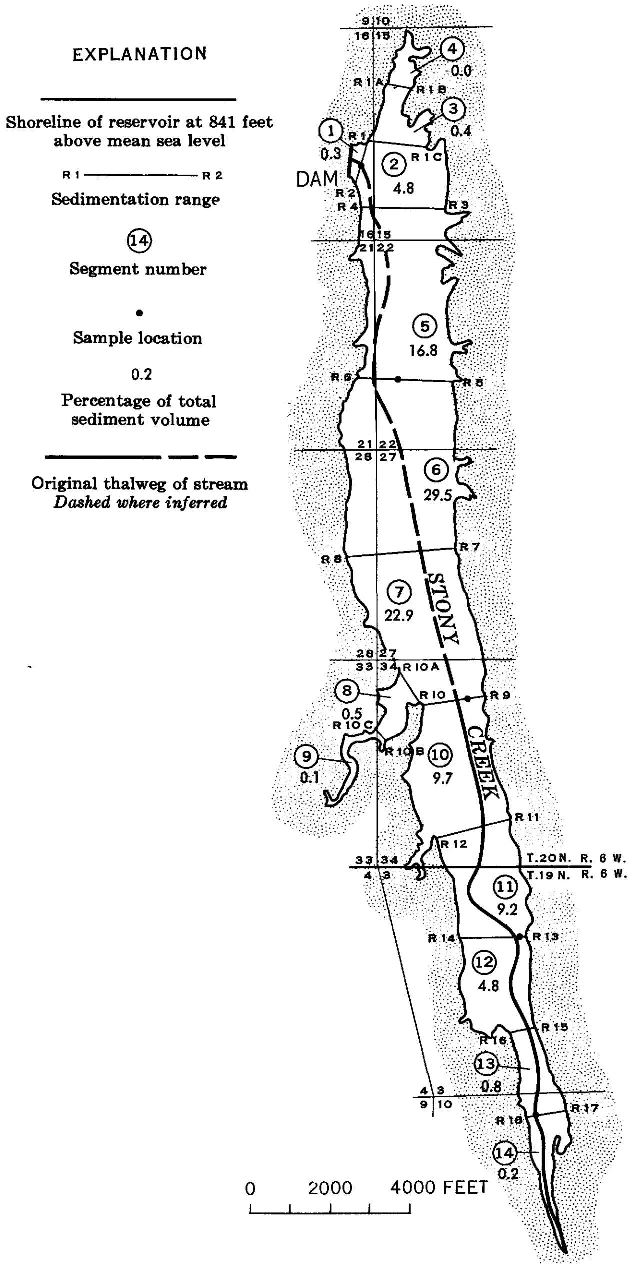

Figure 7. — Stony Gorge Reservoir, Glenn County. Base from unpublished design drawings of U.S. Bureau of Reclamation, 1926.

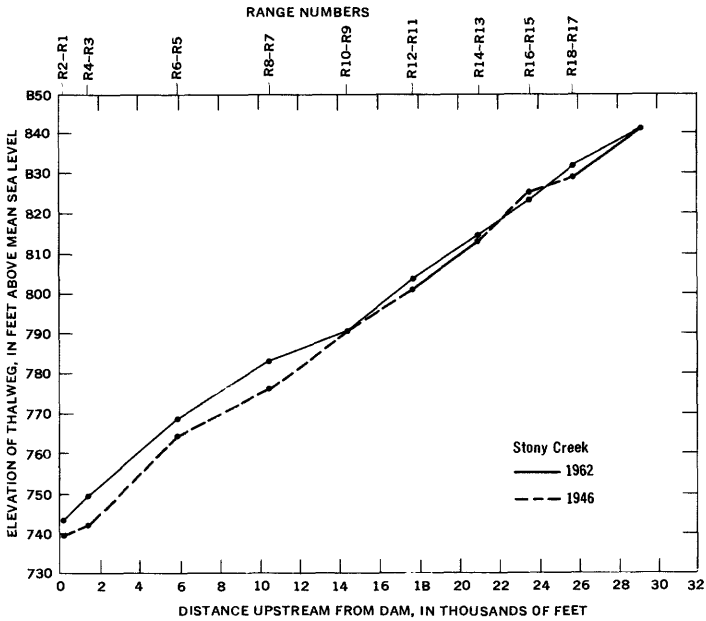

FIGURE 8. — Longitudinal profiles of Stony Creek upstream from Stony Gorge Dam.

the reservoir precludes any significant sediment deposits elsewhere. Sediment deposits generally increase in thickness in a downstream direction (fig. 8) and have a maximum thickness of 12.8 feet at R7–R8.

The channel of Stony Creek is well defined upstream from range R9–R10, although significant sediment deposits occur on low terraces above the streambanks. Downstream from R9–R10 the channel is obscured under gently sloping deposits of sediment. The lowering of reservoir levels during late summer months probably produces effects similar to those observed at East Park Reservoir, where part of the sediment previously deposited in the upstream end of the reservoir was washed downstream by early winter floods. These effects tend to concentrate sediment deposits in the intermediate and lower parts of the reservoir.

PROPERTIES OF SEDIMENT

Samples of reservoir sediment were collected at five ranges on Stony Creek. The results of laboratory analysis for specific weight, specific gravity, and particle-size distribution are given in table 7.

Specific weight of sediment samples ranged from 43.1 to 62.4 pounds per cubic foot. Samples having the lower value were from R1–R2 near the dam, where sediment is composed mostly of clay and fine silt. Sediment from upper and intermediate parts of the reservoir

TABLE 7. — *Specific weight, specific gravity, and particle-size distribution of core samples from Stony Gorge Reservoir*

[Method of analysis: S, sieve; P, pipet; W, distilled water; C, chemically dispersed]

Sample location (range)	Specific weight (lb per cu ft)	Specific gravity	Particle-size distribution (percent finer than indicated size in millimeters)											Median particle size (mm)	Method of analysis
			0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.00	2.00		
R1 -R2	43.1	2.71	56	79	96	99	100	--	--	--	--	--	--	[1]0.0018	SPWC
R5 -R6	56.8	2.68	25	38	55	70	80	86	90	96	99	100	--	.0066	SPWC
R9 -R10	62.4	2.74	12	15	21	30	47	65	98	100	--	--	--	.0350	SPWC
R13-R14	61.8	[1]2.7	16	18	26	36	50	62	77	84	94	98	99	.0310	SPWC
R17-R18	--	--	--	--	--	--	--	4	7	16	20	24	28	--	S
Mean[2]				38	50	59	69	78	91	95	98	100	--	--	

[1] Estimated.
[2] Particle-size distribution at R17–R18 not included in mean.

has higher and more uniform specific weight. Specific weight was not determined for the sample at R17–R18 because it was collected from the streambed of Stony Creek at the upper end of the reservoir and was not representative of deposited sediment. Average specific weight for samples from the reservoir, on the basis of the volume of individual segments, was 59 pounds per cubic foot.

Specific gravity of the samples ranged from 2.68 to 2.74. Particle-size analyses of four core samples (table 7) indicate that sediment deposited in Stony Gorge Reservoir averages about 22 percent sand, 40 percent silt, and 38 percent clay. Median particle size decreases markedly downstream (fig. 9) from R13–R14 to the dam.

The sample taken at R17–R18 is not representative of sediment deposited in the reservoir; however, it was useful in determining the grain size of sediment carried to the reservoir as bedload. Because of the limited depth of sampling at other ranges, samples of the coarse material near the bottom of the reservoir were not obtained.

The data relating specific weight to median particle size for sediment deposits at Stony Gorge Reservoir compare as well with data from other reservoirs (fig. 6) as do similar data from East Park Reservoir.

VOLUME OF SEDIMENT

The volume of sediment deposited in Stony Gorge Reservoir during the 34-year period November 1928–November 1962, as determined by the 1962 survey, was 1,840 acre-feet (table 6). Trap efficiency, estimated by correlating the data with that for other reservoirs (Brune, 1953, p. 407–418), was 94 percent.

No compensating adjustment based on trap efficiency was made in the determination of sediment yield from the area upstream from the dam. The average sediment yield for the 199-square-mile area upstream from Stony Gorge Reservoir, excluding the area upstream from East Park Dam, was 54 acre-feet per year or 0.27 acre-foot per square mile per year.

SEDIMENT DISCHARGE OF STONY CREEK

SUSPENDED SEDIMENT

The suspended-sediment discharge of a stream includes the sediment that is moved in suspension in water and is maintained in suspension by the upward components of turbulent currents or by colloidal suspension (Colby and Hembree, 1955, p. 5). Suspended-sediment data were compiled for one location near the Black Butte Dam (fig. 1) in the upper Stony Creek basin. These data include information pertaining to sources, physical properties, and quantity

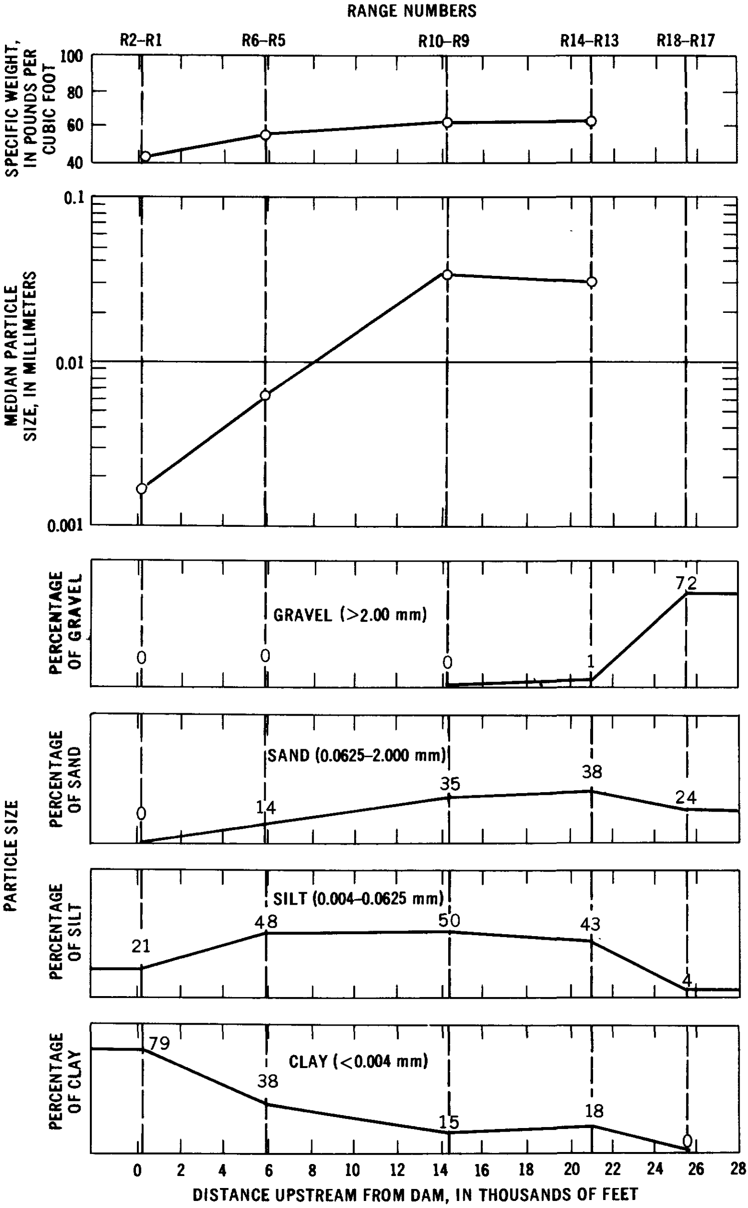

FIGURE 9. — Variation of specific weight and particle size of deposited sediment in Stony Gorge Reservoir.

of sediment transported from the basin prior to completion of the dam in November 1962.

Sediment yield of the basin upstream from the dam is derived from a mixture of relatively clear outflow from Stony Gorge Reservoir and unregulated discharge from the drainage area downstream from the reservoir. Unregulated tributaries of Stony Creek downstream from Stony Gorge Reservoir yield large amounts of sediment during periods of storm runoff. Most of the sediment yield from this area is from the Grindstone Creek basin; Elk Creek and North Fork Stony Creek may transport significant quantities of sediment.

Suspended-sediment data for Stony Creek at Black Butte Dam consist of 54 periodic measurements obtained at water discharges ranging from 0.2 to 17,200 cfs (cubic feet per second). Routine measurements were made about every 30 days; more frequent measurements were made during storm periods.

Each measurement was used in determining daily sediment discharge, which was plotted against daily water discharge to obtain a sediment-transport curve (fig. 10). This curve was used with the continuous streamflow data to estimate sediment discharges for days on which no samples were taken. After storm and seasonal adjustments were applied, as described by Colby (1956, p. 13–26), annual sediment loads were determined by summation of computed and estimated daily discharges. Annual sediment loads of Stony Creek at Black Butte Dam were thus synthesized for the water years 1957–62.

A sediment duration curve (fig. 11) was prepared to evaluate sediment discharge with respect to frequency of occurrence. Examination of the curve in figure 11 shows that days of highest sediment discharge represent only a very small percentage of the total period, but contribute a large percentage of the total sediment discharge. Although days when more than 1,000 tons of sediment was transported occurred only 6 percent of the time during the 1957–62 period, these days accounted for 97 percent of the sediment load. On the other hand, though days of low sediment discharge are frequent, the suspended-sediment discharge during the months of minimum streamflow, May through September, constituted only 0.6 percent of the 1957–62 load. Average sediment discharge during this period was 21 tons per day.

An average particle size for suspended sediment from Stony Creek was determined by weighting the particle-size values with respect to frequency of occurrence of the sediment discharge represented by each sample. Data from other reservoirs (fig. 6) indicate that sediment deposited in Black Butte Reservoir with a median particle size of 0.0092 mm would have a specific weight of 58 pounds per cubic foot. This value compares well with the specific weights of sediment

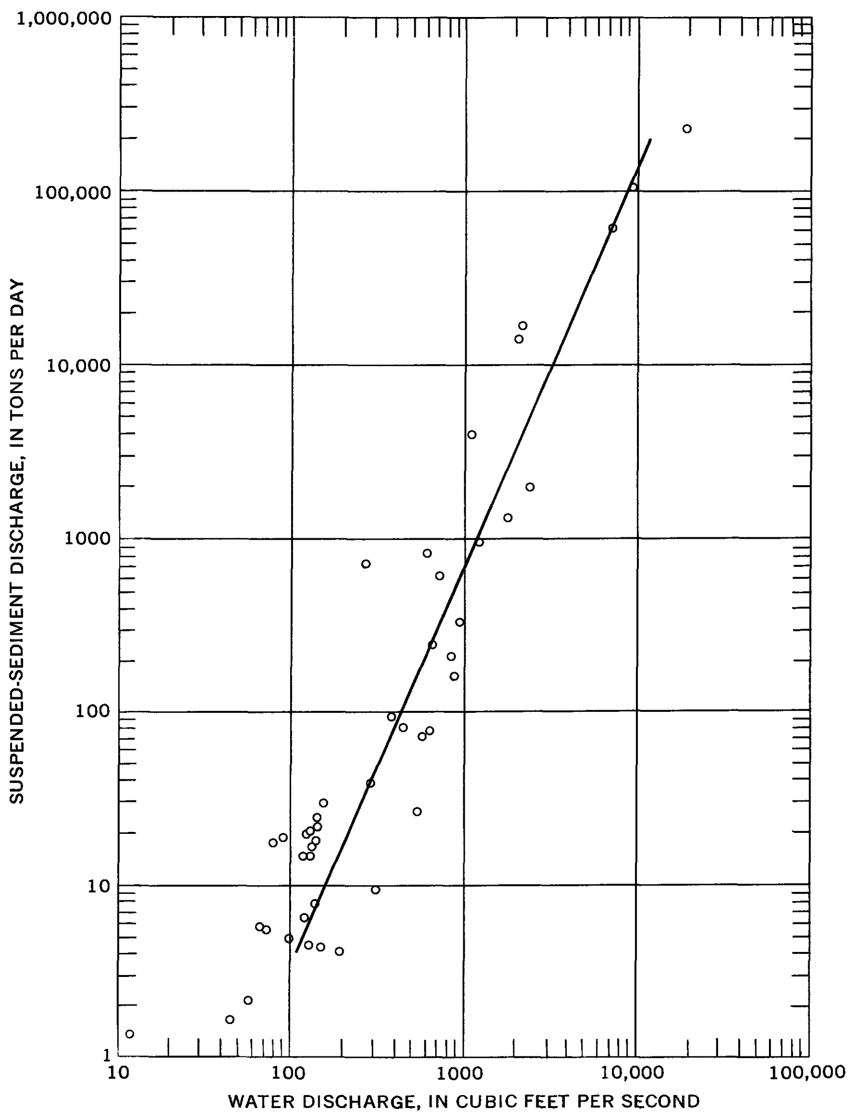

Figure 10. — Relation of daily mean water and suspended-sediment discharge of Stony Creek at Black Butte Dam for water years 1957–62.

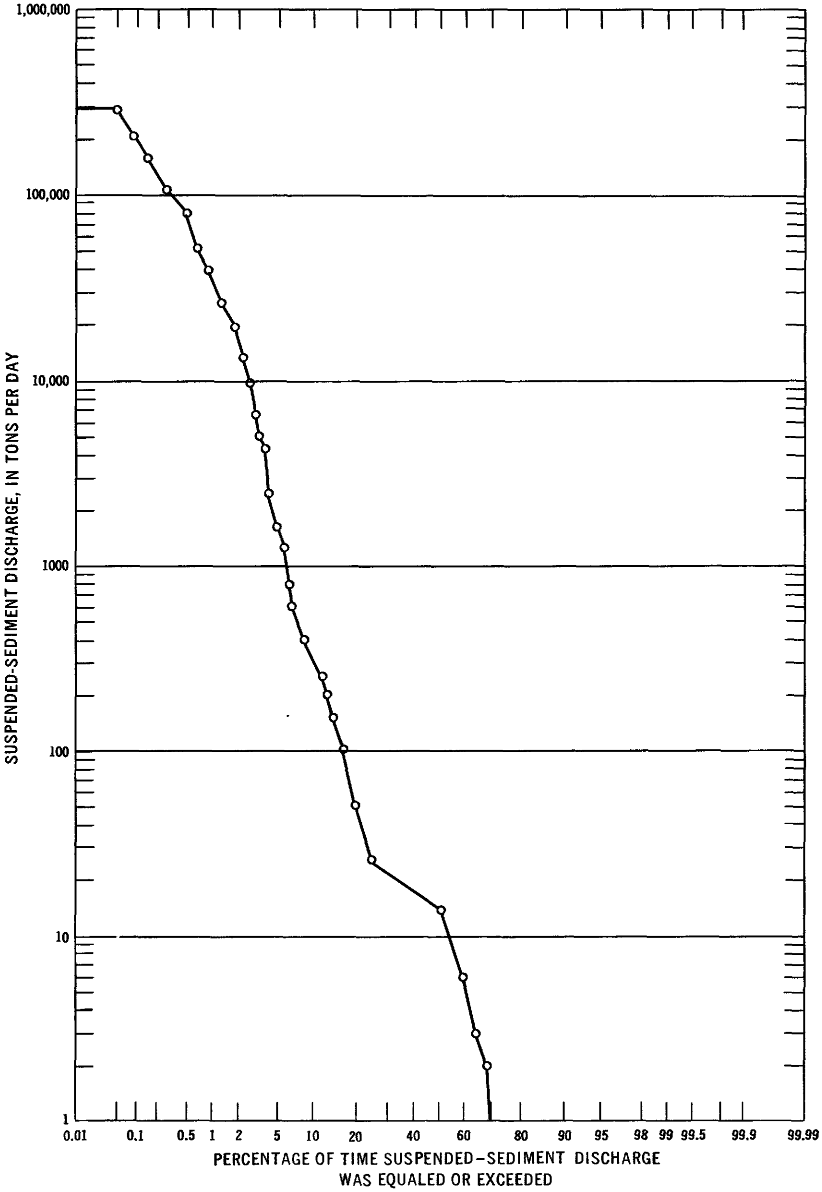

FIGURE 11. — Duration curve of daily suspended-sediment discharge of Stony Creek at Black Butte Dam for water years 1957–62.

TABLE 8. — *Concentration and particle-size distribution of suspended sediment, Stony Creek at Black Butte Dam near Orland*

[Method on analysis: V, visual accumulation tube; P, pipet; W, in distilled water; C, chemically dispersed]

Date of collection	Time (hr)	Water discharge (cfs)	Concentration of sample (mg/l)	Particle-size distribution (percent finer than indicated size in millimeters)											Median particle size (mm)	Method of analysis
				0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.00	2.00		
1957																
Dec. 16	1230	368	4,260	--	37	--	67	--	91	96	100	--	--	--	0.0074	VPWC
1958																
Feb. 18	1420	9,280	3,110	19	27	35	46	60	73	86	95	99	100	--	.0190	VPWC
Feb. 25	1420	17,200	3,440	26	37	50	58	68	78	89	95	99	100	--	.0080	VPWC
Apr. 13	0905	2,480	296	38	41	58	67	72	78	82	93	99	100	--	.0057	VPWC
1960																
Feb. 9	0805	8,060	4,190	--	31	--	60	--	81	88	83	96	99	100	.0098	VPWC
Feb. 12	1250	1,260	284	--	58	--	78	--	87	91	99	100	--	--	.0027	VPWC
Dec. 1	1720	3,090	1,970	--	49	--	76	--	91	96	100	--	--	--	.0042	VPWC
1961																
Jan. 27	1120	545	169	--	--	--	--	--	93	97	100	--	--	--	--	V
Mar. 20	1505	745	137	--	--	--	--	--	90	94	98	100	--	--	--	V
1962																
Feb. 9	1540	1,450	1,470	--	67	--	91	--	98	98	99	100	--	--	.0020	VPWC
Mar. 9	1515	1,770	272	--	--	--	--	--	75	87	99	100	--	--	--	V
Apr. 6	1210	858	93	--	--	--	--	--	91	99	100	--	--	--	--	V
Mean[1]				--	43	--	68	--	85	91	96	99	100	--	--	

[1] Analyses for Jan. 27, 1961; Mar. 20, 1961; Mar. 9, 1962; and Apr. 6, 1962, not included in mean.

deposited in East Park and Stony Gorge Reservoirs — 55 and 59 pounds per cubic foot.

Particle-size analyses of 12 suspended-sediment samples (table 8) indicate that sediment at medium to high streamflow averages about 15 percent sand, 42 percent silt, and 43 percent clay. Generally the percentage of sand increases at high flows because of higher associated stream velocities.

Average annual suspended-sediment discharge of Stony Creek at Black Butte Dam during the 1957–62 water years was 517,000 tons (table 9). Volumetrically, 517,000 tons at 58 pounds per cubic foot

TABLE 9. — *Annual suspended-sediment and water discharge of Stony Creek at Black Butte Dam, near Orland*

Water year Oct. 1–Sept. 30	Water discharge[a] (acre-ft)	Suspended-sediment		Suspended-sediment discharge[c] (acre-ft per sq mi)
		Tons	Acre-ft[b]	
1957	228,000	96,400	76	0.17
1958	1,060,000	2,360,000	1,870	4.25
1959	238,400	150,000	119	.27
1960	264,100	265,000	210	.47
1961	223,500	73,400	58	.13
1962	267,800	158,000	125	.28
Average	380,000	517,000	409	0.93

[a] Adjusted to include diversion to South Diversion Canal.
[b] Based on a specific weight of 58 lb per cu ft.
[c] Based on a drainage area of 440 sq mi.

is equivalent to 409 acre-feet, or about 0.93 acre-foot per square mile. The average annual sediment discharge for the 6-year period is probably not representative of long-term conditions because of the large quantity of sediment transported during the 1958 water year, the wettest year of record in the basin. The frequency of such a wet year has not been determined. The average sediment discharge, excluding that for the 1958 water year is 118 acre-feet per year, or 0.27 acre-foot per year per square mile. This rate is comparable to the average annual sediment deposition of 0.37 and 0.27 acre-foot per square mile for East Park and Stony Gorge Reservoirs.

BEDLOAD

Bedload includes sediment transported near or in contact with the streambed. This load could not be measured by available sampling equipment. However, an approximate range of the magnitude was determined by three methods — those of Einstein, Meyer-Peter and Muller, and Schoklitsch.

The modified Einstein method (Colby and Hembree, 1955, p. 66–113) is an empirical formula developed from studies on total sediment discharge of several alluvial streams in the midwestern United States. The equation is

$$i_B Q_B = 51{,}840 \cdot D^{3/2} \cdot w \cdot i_B \cdot \frac{\Phi^*}{2}$$

where

$i_B Q_B$ = sediment discharge through the bed layer of particles of a size class, in tons per day.

D = geometric mean diameter of a given size range, in feet.

w = effective width, in feet.

i_B = fraction by weight of bed material in a given size range.

$\frac{\Phi^*}{2}$ = intensity of bedload transport.

The Meyer-Peter and Muller bedload formula, converted to English units by the U.S. Bureau of Reclamation (1960), was developed from flume studies in Switzerland. The converted equation is

$$G_s = 1.606B\left[3.306\left(\frac{Q_s}{Q}\right)\left(\frac{D_{90}^{1/6}}{n_s}\right)^{3/2} dS - 0.627D_m\right]^{3/2}$$

where

G_s = total bedload discharge, in tons per day.

B = bottom width of the stream channel, in feet.

Q_s = the water discharge that transports a specific bedload, in cubic feet per second.

Q = total water discharge, in cubic feet per second.

D_{90} = particle size at which 90 percent of the bed material is finer, in millimeters.

n_s = Manning n value for the streambed.

d = depth of flow, in feet.

S = slope of the energy gradeline, in feet per foot.

D_m = effective size of bed material, in millimeters.

[$D_m = \frac{\Sigma D \triangle p}{100}$ where D is the geometric mean diameter of particles in a given size fraction and p is the percent by weight in that size fraction.]

The Schoklitsch bedload formula, as discussed by Shulits (1935, p. 644–646, 687), was developed from flume studies of bed material that consisted of quartz grains of uniform size. The Schoklitsch equation is

$$G=\frac{3745}{{D_{50}}^2}S^{3/2}\,Q-0.00532w\frac{D_{50}}{S^{4/3}}$$

where

G = total bedload discharge, in tons per day.
D_{50} = median diameter of the particles, in inches.
S = slope of the energy gradeline, in feet per foot.
w = width of the stream, in feet.
Q = total water discharge, in cubic feet per second.

Average annual bedload discharges were computed from each of these formulas on the basis of one composite bed-material sample, discharge measurements ranging from 300 to 36,000 cubic feet per second, and flow-duration data for the 6-year period 1957–62. The annual sediment loads determined from the modified Einstein, Meyer-Peter and Muller, and Schoklitsch formulas were 4,000, 9,000, and 30,000 tons per year, respectively. Estimated bedload ranged from 1 to 6 percent of suspended load.

Information used in estimating the bedload of Stony Creek was fragmentary, and an evaluation of applicability of the three formulas was not made; therefore, the range of values indicates only the approximate magnitude of bedload in Stony Creek.

SUMMARY AND CONCLUSIONS

Basic data collected in the upper Stony Creek basin will be useful in evaluating sedimentation characteristics for other basins in the Coast Ranges. The study was based on sediment surveys of East Park and Stony Gorge Reservoirs made in 1962 and on 54 periodic measurements of sediment discharge for Stony Creek at Black Butte Dam for the period 1957–1962.

The sediment survey of East Park Reservoir indicated only moderate sediment accumulation. Most of the sediment was deposited along the old stream channels within the reservoir. Stream channels are well defined at the upstream end of the reservoir but are completely buried by sediment at the downstream end. The average annual rate of sediment accumulation during the period 1910–62 was 0.37 acre-foot per square mile. The reservoir capacity was reduced an average of 0.07 percent per year for a capacity loss of 3.85 percent. Average composition of reservoir sediment, determined from nine core samples, was 7 percent sand, 40 percent silt, and 53 percent clay. Average specific weight of the sediment was 55 pounds per cubic foot.

Areal distribution and physical characteristics of sediment deposits in Stony Gorge Reservoir were generally similar to those of East Park Reservoir. Sediment accumulated at an average annual rate of 0.27 acre-foot per square mile during the period 1928–62. Reservoir capacity has been reduced an average of 0.11 percent per year. Loss of storage capacity as of 1962 was 3.68 percent. Average sediment composition, from four selected core samples, was 22 percent sand, 40 percent silt, and 38 percent clay. Average specific weight of deposited sediment was 59 pounds per cubic foot.

Suspended-sediment discharge of Stony Creek at Black Butte Dam averaged 517,000 tons per year for water years 1957–62. This discharge is probably not representative of the long-term average because 1958, one of the wettest years ever recorded, biases the short-term record. The quantity of sediment transported at Black Butte Dam in 1958, 2,360,000 tons, was more than three times the sediment load transported during the other 5 years 1957 and 1959–62. Average sediment yield of 0.27 acre-foot per square mile, based on the load transported during 1957 and 1959–62, probably approximates the long-term yield of Stony Creek.

Sediment transported as bedload was computed from the modified Einstein, Meyer-Peter and Muller, and Schoklitsch formulas. Average bedload, determined from these formulas, ranged from 4,000 to 30,000 tons per year during the 6-year period 1957–62. Because of insufficient data, these values are representative only of the approximate magnitude of bedload transported by Stony Creek.

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CONSTRUCTION AND HYDROLOGIC DATA FOR RESERVOIRS

EAST PARK RESERVOIR

Dam:
- Parapet elevation above mean sea level — 1,202 feet
- Crest elevation above mean sea level — 1,199 feet
- Crest height above streambed — 95 feet

Spillway:
- Crest elevation above mean sea level — 1,198.18 feet
- Flashboard height — 1.5 feet

Reservoir:
- Age (December 1910–November 1962) — 52.0 years
- Surface area at 1,198.18 feet above mean sea level — 1,707 acres
- Storage capacity:
  - 1910 — [1]46,000 acre-feet
  - 1962 — 48,940 acre-feet
- Inflow (1920–61) — 61,130 acre-feet per year
- Drainage area — 102 square miles

Sediment accumulated (1910–62):
- Total — 1,960 acre-feet
- Average per year — 38 acre-feet
- Average per year per square mile drainage area — 0.37 acre-foot
- Average specific weight — 55 pounds per cubic foot
- Average specific gravity — 2.69

Depletion of storage capacity (1910–62):
- Loss of original capacity — 3.85 percent
- Average loss per year — 0.07 percent

STONY GORGE RESERVOIR

Dam:
- Top walkway elevation above mean sea level — 847 feet
- Spillway gate elevation above mean sea level — 841 feet
- Spillway elevation above mean sea level — 821 feet
- Spillway height above streambed — 94 feet

Reservoir:
- Age (November 1928–November 1962) — 34.1 years
- Surface area at 841 feet above mean sea level — 1,274 acres
- Storage capacity:
  - 1928 — 50,000 acre-feet
  - 1962 — 48,160 acre-feet
- Inflow (1929–62)[2] — 166,100 acre-feet per year
- Drainage area — 301 square miles
- Sediment accumulated (1928–62):
  - Total — 1,840 acre-feet
  - Average per year — 54 acre-feet
  - Average per year per square mile drainage area — 0.27 acre-foot
  - Average specific weight — 59 pounds per cubic foot
  - Average specific gravity — 2.70
- Depletion of storage capacity (1928–62):
  - Loss of original capacity — 3.68 percent
  - Average loss per year — 0.11 percent

[1] Capacity of reservoir can be increased to 50,900 acre-feet by using flashboards.
[2] The reported inflow to Stony Gorge Reservoir is computed by change in storage in the reservoir and includes outflow from East Park Reservoir in addition to flow from Stony Creek.

BLACK BUTTE RESERVOIR

Drainage area	741 square miles
Unregulated drainage area	440 square miles
Average annual runoff (1948–62)	346,300 acre-feet
Average annual runoff (1957–62)	380,300 acre-feet
Suspended-sediment discharge (1957–62):	
Average per year	517,000 tons
Average specific weight	58 pounds per cubic foot

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