Fluvial Sediment in Kiowa Creek Basin Colorado

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1798-A

Prepared in cooperation with the U.S. Department of Agriculture, Soil Conservation Service

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By JAMES C. MUNDORFF

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FLUVIAL SEDIMENT IN KIOWA CREEK BASIN, COLORADO

By James C. Mundorff

ABSTRACT

The U.S. Geological Survey began an investigation of streamflow and sedimentation in 1955 and 1956, respectively, in Kiowa Creek basin, Colorado. This investigation is part of a broad program to evaluate the physical and economic effects of soil and water conservation, flood control, and sediment control.

The investigational area of 111 square miles is part of Kiowa Creek basin and is in the Colorado Piedmont section of the Great Plains province. Kiowa Creek is one of several northward-flowing streams that have source areas in the Platte River–Arkansas River divide area east of the Front Range. Altitudes range from about 7,700 feet at the headwaters to about 6,350 feet at the town of Kiowa. The surficial geologic material is mainly arkose. Native vegetation ranges from coniferous forest in much of the upstream part of the area to sparse short grass in much of the downstream part. Average annual precipitation at Kiowa is about 16.6 inches. Livestock raising is the major economic enterprise.

Since 1956, concurrent investigations of fluvial sediment and runoff have been made at K–79 Reservoir, which is in the headwaters area of Kiowa Creek; at Kiowa Creek at Elbert, which is just upstream from West Kiowa Creek; and at Kiowa Creek at Kiowa, which is about 11 miles downstream from Elbert.

From April 1956 to September 1961, about 1,880 tons of sediment was discharged from K–79 Reservoir; about 1,600 tons, or about 85 percent of the 1,880 tons, was discharged during the period July 30–August 1, 1957. Unit hydrograph analysis for this period indicates a peak rainfall intensity far in excess of the computed maximum 5-minute inflow of 5,280 cubic feet per second, or 2.6 inches per hour. Reservoir surveys made by the Soil Conservation Service and outflow records indicate that about 4.2 acre-feet of sediment was delivered to K–79 Reservoir by runoff resulting from the storm of July 30; about 2.65 acre-feet of this sediment was retained in the reservoir, and about 1.55 acre-feet was discharged from the reservoir.

Particle-size data on sediment deposited in and discharged from the reservoir indicate that the sediment delivered to the reservoir was about 3 percent gravel, 29 percent sand, 28 percent silt, and 40 percent clay. However, this particle-size distribution may not be representative of the K–79 drainage area of 3.2 square miles. All the bedload and part of the suspended sediment discharged from the upper 2 square miles of the area were probably trapped in two main-stem reservoirs upstream from K–79 Reservoir.

During 1956–61, nearly all the suspended-sediment discharge of Kiowa Creek at Kiowa was from West Kiowa Creek and from Kiowa Creek basin between Elbert and Kiowa. The drainage area of Kiowa Creek at Elbert is about 25 percent of the total drainage area of Kiowa Creek at Kiowa; however, the suspended-sediment discharge from this 25 percent of the total drainage area was less than 3 percent of the suspended-sediment discharge at Kiowa. The low discharge at Elbert compared to the discharge at Kiowa probably can be attributed mainly to the greater control of runoff by detention structures in the area upstream from Elbert. On January 1, 1957, runoff from nearly 60 percent of this area was partly controlled, whereas runoff from only about 7 percent of the rest of the basin was controlled. Computations indicate that the total sediment discharge is significantly greater than the suspended-sediment discharge for a wide range of streamflow at Kiowa Creek at Kiowa. Because flow in the narrow artificial channel at Kiowa is extremely turbulent compared to the flow in most natural channel reaches of Kiowa Creek, the ratio of suspended-sediment discharge to total sediment discharge at Kiowa may be somewhat higher than that in most of the natural channel reaches.

INTRODUCTION

An investigation of streamflow and sedimentation in Kiowa Creek basin, Colorado (fig. 1), was begun in 1955 and 1956, respectively, by the U.S. Geological Survey in cooperation with the U.S. Soil Conservation Service. This investigation is part of a broad program to evaluate the physical and economic effects of soil and water conservation, flood control, and sediment control in the area included in the Kiowa Creek Watershed Protection Project; other participating agencies are the U.S. Weather Bureau and the U.S. Agricultural Research Service. Data on runoff and sediment were obtained at selected sites to provide information on major sources of sediment, mode of sediment transport, characteristics of fluvial sediment, and effects of conservation practices on runoff and on sediment yield. As part of a national trap-efficiency investigation of detention reservoirs in "pilot watersheds," the quantity and characteristics of sediment flowing into, retained in, and discharged from K–79 Reservoir were determined.

Streamflow data have been obtained since May 1955 from Kiowa Creek at Elbert, since August 1955 from K–79 Reservoir near Eastonville, and since October 1955 from Kiowa Creek at Kiowa. Data on suspended sediment and bed material have been obtained since April 1956. This report summarizes these data to September 30, 1961.

CHARACTERISTICS OF THE DRAINAGE BASIN

The drainage area of Kiowa Creek basin upstream from the bridge on State Route 86 at Kiowa, Colo. (fig. 1), is about 118 square miles; it is about 26 miles long and is on the average about 5 miles wide. The drainage area upstream from the sediment and gaging station 0.7 mile south of Kiowa is about 111 square miles. Kiowa Creek

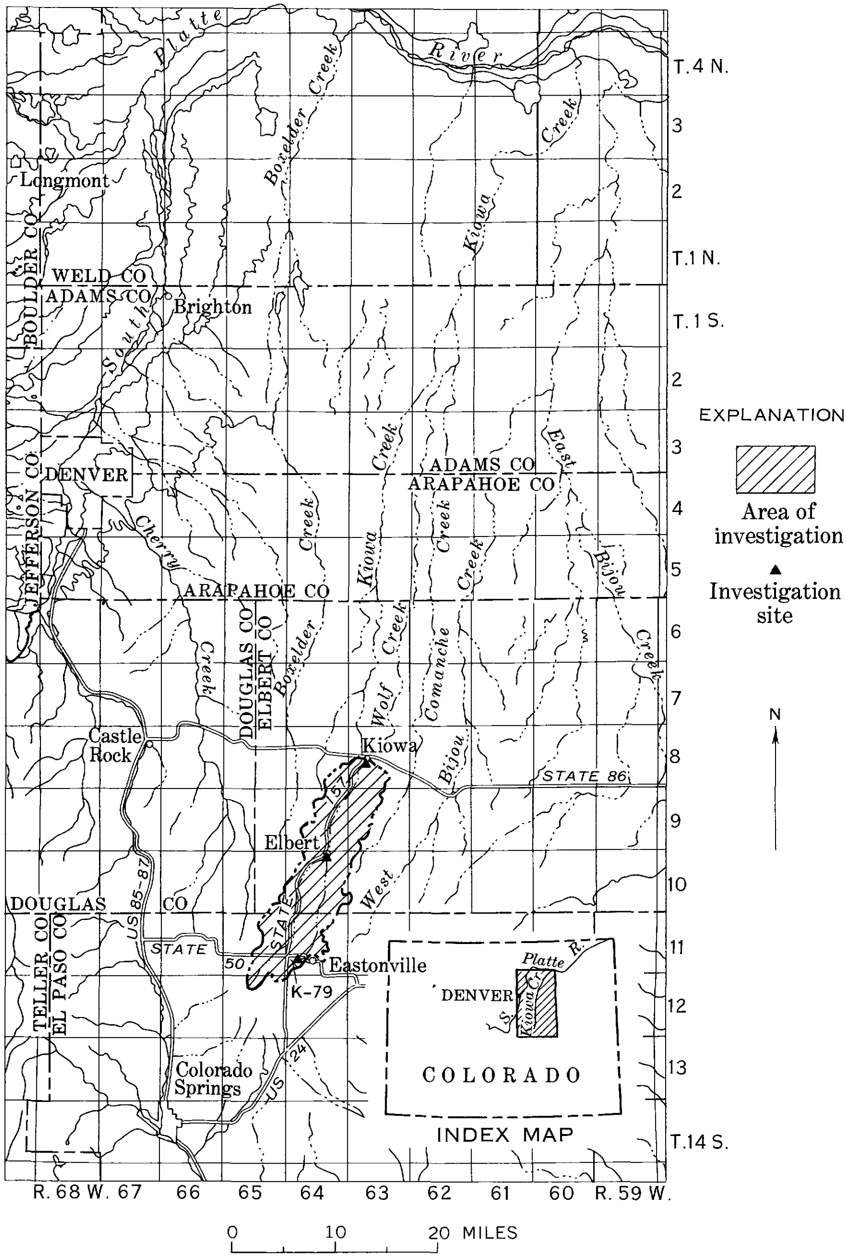

Figure 1.—Map showing Kiowa Creek basin upstream from Kiowa, Colo., and surrounding area.

basin, trending north-northeast, is about 100 miles long and has an area of about 703 square miles.

State Route 157 from Kiowa to Elbert is the only paved road in the area of investigation. No railroads are in the area; a branch line of the Colorado and Southern Railway was abandoned after being severely damaged by a major flood in 1935.

Physiographically, the area is part of the Colorado Piedmont section of the Great Plains province. Altitudes range from about 7,700 feet at the headwaters of West Kiowa Creek to about 6,350 feet at Kiowa.

Livestock was the major source of income for at least 84 percent of the farm units in 1954; beef production and dairying were of about equal importance. Cash crops, mainly wheat, were major sources of income for 16 percent of the farm units (U.S. Department Agriculture, 1959).

CLIMATE

For the period 1921–54, unofficial records indicate an average annual precipitation at Kiowa of 16.6 inches; the minimum was 6.91 inches in 1939, and the maximum was 24.04 inches in 1947 (U.S. Dept. Agriculture, 1959). For the period 1956–61, Weather Bureau records indicate that annual precipitation ranged from considerably below normal to much above normal. Most of the precipitation is the result of spring and summer thunderstorms; for any single storm, precipitation distribution is highly variable. The range in annual precipitation over the basin is likely to be considerable; the minimum and maximum reported at the different weather stations in the area for the period 1956–61 are as follows:

Year	*Minimum precipitation (inches)*	*Maximum precipitation (inches)*
1956	9. 1	13. 1
1957	19. 8	27. 3
1958	16. 9	20. 3
1959	13. 6	19. 7
1960	12. 8	18. 3
1961	16. 8	23. 9

Because altitude decreases from about 7,700 feet at the headwaters of Kiowa Creek to about 6,350 feet at Kiowa, the average number of days without killing frost varies within the basin. In most of the area however, the average frost-free growing season ranges from about 120 to 130 days.

VEGETATION AND LAND USE

Native vegetation ranges from dense stands of Ponderosa pine to sparse short grass. The percentage of land forested decreases sharply from south to north: about 70 percent is forested south of State Route

50; about 35 percent is forested between State Route 50 and Elbert; and only a very minor percentage is forested between Elbert and Kiowa. About 20 percent of the 111 square miles upstream from Kiowa Creek at Kiowa is forested. (See fig. 2.)

According to a 1954 farm survey (U.S. Dept. Agriculture, 1959), about 80 percent of the land is used for grazing. About 40 percent of the 6,840 acres of flood plain is cropland, whereas only about 16 percent of the 68,680 acres of upland is cropland. Wheat and other small grains are the main upland crops; hay and other roughage are the main flood-plain crops.

Irrigation, mainly by the sprinkler method, is used on only about 590 acres and is restricted to the valleys.

GEOLOGY

The Colorado Piedmont is underlain by rocks ranging in age from Precambrian to Tertiary; however, only two formations directly influence erosion and deposition in Kiowa Creek basin upstream from Kiowa. The Dawson Arkose, of Late Cretaceous and Paleocene age, is an arkosic sandstone and arkosic clay interbedded in some places with greenish, drab clay and shale. The Dawson Arkose is in an advanced stage of weathering. The weathering products vary considerably within very short distances both laterally and vertically. The Castle Rock Conglomerate, of Oligocene age, is of variable composition but is predominantly a conglomeratic arkose. It is covered by a variable thickness of weathering products and is commonly a resistant capping material on ridges and divides. The distribution of the Castle Rock Conglomerate and Dawson Arkose in Kiowa Creek basin upstream from Kiowa is shown on the generalized geologic map (fig. 3), on which some small outcrops are not delimited. The surface material consists of Dawson Arkose in about 60 percent of the investigational area, Castle Rock Conglomerate in about 30 percent, and alluvium of variable composition in about 10 percent.

The Dawson Arkose is the equivalent of the Denver and Arapahoe Formations of other parts of the Denver basin (Lovering and Goddard, 1950); the Dawson and its equivalents are of continental origin and were formed during the Laramide revolution. The Castle Rock Conglomerate, which had its source to the northwest, unconformably overlies the older rocks (Lovering and Goddard, 1950).

SOILS

Soils in the area have developed mainly on arkosic material in the uplands or on alluvial deposits along the major drainageways. The vegetation under which the soils developed ranges from dense conif-

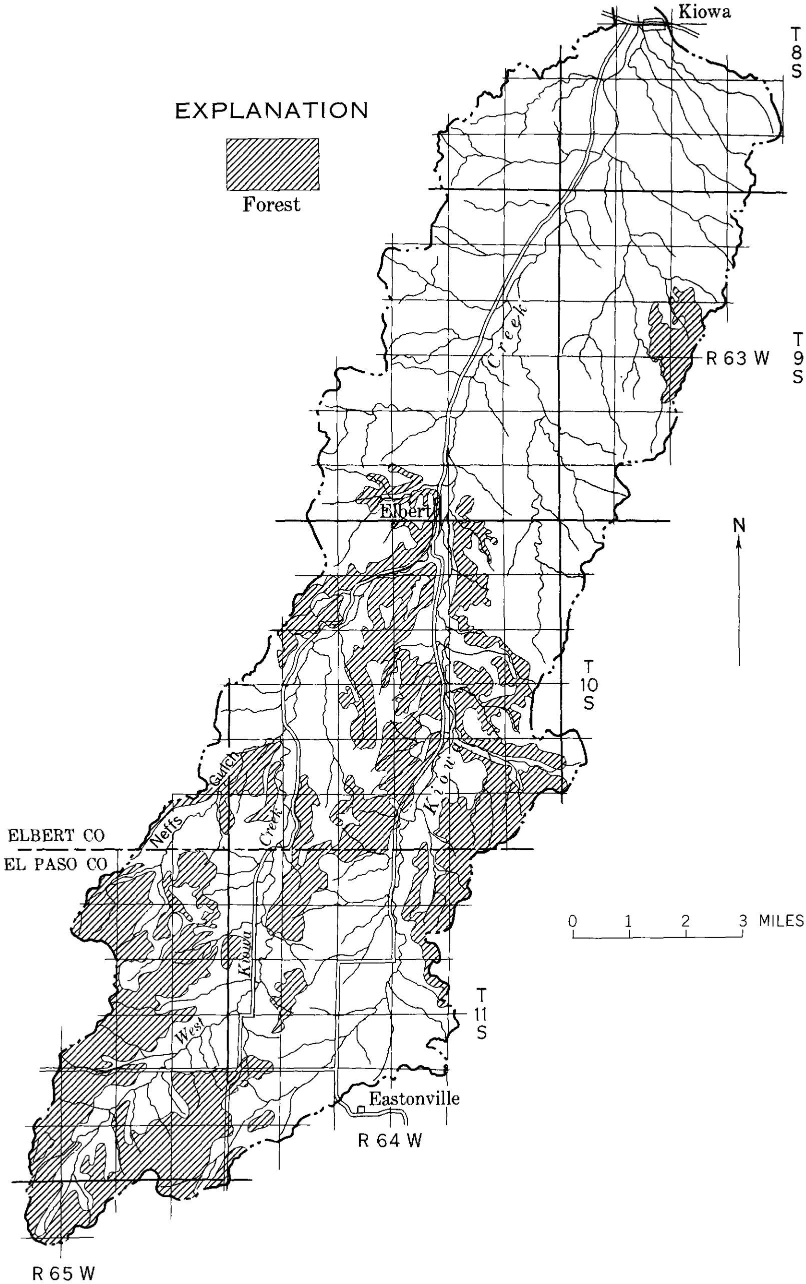

Figure 2.—Areal distribution of forest.

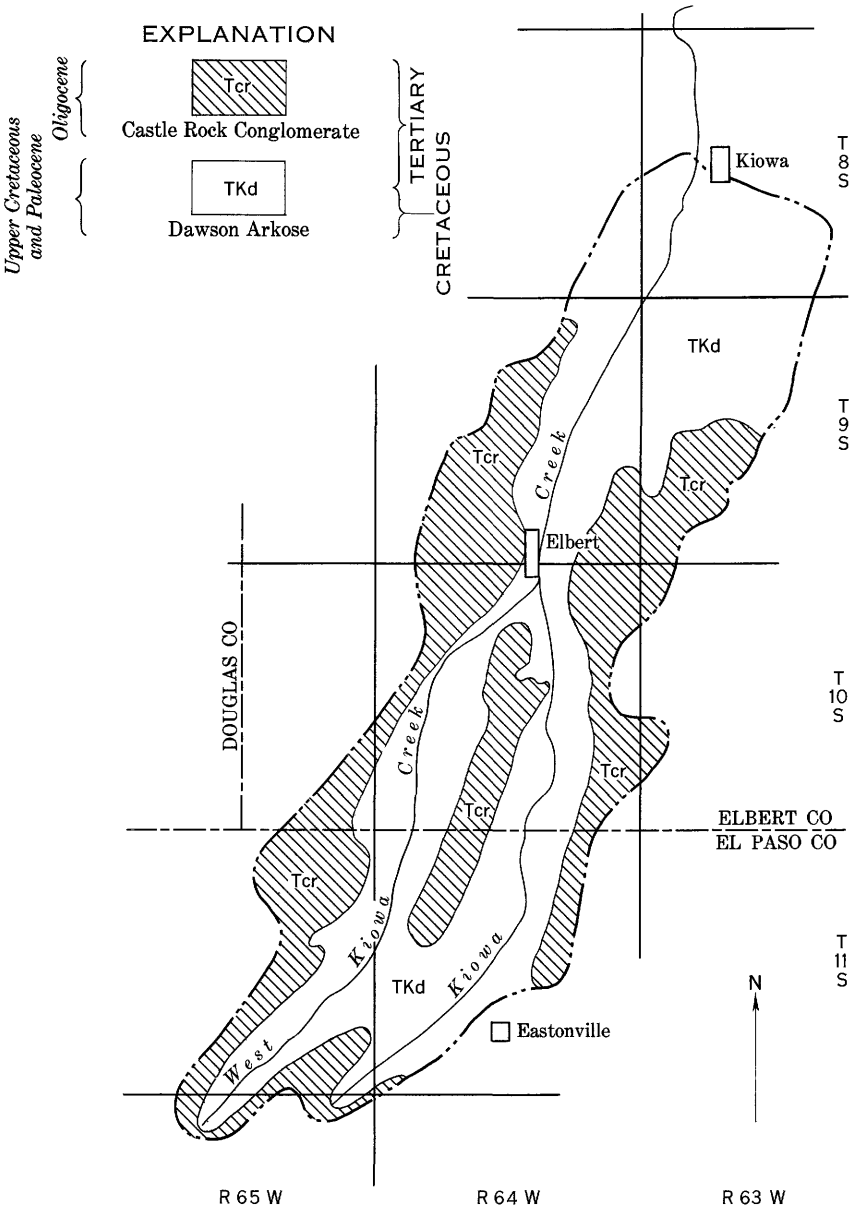

FIGURE 3.—Map showing general geology in Kiowa Creek basin. After Brown (1949) and McLaughlin (1946).

erous forest to sparse grass cover. The physiography ranges from nearly level or hummocky to rough, broken land. Variations in vegetation, soil slope, microrelief, parent material, and soil-moisture conditions result in both catenary and noncatenary complexes in the area.

Soils of the area are mainly loams and sandy loams. The Falcon gravelly sandy loam, the Pring sandy loam, and the soils tentatively correlated as Larkspur loamy fine sand, Tructon sandy loam, and Fondis loam are the dominant upland soils; Cass and Sarpy fine sandy loams are the dominant alluvial soils. These soils developed predominantly under grass cover; well-developed podzolic profiles similar to those of the Kettle series have been noted in some coniferous-forest areas. Runoff from, and erodibility of, grassland soils are moderate to high and depend on the density of vegetal cover maintained during grazing or cultivation. For a considerable part of the forest soils, the combination of surface litter, high infiltration rate, and precipitation interception by the forest cover probably results in low runoff and sediment yield.

GEOMORPHOLOGY AND PHYSICAL CHARACTERISTICS OF THE DRAINAGE

Geomorphic forms in Kiowa Creek basin upstream from Kiowa resulted mainly from the erosion of sedimentary rocks of continental origin and of Late Cretaceous and Tertiary age. A brief summary of past geologic events is necessary for an understanding of the development of the present surface.

Kiowa Creek basin is in the southeastern part of a structural depression or trough known as the Denver basin, which lies just east of the central part of the present Front Range. During the Paleozoic Era and again during the Cretaceous Period of the Mesozoic Era, sediments thousands of feet thick were deposited in this structural trough (Lovering and Goddard, 1950). During the Laramide revolution, which began in Late Cretaceous time and ended in early Tertiary time, rocks of Cretaceous age and older were tilted to an almost vertical position along the eastern margin of the Front Range but were much less steeply tilted east of the range. During this time, the Dawson Arkose and its equivalents, composed of erosional debris from the Front Range, were deposited unconformably on rocks of Cretaceous age and older in the structural trough to the east of the central part of the Front Range. A rather complex sequence of minor uplift and erosion in the Front Range area was followed by deposition of the Castle Rock Conglomerate during Oligocene time. Intermittent uplifts, some of a local nature and some on a broad regional scale, continued during the Tertiary Period. In some areas, the Castle Rock

Conglomerate has been removed by erosion, and the Dawson Arkose is the surface material; in other areas, the Castle Rock Conglomerate protects the more erodible Dawson Arkose.

Kiowa Creek is one of several northward-flowing streams that have source areas in the Platte River–Arkansas River divide area in the central part of the Colorado Piedmont and that are tributary to the Platte River in the northern part of the Colorado Piedmont. These streams are in long, narrow drainage basins. The shape of a basin can be expressed by an elongation ratio, which is defined as the ratio of the diameter of a circle having the same area as the basin to the maximum length of the basin parallel to the principal drainage line (Schumm, 1956); thus, an elongation ratio of 1.0 indicates a circular area, and progressively lower values indicate an increasing ratio of basin length to width. Table 1 shows elongation ratios computed for Kiowa Creek basin and for some other drainage basins in Colorado, Kansas, and Nebraska. Except for the first two basins shown in the table, measurements were made from small-scale maps and are only approximate.

TABLE 1.—*Elongation ratios of Kiowa Creek basin and other selected basins*

Basin	Drainage area (sq mi)	Basin length (miles)	Elongation ratio
Kiowa Creek upstream from Elbert	28.6	14	0.43
Kiowa Creek upstream from Kiowa	118	26	.47
Kiowa Creek upstream from Comanche Creek	327	65	.24
Kiowa Creek	703	95	.32
Wolf Creek	102	43	.27
Comanche Creek	148	57	.24
West Bijou Creek	323	59	.35
Bijou Creek	1,420	87	.49
Beaver Creek (northwestern Kansas)	2,060	165	.31
Sappa Creek (northwestern Kansas)	1,500	130	.34
Prairie Dog Creek (northwestern Kansas)	980	112	.32
Saline River (north-central Kansas)	3,425	200	.32
Little Blue River (central Nebraska and northern Kansas)	3,440	134	.49

The data in table 1 indicate that low elongation ratios are common, not only in the Colorado Piedmont but also in the High Plains and Plains Border physiographic sections to the east, and that basins of about the same shape develop under a wide range in climate and geology. In basins having low elongation ratios, all parts of the drainage area are close to the main stream, and subbasins are generally relatively small; thus, surface runoff reaches the main stem a short time after any given storm. Such conditions were characteristic of Kiowa Creek basin before completion of numerous control structures, which generally decrease both the peak flow and the total flow of Kiowa Creek for any given storm.

In addition to elongation ratio, other measured or computed geomorphic parameters can be used to describe a basin or the stream system within a basin. Elongation ratio, drainage density, relief ratio, and stream or basin order were obtained for selected drainage areas within Kiowa Creek basin. Drainage density is the ratio of the total length of all channels to the drainage area. Relief ratio is the ratio of the maximum relief in a basin to the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956); this dimensionless height-length ratio allows comparison of the relative relief of basins regardless of differences in scale of topography. The method described by Strahler (1952) was used to determine stream or basin order: for example, the first-order streams are the smallest, or "fingertip," channels; the second-order streams are formed by the junction of any two first-order streams; the third-order streams are formed by the junction of any two second-order streams. The geomorphic values were determined for selected areas (fig. 4) in Kiowa Creek basin. (See table 2.) Aerial photographs (scale, 3 in. equals 1 mile) are available for the entire area; 7½-minute quadrangles are available for about the upper one-fourth of the area; and a 15-minute quadrangle is available for the upper three-fifths of the area. All values shown in table 2 are subject to map inaccuracies and to lack of clarity in some aerial photographs. Values shown for subbasins J-33, Q-51, B-9, 2-K-10, and 3-D-10 do not include the parts of the drainage downstream from a major detention structure; however, values computed for the entire drainage did not differ significantly from those computed for the area upstream from the structures.

TABLE 2.—*Geomorphic values for selected parts of Kiowa Creek basin*

Drainage area	Area (sq mi)	Length (miles)	Stream order	Elongation ratio	Relief ratio	Drainage density
Kiowa Creek upstream from gaging station at Kiowa	111	25.5	7	0.46	0.0098	
Kiowa Creek upstream from Elbert	28.6	14	6	.43	.012	
West Kiowa Creek	37.1	16	6	.43	.011	
Subbasin K-79	3.20	3.1	5	.65	.021	4.34
J-33	1.12	1.5	4	.76	.036	6.02
Q-51	.59	1.0	3	.88	.039	3.90
B-9	.64	1.3	4	.69	.032	5.93
2-K-10	3.02	2.65	5	.74	.024	3.81
1-P-10	4.78	3.2	5	.77	.018	4.14
3-D-10	7.84	5.75	6	.55	.016	5.25

A practical application of the relief ratio is in estimating sediment yield from any region. Schumm (1956) states that form, or geomorphic character, of a drainage basin, and even rates of erosion, may be predicted from the relief ratio, which, in turn, is probably related to lithology, structure, vegetation, and climate. Once the characteristic regression trend has been established for a region, areas of high potential sediment yield can be selected from topographic maps

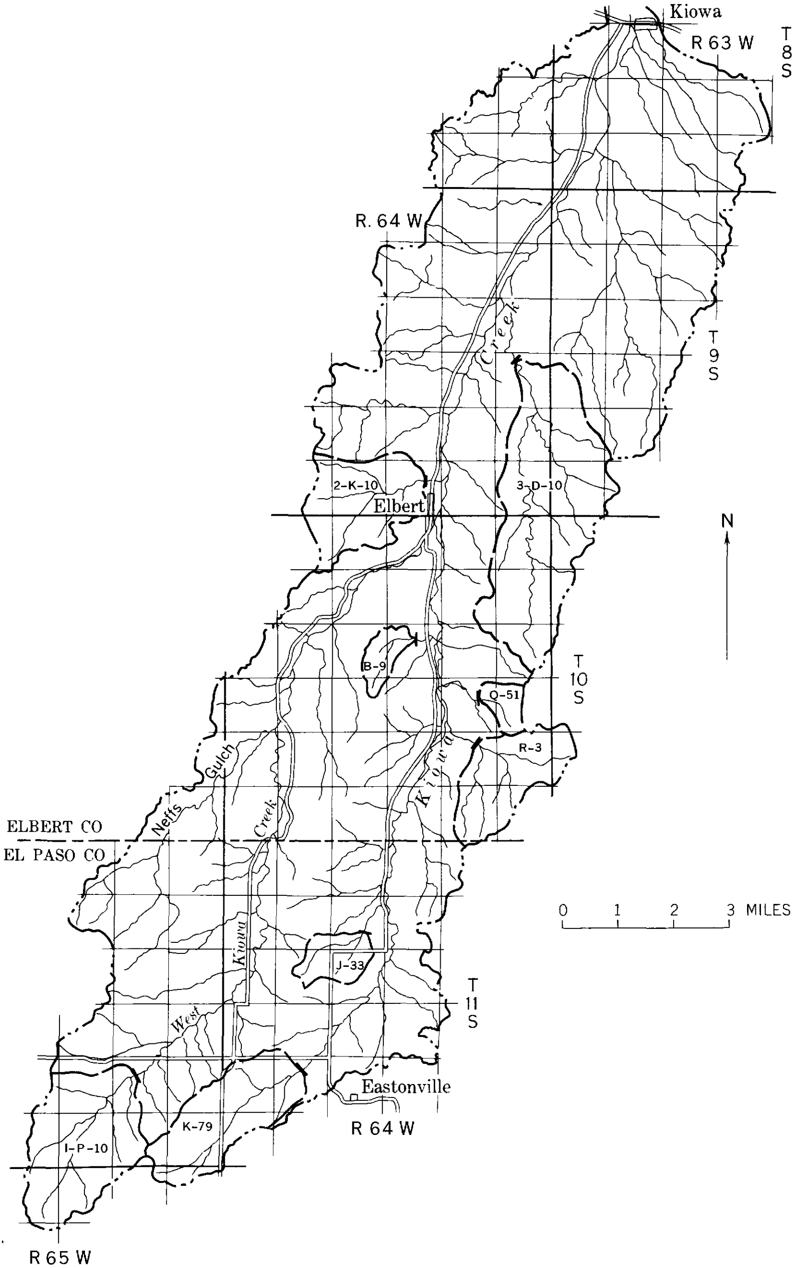

FIGURE 4.—Location of subbasins in Kiowa Creek basin upstream from Kiowa, Colo.

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(Schumm, 1955). Of the subbasins listed in table 2, sediment yields from 2–K–10, 3–D–10, J–33, and the downstream half of K–79 are estimated to be high. The estimate is based on type and density of vegetal cover, on land-use intensity, on relief ratio, and on drainage density.

Sufficiently detailed geologic and hydraulic information is not available to evaluate and interpret variations in channel characteristics of Kiowa Creek upstream from Kiowa. Channel widths differ greatly; on both West Kiowa Creek and Kiowa Creek upstream from Elbert, widths of less than 100 feet to about 500 feet were measured from aerial photographs. On Kiowa Creek between Elbert and Kiowa, channel widths range from about 100 to 550 feet.

Neither Kiowa Creek nor most of its tributaries have particularly sinuous channels. Channel sinuosity, defined as the ratio of channel length to valley length, was computed for Kiowa Creek and some tributary channels. Because thalweg length could not be determined accurately from the aerial photographs, channel length was measured along the centerline of the channel. From Kiowa Creek at Kiowa to the mouth of West Kiowa Creek at Elbert, the channel sinuosity is 1.10; for Kiowa Creek upstream from West Kiowa Creek, 1.07; for West Kiowa Creek, 1.21; and for subbasin 3–D–10, 1.29. The highest sinuosity observed in the basin was 1.57 for a 2½-mile reach of channel in the central part of subbasin 3–D–10. Leopold and Wolman (1957) arbitrarily assign a sinuosity of 1.5 as the division point between nonmeandering reaches and meandering reaches; if the sinuosity exceeds 1.5, the stream is regarded as meandering. Therefore, most of the main channels in Kiowa Creek basin upstream from Kiowa are classed as straight to slightly sinuous.

The average gradient of both Kiowa Creek and West Kiowa Creek is about 40 feet per mile. Figure 5 shows the long profiles of Kiowa Creek from the headwaters to the gaging station at Kiowa and of West Kiowa Creek and selected tributaries; topographic maps were not available for about 5 miles of channel just upstream from Kiowa. Vanoni (written commun.) found that the average slope of an 8,000-foot reach of Kiowa Creek channel about 3 miles south of Elbert was about 41 feet per mile. The upstream half of the West Kiowa Creek profile shows only minor irregularities; the lower half of the profile indicates that the channel descends to the confluence with Kiowa Creek in a series of long, sloping steps. The profile irregularities on West Kiowa Creek are apparently independent of tributary confluence areas but may be attributed to geologic controls. The profile irregularities on Kiowa Creek are neither so pronounced nor so regular as those on the lower part of West Kiowa Creek.

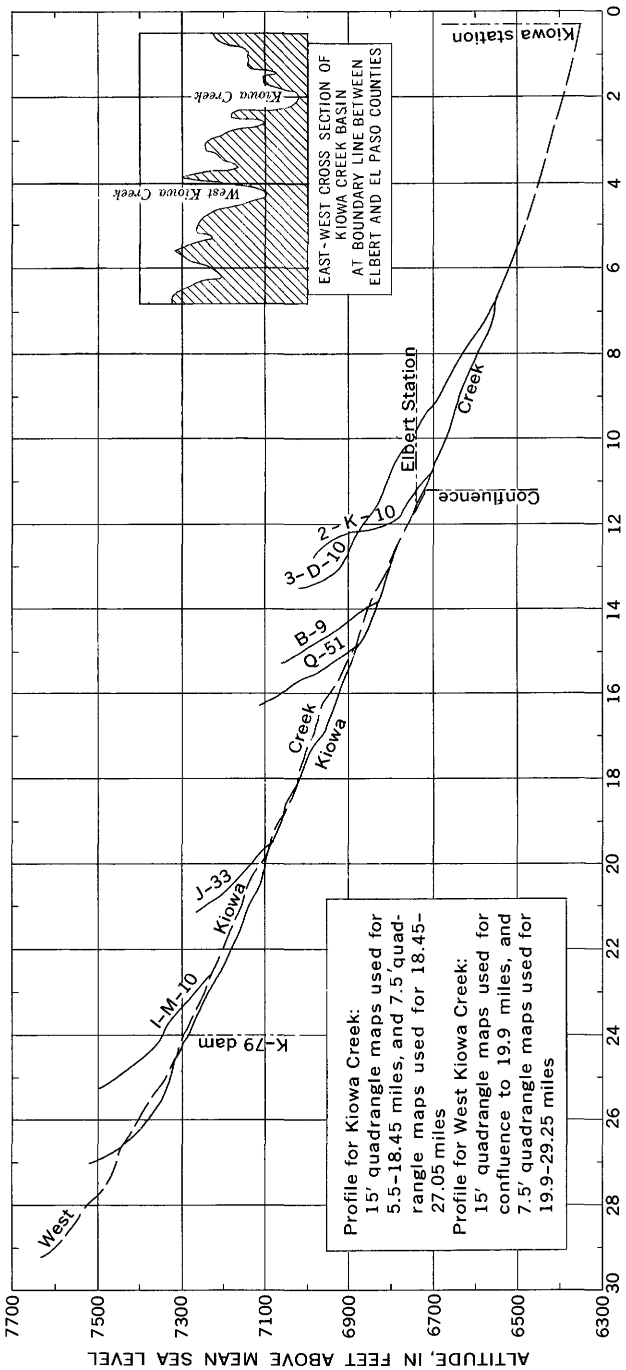


FIGURE 5.—Transverse basin profile and long profiles of Kiowa Creek and some selected tributaries.

Figure 5 also shows an east-west cross section of Kiowa Creek basin at the Elbert–El Paso County line. This cross section, constructed to the same horizontal and vertical scale as the stream profiles, is indicative of the steep slopes common in Kiowa Creek basin. The maximum slope in the area, however, may be greater than that indicated in figure 5 because the cross section does not necessarily cross the slopes at right angles to the contour lines.

FLOODS ON KIOWA CREEK

By CLIFFORD T. JENKINS

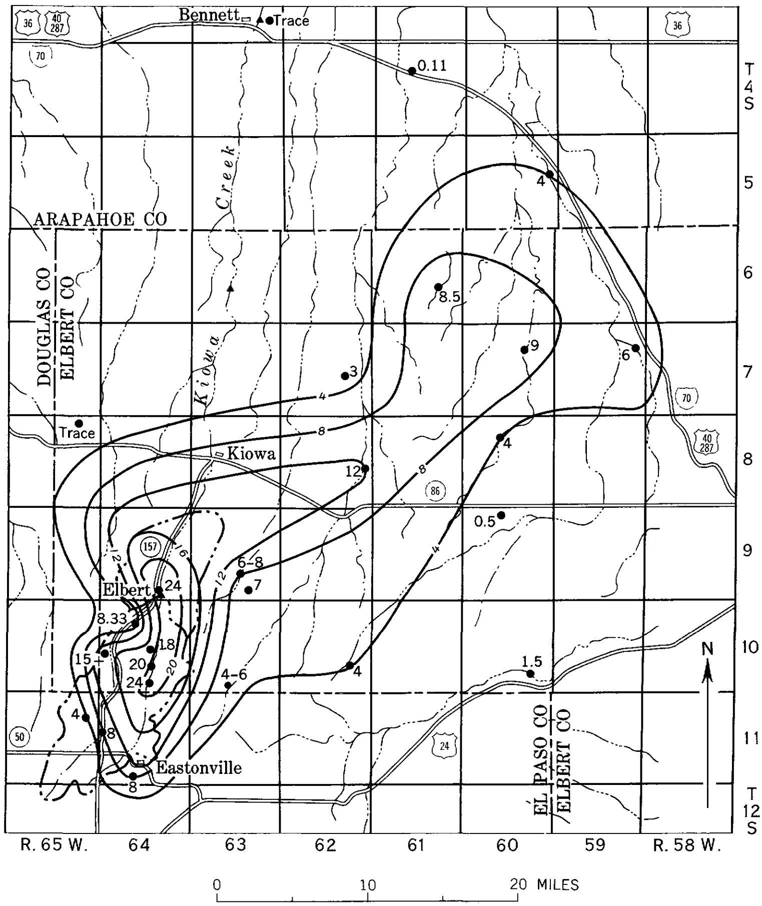
FLOOD HISTORY

Systematic collection of streamflow records in the Kiowa Creek basin began in 1955; however, fragmentary data for floods and rainfall in two earlier years, 1878 and 1935, are contained in a report by Follansbee and Sawyer (1948). A recent major flood on the headwaters of Kiowa Creek occurred on July 30, 1957.

The flood of May 21, 1878, washed out a railroad bridge near Bennett, Colo., but no quantitative data are available. Before the washout was discovered, a standard-gage locomotive and several freight cars plunged into the "swirling torrent of water." After the flood, a search was made for the locomotive, but it was never found (Follansbee and Sawyer, 1948, p. 68). No estimates have been made of the peak discharge of this flood, but it was obviously a major one.

The flood resulting from the storm of May 30–31, 1935, was investigated by personnel of the Geological Survey and of the Office of the Colorado State Engineer in June 1935. Information on rainfall was collected, and indirect measurements of peak discharge were made on Kiowa and Bijou Creeks. The isohyetal map of the storm (fig. 6) is based on the data from Follansbee and Sawyer (1948, p. 70). Estimates of peak discharge were made at three points on Kiowa Creek. (See fig. 6.) At Elbert, downstream from West Kiowa Creek, the discharge was estimated as 43,500 cfs (cubic feet per second); at the site 21 miles downstream, 110,000 cfs; and near Bennett, 75,300 cfs. The drainage areas affected by storm were 60, 190, and 266 square miles, respectively; however, figure 6 shows that only parts of the drainage areas were affected by the most intense part of the storm. The values of peak discharge are estimates and, to quote the Colorado State Engineer (Follansbee and Sawyer, 1948, p. 71), "'* * * appear to be incredible and entirely beyond anything which has ever occurred in Colorado or adjacent areas * * *.'" Undoubtedly, the flood of 1935 was the largest flood on Kiowa Creek since about 1860.

The largest flood in the Kiowa Creek basin since 1955, which resulted from the storm of July 30, 1957, was on Kiowa Creek at K–79 Reservoir near Eastonville, Colo. (drainage area, 3.20 sq mi). Precipitation ranged from 0.1 to 0.6 inch on 10 of the 12 days immediately preceding the storm. Unfortunately, there are no records of rainfall intensities during the storm. The isohyetal map of the storm, esti-



EXPLANATION

Isohyetal contour, showing precipitation, in inches	Point of observed rainfall in inches	Point of estimated peak discharge for drainage area shown by dashed line

FIGURE 6.—Isohyetal map of storm on May 30, 1935.

mated from the only data available, is shown in figure 7. From figure 7, the average total rainfall on the watershed is estimated as 3½ inches. According to available information, the storm began at 5:30 p. m. and lasted about 45 minutes. The estimated-inflow hydrograph, shown on plate 1, is based on change in contents of K–79 Reservoir and on outflow through rated spillways. Because of uncertainties due to

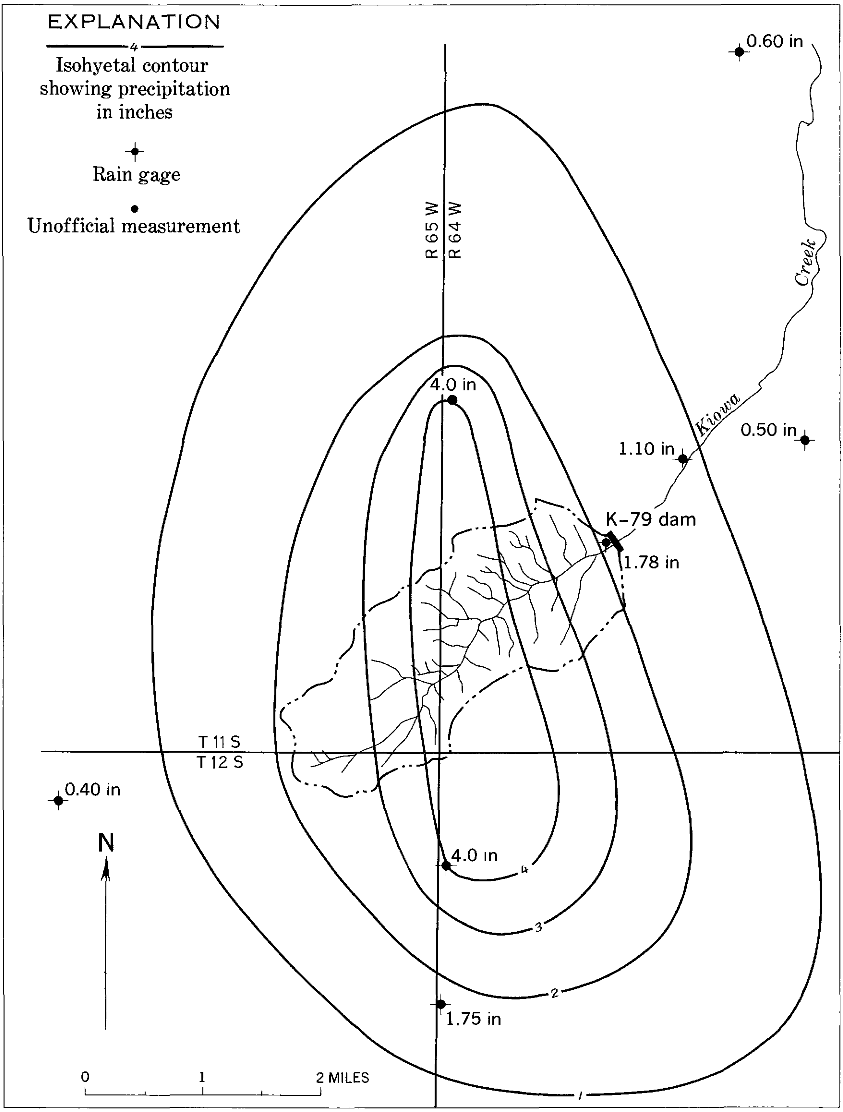


FIGURE 7.—Isohyetal map of storm on July 30, 1957.

extremely rapid change in contents of the reservoir, any one point on the hydrograph may be considerably in error. The computed maximum 5-minute inflow of 5,280 cfs is to be regarded merely as the best estimate that can be made with the instrumentation provided. The total inflow into K–79 from the beginning of the flood to 11:00 p. m., when inflow had dropped to 2.4 cfs, was 262 acre-feet, which represents a depth of runoff of 1.53 inches from the watershed. Two small reservoirs are upstream from K–79. Their capacities, and their contents before the flood of July 30, 1957, are not known. Neither structure failed during the flood; thus, any effects they may have had on inflow to K–79 would have been to attenuate the peak and to reduce the quantity. Their effects were probably negligible.

COMPARISON OF FLOODS OF 1935 AND 1957

There are indications that the flood of July 30, 1957, on Kiowa Creek at K–79 Reservoir was comparable, in terms of recurrence interval, to the 1935 flood at Elbert and at the site 21 miles downstream and that it may have been greater than the 1935 flood at the site of K–79 Reservoir.

Studies that have been made in other States and in other parts of Colorado of the relation between magnitudes of floods of given recurrence intervals and sizes of contributing drainage basin frequently have produced regional relations of the form $Q=C(A)^x$, where Q is the discharge, in cubic feet per second, of the flood of the given recurrence interval; C is a measure of the recurrence interval of the discharge Q; A is size of contributing drainage basin, in square miles; and x is an exponent, usually ranging between 0.6 and 0.8. If such a relation is valid in the Kiowa Creek basin and if x is assumed to be 0.7, the value of the coefficient C for the flood of 1935 at Elbert is 2,480, and at the site 21 miles downstream, 2,790. The value of C for the flood of July 30, 1957, on Kiowa Creek at K–79 Reservoir is 2,370. Data are insufficient to estimate the recurrence intervals corresponding to the computed values of C; however, they are very large and are of the same order of magnitude. Figure 6 indicates that the watershed upstream from the reservoir was not subjected to the most intense part of the storm; therefore the recurrence interval and the value of C for the flood of 1935 probably were smaller at the reservoir site than at Elbert or at the site 21 miles downstream. If the value of C at the reservoir site in 1935 was much less than that at the two downstream sites, then the peak discharge at the reservoir site was less in 1935 than in 1957.

The effect of storage in K–79 Reservoir on the flood of July 30, 1957, reduced the peak outflow to 1,480 cfs, and the resulting peak at Elbert was only 211 cfs. However, even without effect of storage in K–79 Reservoir, water storage in the channel and water seepage from the channel would have resulted in a substantial reduction of the peak flow, and the flood would not have been a major one at Elbert. If there had been no gaging station at K–79 Reservoir in 1957, there would have been little evidence that a flood comparable to the largest known had occurred in the headwaters of Kiowa Creek.

The basis for comparison between the floods of 1935 and 1957 is tenuous and is unsupported by data from Kiowa Creek and similar streams, but the indications are that it is quite possible for an extremely large flood from a small ungaged part of a drainage basin to be unnoticed, even though parts of the same basin are gaged.

RUNOFF-RAINFALL RELATIONS, FLOOD OF JULY 30, 1957

The ratio, 0.44, between total runoff and total observed rainfall for the storm of July 30, 1957, on watershed K–79 is rather high for semiarid areas; but because the watershed had appreciable antecedent precipitation and because the storm was of very short duration, the high ratio is not sufficient evidence to question the estimated total rainfall (fig. 7). Inconclusive studies of the shape of the inflow hydrograph at K–79 Reservoir, however, indicate that the maximum rate of rainfall was far in excess of the average rate, which was estimated by the Soil Conservation Service to be as much as about 6 inches per hour at the centroid of the basin. Further study of small-area hydrology will give additional insight on the relation between rainfall rates and the shapes of resulting flood hydrographs.

RECORDS AT GAGING STATIONS

Continuous records of streamflow and of reservoir stages have been collected on Kiowa Creek and on subwatersheds of the basin since 1955. (See table 3.) On the four subwatersheds J–33, R–3, Q–51, and B–9 (see fig. 4), flows have been so small that satisfactory records of discharge have not been computed. Numerous measurements of inflow, all less than about 9.40 cfs, have been made at the four structures. Parshall flumes were installed below structure B–9 on May 12, 1959, below structure Q–51 on May 19, 1959, and below structure J–33 on May 25, 1959.

Hydrographs for selected runoff periods are shown on plate 1 for inflow to K–79 Reservoir, for outflow from K–79 Reservoir, for Kiowa Creek at Elbert, and for Kiowa Creek at Kiowa.

TABLE 3.—*Gaging stations in Kiowa Creek basin*

Stream or subwatershed and location	Drainage area (sq mi)	Date established	Type of record obtained
Kiowa Creek at K-79 Reservoir, near Eastonville	3.20	July 20, 1955	Inflow, outflow, and stage.
J-33 near Eastonville	1.12	June 6, 1956	Stage and measurements.
R-3 near Elbert	2.82	June 20, 1956	Do.
Q-51 near Elbert	.59	Apr. 17, 1957	Do.
B-9 near Elbert	.64	Nov. 28, 1955	Do.
Kiowa Creek at Elbert	28.6	May 3, 1955	Stage and discharge.
Kiowa Creek at Kiowa	111	Nov. 28, 1955	Do.

FLUVIAL SEDIMENT

The sediment load of streams can be divided into two general classes: bedload and suspended load. Bedload is the sediment that moves along in almost continuous contact with the streambed. Suspended sediment is the sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid. From depth-integrated samples collected with standard samplers, the suspended-sediment concentrations, in parts per million by weight, were determined in the laboratory. Particle-size distribution of the suspended sediment was determined by standard methods based on the fall velocity of the particles.

The suspended-sediment concentrations were plotted on the gage-height chart, and a smooth curve was drawn through the plotted points; the mean daily concentration was determined from this curve. Daily suspended-sediment discharges, in tons, were computed by multiplying daily mean concentrations by daily mean water discharge and by a constant. On days when both concentration and water discharge were changing rapidly, each day was divided; sediment discharges that had been computed separately for parts of the day were totaled for the daily discharge.

Samples of bed material were collected periodically, and particle-size distribution of the material was determined by standard methods. Data on bed material, as well as data on suspended sediment, are utilized in the computation of total sediment discharge of a stream.

Three sites were selected for the investigation of fluvial sediment in Kiowa Creek basin. These sites are K-79 Reservoir in the headwaters area of Kiowa Creek; Kiowa Creek at Elbert, which is just upstream from the confluence of Kiowa Creek and West Kiowa Creek; and Kiowa Creek at Kiowa. (See fig. 1.)

The suspended-sediment discharge of a stream depends on the physical characteristics of the drainage basin and on the hydraulic characteristics of the stream. Precipitation intensity-duration relations,

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erodibility of the surface material, vegetal cover, and steepness of land slopes affect the quantity of sediment delivered to channels. Water discharge, slope, turbulence, water temperature, and particle size of available material affect the suspended-sediment discharge of the stream. In Kiowa Creek basin, precipitation is commonly of high intensity and short duration, land slopes are generally moderate to steep, surface material is generally easily eroded, and vegetal cover ranges from rather dense coniferous forest to sparse grass and cultivated land. Channel slopes average about 40 feet per mile on Kiowa Creek; slopes are as much as 200 feet per mile on tributary channels.

Standard suspended-sediment samplers collect samples integrated from the water surface to about 0.4 foot above the streambed; the concentration of these samples is used to compute the suspended-sediment discharge. The difference between the computed sediment discharge and the total sediment discharge is usually significant on streams such as Kiowa Creek, which have steep slopes, high flow velocities, and sand beds.

SUSPENDED SEDIMENT—K–79 RESERVOIR

At K–79 Reservoir, samples of the water-sediment mixture discharged from the reservoir are obtained at the downstream end of the outflow tube. (See fig. 8.) The entire depth of water in the tube can be sampled with standard samplers; therefore, the observed concentration is representative of the water-sediment mixture discharged from the reservoir. Except for a period of about 4 hours on the evening of July 30, 1957, when the reservoir discharged through both the outflow tube and the open emergency spillway, the reservoir has discharged only through the tube. Automatic single-stage samplers near the drop-inlet structure in the reservoir (fig. 9) obtained samples during rising reservoir stages, and automatic single-stage samplers in two main inflow channels obtained samples during rising stream stages.

Table 4 is a summary of all significant-outflow periods at K–79 Reservoir from April 1956 through September 1961. These outflow events represent about 90 percent of the runoff for the period and probably nearly 100 percent of the sediment discharge for the period. Of the total sediment discharge of about 1,880 tons during this period, 1,600 tons, or about 85 percent of the total, was discharged during the single runoff event of July 30–August 1, 1957. Figures 10 and 11 show the relation between reservoir stage and sediment concentration of outflow during selected rises in stage in the reservoir.

FIGURE 8.—Outflow tube at K–79 Reservoir near Eastonville, Colo.

FIGURE 9.—Automatic samplers, drop inlet, and stage recorder at K–79 Reservoir near Eastonville, Colo. Pikes Peak in background.

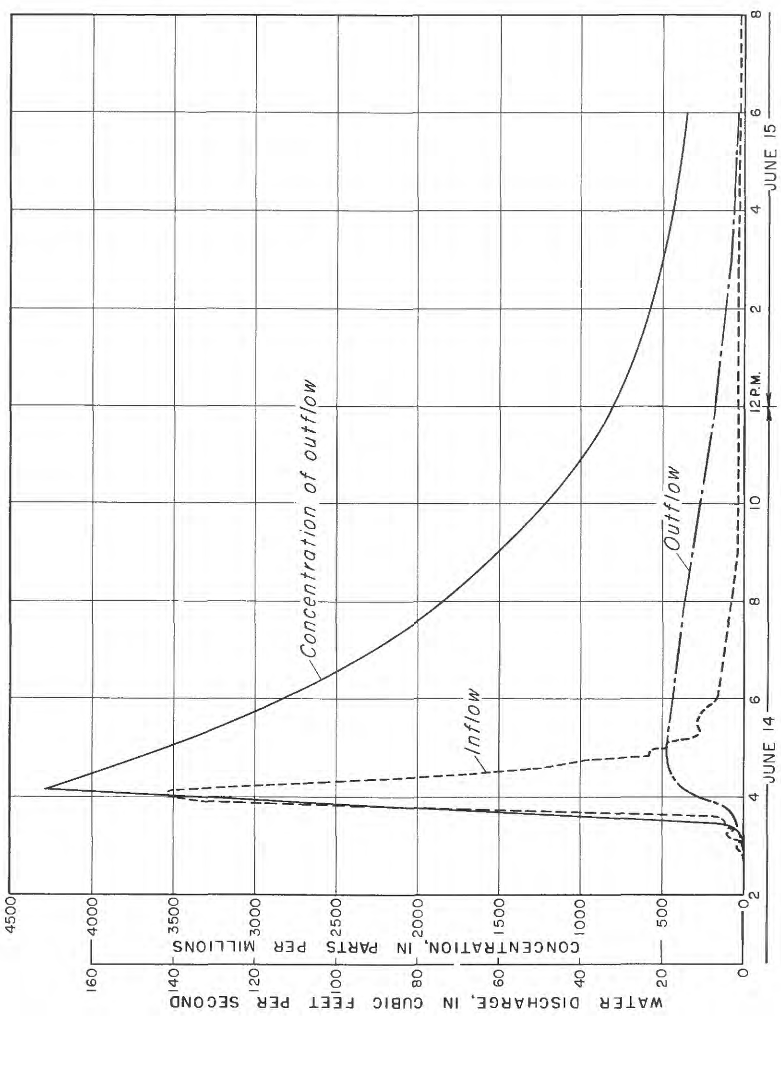

FIGURE 10.—Hydrographs and suspended-sediment concentration curve, K-79 Reservoir, June 14–15, 1957.

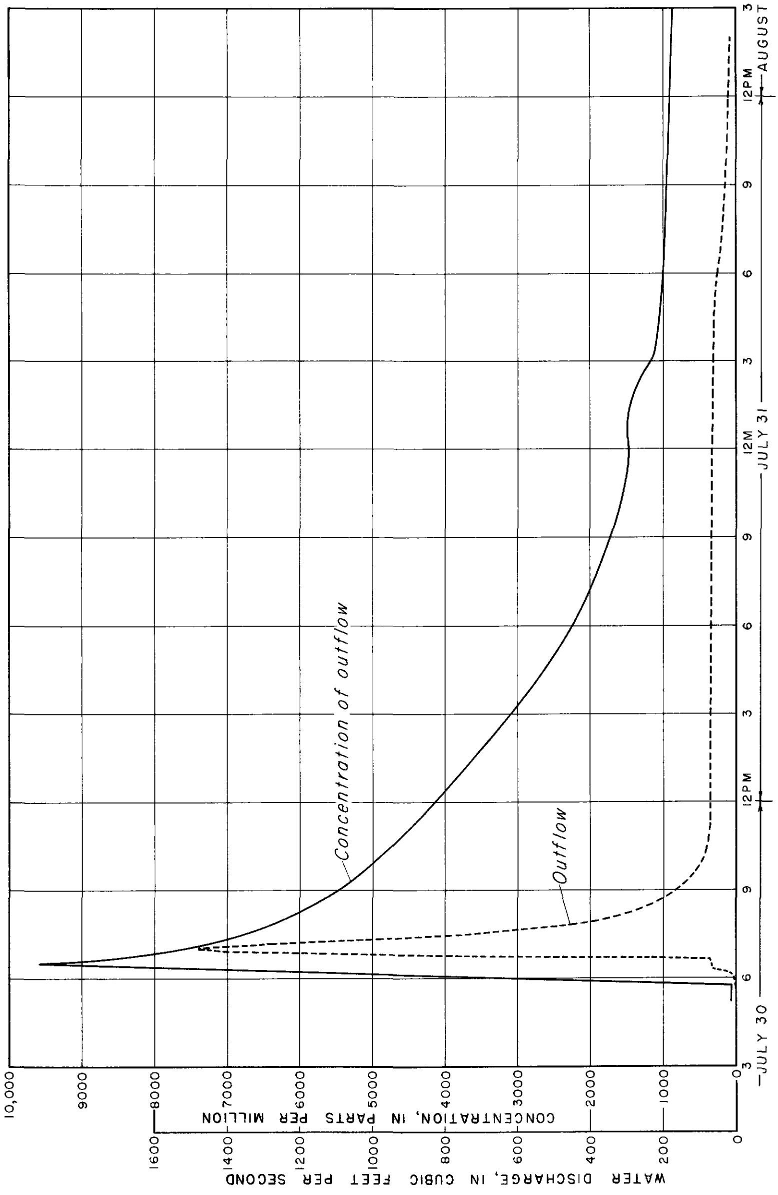

FIGURE 11.—Hydrographs and suspended-sediment concentration curve, K-79 Reservoir, July 30–August 1, 1957.

TABLE 4.—*Summary of significant-outflow periods at K–79 Reservoir*

Date	Water discharge (cfs-days)	Water discharge (acre-feet)	Weighted mean concentration (ppm)	Maximum concentration (ppm)	Sediment discharge (tons)
1956					
June 8	0.20	0.4	2,220	4,130	1.2
June 27–28	.60	1.2	1,360	2,000	2.2
July 16–17	4.0	7.9	2,270	5,000	24.5
Aug. 1–2	2.1	4.1	1,600	4,800	9.1
1957					
May 18–19	1.7	3.4	205	600	.94
May 31–June 1	.6	1.2	216	500	.35
June 14–15	5.9	11.7	1,910	4,300	30.4
July 10–11	6.8	13.5	1,510	7,000	27.8
July 20	.6	1.2	1,230	3,000	2.0
July 23–24	3.0	6.0	1,570	4,100	12.7
July 25–26	1.2	2.4	710	2,100	2.3
July 29–30	1.1	2.2	1,310	3,400	3.9
July 30–Aug. 1	136	270	4,360	9,600	1,600
Aug. 6–7	2.8	5.6	1,650	4,200	12.5
Aug. 28	.5	1.0	1,110	2,600	1.5
Oct. 16–20	.5	1.0	74		.1
1958					
Mar. 1–20	2.0	4.0	37		.2
Mar. 21	4.0	7.9	407	1,460	4.4
Mar. 22	1.5	3.0	790	1,680	3.2
Mar. 23–31	1.2	2.4	154		.5
Apr. 1–May 9	8.3	16.5	134		3.0
May 10–14	.7	1.4	159		.3
May 15–16	.9	1.8	617	1,290	1.5
May 17–June 7	2.6	5.2	28		.2
July 19–21	3.6	7.1	741	1,350	7.2
July 25–27	5.4	10.7	665	1,220	9.7
Aug. 13–14	1.1	2.2	572		1.7
Sept. 9–10	6.4	12.7	856	1,410	14.8
1959					
July 16–17	9.8	19.4	1,350	2,900	35.6
Aug. 4–5	.8	1.6	324	470	.7
Sept. 9	.4	.8	278		.3
Oct. 1–31	3.3	6.5	11		.1
1960					
Mar. 22–31	40.3	79.9	519		56.5
Apr. 1–12	13.0	25.8	34		1.2
Apr. 13–30	5.6	11.1	20		.3
May 5–7	2.9	5.8	51		.4
July 2	1.5	3.0	1,040		4.2
1961					
June 1–4	1.6	3.2	162		.7
Aug. 8	.6	1.2	62		.1
Aug. 17	.8	1.6	93		.2

From April 1956 to September 1961, the discharge-weighted suspended-sediment concentration of outflow from K–79 Reservoir was about 2,200 ppm (parts per million). This is the concentration that would result if all the water discharged from the reservoir during the period were uniformly mixed with all the sediment discharged from the reservoir during the same period. If the discharge for July 30–August 1, 1957, were omitted, the weighted concentration for the period would be only about 600 ppm. For July 30–August 1, the concentration of outflow from the reservoir was about 4,360 ppm. If 4.2 acre-feet of sediment was delivered to the reservoir as a result of the storm of July 30, 1957 (U.S. Dept. Agriculture, 1959), the total sediment concentration of the inflow to the reservoir was about 17,400 ppm; this concentration includes both suspended sediment and bedload.

Figure 12 indicates that most of the sand contained in inflow to the reservoir is trapped and that suspended-sediment outflow from the reservoir is nearly all silt and clay. The particle-size distributions of suspended-sediment samples collected at K–79 Reservoir are shown in table 5.

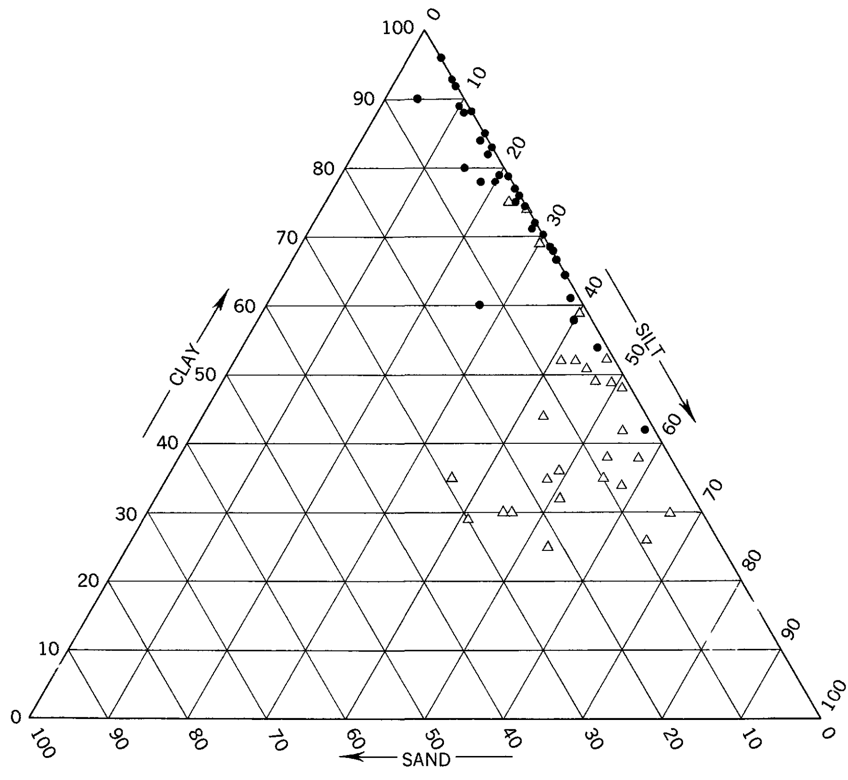

FIGURE 12.—Percentage of sand, silt, and clay in suspended-sediment samples of inflow and outflow, K–79 Reservoir. △, inflow; ●, outflow.

Annual sediment yield per square mile computed on the basis of deposition in K–79 Reservoir and on sediment discharge from the reservoir is of limited value because of other structures and reservoirs upstream from K–79. Two reservoirs have existed on the main channel upstream from K–79 Reservoir throughout the period of investigations; and in 1960, many small hydraulic structures were completed in the downstream half of the K–79 drainage area. (See fig. 13.)

TABLE 5.—*Particle-size analyses of suspended sediment in inflow and outflow, K–79 Reservoir*

[Methods of analysis: B, bottom-withdrawal tube; P, pipet; S, sieve; N, in native water; W, in distilled water; C, chemically dispersed; M, mechanically dispersed; V, visual accumulation tube]

Date	Sampling location [1]	Time	Water discharge (cfs)	Water temperature (°F)	Suspended sediment: Concentration (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size, in millimeters: 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	2.000	Methods of analysis
1956																		
June 8	1	5:00 p.m.	0.25		2,520	3,630		94		98		100						SPWCM
July 16	3	[2] 4:00 p.m.			18,100	4,160		29		52		72	79	92	99	100		SPWCM
Do	2	[2] 4:15 p.m.	[3] 3.5		4,610	4,000		61		88		99	99	100				SPWCM
Do	2	[2] 4:45 p.m.	[3] 3.5		4,030	2,660	43	52	69	85	97	99						BWCM
Do	1	6:30 p.m.	[3] 3.5		2,510	1,750	54	71	85	95	98	99						BWCM
Do	1	9:30 p.m.	[3] 3.5		1,430	1,050	66	85	95	98	99	100						BWCM
July 17	1	10:10 a.m.	.11		890	1,380	88	93	96	98	100							BWCM
Aug. 1	4	[2] 2:15 p.m.			7,860	6,130		34		65		96	99	100				SPWCM
Do	3	[2] 2:15 p.m.			10,400	2,860		44		72		90	93	98	100			SPWCM
Do	3	2:35 p.m.			7,120	4,280		51		82		97	99	100				SPWCM
Do	4	2:40 p.m.			4,050	3,060		49		90		99	100					SPWCM
Do	2	[4] 2:45 p.m.	6.3		3,950	2,600		72		98		100						PWCM
Do	1	2:50 p.m.	7.1		4,240	4,570		60		86		87	87	88	90	91	92	SPWCM
Do	3	3:15 p.m.			3,160	1,940	61	74	87	96	99	100						BWCM
Do	4	3:20 p.m.			2,160	1,340		69		98		99	99	99	100			SPWCM
Do	1	3:30 p.m.	8.0		2,290	1,760	63	78	90	96	98	98						BWCM
1957																		
June 14	4	3:25 p.m.			7,950	4,690		42		69		96	99	100				SPWCM
Do	3	3:30 p.m.			15,700	5,650	30	38	48	61	76	92	98	100				VPWCM
Do	3	3:30 p.m.			15,700	5,510	16	26	39	54	71	91	98	100				VPNM

June 14	4	3:30 p.m.			7,560	3,040	29	38	51	63	75	96	100					VPWCM
Do	4	3:30 p.m.			7,560	2,850	15	30	45	62	81	96	100					VPNM
Do	2	3:45 p.m.	3.7		2,060	1,600		88		98		99	100					SPWCM
Do	1	6:00 p.m.	17.5	43	2,850	1,640		76		95		100						SPWCM
July 10	3	3:30 p.m.			10,700	5,220	24	30	38	47	57	76	90	98	100			VPWCM
Do	2	3:35 p.m.	2.9		7,000	5,510		58		82		98	99	100				SPWCM
Do	2	4:00 p.m.	16.1		5,000	1,430	60	77	88	96	99	100						SBWCM
Do	2	4:25 p.m.	17.3		3,300	1,230	69	83	94	98	99	100						SBWCM
Do	1	5:30 p.m.	22.6	43	2,070	1,310	61	75	87	96	99	99		100				SBWCM
July 23	3	4:30 p.m.			11,700	6,460	29	36	46	58	70	85	92	98	100			VPWCM
July 30	3	5:45 p.m.			13,500	8,010	19	25	33	44	60	78	85	92	98	100		VPWCM
Do	4	5:45 p.m.			4,450	3,300	28	35	42	53	68	90	97	100				VPWCM
Do	2	5:50 p.m.	.51		6,450	5,440			54	67	82	98	100					VPWCM
Do	2	5:55 p.m.	1.7		7,000	5,020	33	42	51	64	78	99	100					SPWCM
Do	2	6:00 p.m.	3.0		8,000	3,820	36	44	52	63	80			100				VPWCM
July 31	1	9:00 a.m.	66.7	48	1,750	1,800	66	84	96	96	96	99	100					SPWCM
Do	1	9:00 a.m.	66.7	48	1,750	1,790	58	82	99	97	98	99	99	100				SPNM
Aug. 6	2	8:25 p.m.	11.0		3,900	2,450	54	68	86	97	97	100						SPWCM
1958																		
Mar. 21	1	[5]4:00 p.m.	[3]4.0		1,370	1,670	58	64		97		100						SPWCM
Do	1	9:00 p.m.	[3]4.0		597	724	74	89	96	98	98	99						BWCM
July 19	3	2:15 p.m.			1,830	1,360	55	64		88								PWCM
Do	4	2:30 p.m.			3,310	2,470	57	67		89		99	100					VPWCM
Do	1	2:55 p.m.	7.5		1,150	3,440	65	79		97		100						SPWCM
Do	1	8:00 p.m.	5.0		741	1,450	82	92		96		100						SPWCM
July 25	1	4:35 p.m.	11.0		845	2,310	65	77		96		100						SPWCM
Do	1	5:30 p.m.	11.5		1,060	1,150	69	79				100						VPWCM
Do	1	7:30 p.m.	10.0		741	810	77	85		87		100						SPWCM
Sept. 10	1	4:40 p.m.	.44		361	910	95	96		96		100						SPWCM
Sept. 26	1	9:00 a.m.	.07		149	989	51	54										PWCM
1959																		
July 16	1	2:30 p.m.	16.9	48	2,370	3,300	51	64		88		100						VPWCM
Do	1	2:45 p.m.	20.3	45	2,990	4,080	53	64		92		100						VPWCM
Do	1	3:00 p.m.	21.6	44	2,820	4,010	57	67		94								PWCM
Do	1	3:15 p.m.	22.0	43	2,640	3,320	58	68		94		100						VPWCM
Do	1	3:30 p.m.	22.1	42	2,490	3,690	59	70		96		100						VPWCM
Do	1	3:45 p.m.	21.9	43	2,230	3,230	61	71		97		100						VPWCM
Do	1	4:30 p.m.	20.2	42	2,050	2,570	63	74		96		100						VPWCM
Do	1	10:45 p.m.	[5]10.7	45	1,020	1,430	74	88		99		100						VPWCM

See footnotes at end of table.

TABLE 5.—*Particle-size analyses of suspended sediment in inflow and outflow, K–79 Reservoir*—Continued

Date	Sampling location[1]	Time	Water discharge (cfs)	Water temperature (°F)	Suspended sediment													Methods of analysis
					Concentration (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size, in millimeters											
							0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	2.000	
July 16—Con.	3	2:25 p.m.	--------	48	1,910	2,840	42	52	--------	78	--------	99	100	--------	--------	--------	--------	VPWCM
Do.	4	2:35 p.m.	--------	43	7,800	8,930	27	32	--------	47	--------	83	94	99	100	--------	--------	VPWCM
Do.	3	[2] 3:00 p.m.	--------	--------	15,400	6,520	26	30	--------	46	--------	75	81	82	82	100	--------	VPWCM
Aug. 4	5	[2] 1:30 p.m.	--------	--------	7,840	3,220	29	35	--------	49	--------	83	93	98	99	100	--------	VPWCM
Do.	4	[2] 2:30 p.m.	--------	--------	2,240	1,620	44	49	--------	70	--------	96	97	98	100	--------	--------	VPWCM
Do.	4	3:45 p.m.	--------	68	4,050	4,480	29	35	--------	49	--------	71	78	87	98	100	--------	VPWCM
1960																		
July 3	1	2:10 p.m.	3.90	[6] 34	1,700	4,380	66	79	--------	98	--------	99	100	--------	--------	--------	--------	VPWCM
Do.	4	2:17 p.m.	--------	--------	1,010	2,620	63	75	--------	93	--------	98	99	99	100	--------	--------	VPWCM
Do.	3	2:30 p.m.	--------	[6] 34	2,550	6,350	50	59	--------	82	--------	99	100	--------	--------	--------	--------	VPWCM
Do.	4	2:40 p.m.	--------	[6] 34	3,430	5,850	44	52	--------	70	--------	95	99	100	--------	--------	--------	VPCWM
Do.	1	2:50 p.m.	6.66	[6] 37	771	2,010	71	78	--------	91	--------	96	98	99	100	--------	--------	VPWCM
Do.	3	2:50 p.m.	--------	--------	8,780	6,060	44	52	--------	70	--------	93	97	97	99	100	--------	VPWCM
Do.	1	3:40 p.m.	8.14	[6] 39	1,170	2,970	70	85	--------	99	--------	100	--------	--------	--------	--------	--------	PWCM
1961																		
Aug. 8	4	4:00 p.m.	--------	--------	6,540	----	43	48	61	74	88	99	100	--------	--------	--------	--------	VPWCM

[1] See figure 2: 1, downstream end of outlet discharge tube; 2, outlet structure in reservoir; 3, Kiowa Creek about ¾ mile upstream from K–79 Dam; 4, channel of right tributary to reservoir; and 5, Kiowa Creek just donwnstream from State Route 157.
[2] Approximate.
[3] Daily mean discharge.
[4] Obtained from gage-height chart.
[5] Mean, 8:00 p.m. to 12:00 p.m.
[6] Runoff mostly from melting hail.

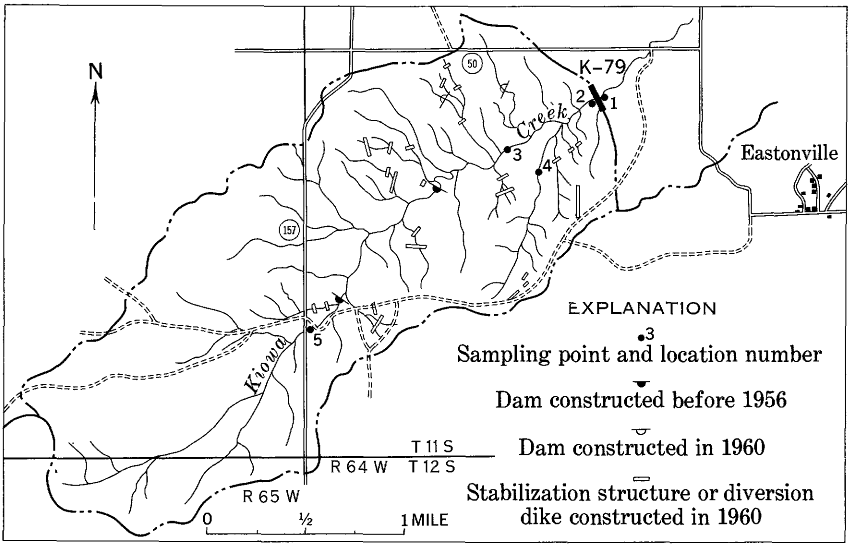

FIGURE 13.—Map of K–79 drainage basin, 1961.

The trap efficiency of the two upstream main-stem reservoirs is not known, but it is probably high. Both reservoirs have significant retention capacities; an emergency spillway is the only discharge arrangement for either reservoir, and a fairly high stage is necessary for spillage. Therefore, for all except major runoff events, these small upstream reservoirs probably have 100-percent trap efficiencies.

No observations on outflow from the upstream reservoirs are available except for the summer of 1959. Between June 1 and September 15, 1959, inflow to K–79 Reservoir was exclusively from the area between K–79 and the dam about 1 mile upstream; only about 1.2 square miles of the drainage contributed runoff and sediment to K–79 Reservoir. For example, on July 16, 1959, about 1½ inches of rain was rather uniform over the K–79 drainage area. Neither of the upstream reservoirs spilled, although significant inflow having high suspended-sediment concentration was observed. On August 4, 1959, rain was heavy in the extreme upper part of the area. The upper-reservoir discharge through the spillway was appreciable; however, the middle reservoir retained the entire discharge from the upper reservoir as well as additional inflow from the intervening drainage area. Therefore, the concentrations and particle-size distribution of samples collected at the outflow tube of K–79 Reservoir, the sediment discharge from K–79 Reservoir, and the quantity and characteristics of material deposited in the reservoir area would probably be somewhat different if the two upstream reservoirs did not exist.

In addition to the two dams that have existed on the main channel throughout the period of investigations, numerous small dams, stabilization structures, and diversion dikes were constructed in the downstream half of the K–79 drainage area during the spring and summer of 1960. Several of the structures affect runoff and sediment delivery to K–79 Reservoir from the downstream 1.2 square miles of the drainage area. Therefore, by 1961, runoff from nearly the entire drainage area was affected by structures upstream from K–79 Reservoir.

DEPOSITED SEDIMENT—K–79 RESERVOIR

K–79 Reservoir, on completion in June 1955, had a sediment-pool storage capacity of 24.3 acre-feet and a detention-pool storage capacity of 105.2 acre-feet. A resurvey of the reservoir was made by the Soil Conservation Service about 1 month after the major storm of July 30, 1957. Most of the sediment deposited in the reservoir area during the period between the original survey and the resurvey was probably deposited on July 30–31. A total of about 4.2 acre-feet of sediment was delivered to the reservoir by runoff resulting from the storm of July 30; about 2.65 acre-feet, or 63 percent of the total sediment delivered to the reservoir, was retained in the reservoir and delta, and about 1.55 acre-feet was discharged from the reservoir (U.S. Dept. Agriculture, 1959). Samples of sediment deposited in the reservoir and delta were collected September 25, 1957. The dry weight for all samples averaged 77.6 pounds per cubic foot; reservoir deposits averaged 66.9 pounds per cubic foot, and delta deposits averaged 93.6 pounds per cubic foot (U.S. Dept. Agriculture, 1959). The reservoir deposits were 1 percent gravel, 45 percent sand, 34 percent silt, and 20 percent clay; the delta deposits were about 46 percent gravel and 53 percent sand (U.S. Dept. Agriculture, 1959).

The reservoir was resurveyed in 1961, but computations were not completed at the time of this report. Subsequent resurveys may show a slight decrease in volume of deposited sediment compared to the 1957 data. Since 1957, only relatively minor inflow to K–79 Reservoir has occurred, and relatively minor amounts of sediment probably have been deposited in the reservoir. Since 1957, settling and compaction of the deposited sediment may have at least compensated volumetrically for any additional sediment that entered the reservoir. A significant amount of sediment may have been removed by erosion of the reservoir bottom. In numerous places, the reservoir bottom is significantly higher than the lowest opening in the drop-inlet structure. During periods of minor precipitation and runoff, the reservoir bottom may erode rather rapidly. Many small rills and gullies have been observed in the reservoir bottom; the largest of the gullies was 18–24 inches deep and had eroded through the deposited sediment and into the underlying geologic material.

The lower 1.2 square miles of the 3.2 square miles within the K–79 drainage area probably contributed all the gravel, nearly all the sand, and a major part of the silt and clay delivered to K–79 Reservoir. The upper half of the drainage area is mostly forested and has somewhat gentler slopes than the lower half of the area. Much of the material eroded from the upper 2 square miles of the area is probably trapped in the two main-stem reservoirs upstream from K–79 Reservoir; some of the material eroded from parts of the downstream 1.2 square miles is trapped by the structures completed in 1960. Therefore, neither the quantity nor the particle-size distribution of K–79 Reservoir deposits is necessarily representative of deposits that might have accumulated if the upstream reservoirs were not present. On the basis of particle-size data available for deposited sediment and for outflow from the reservoir, the particle-size distribution of material delivered to the reservoir area was about 3 percent gravel, 29 percent sand, 28 percent silt, and 40 percent clay. This particle-size distribution probably is representative of the total sediment discharge of the stream between the reservoir and the first dam upstream from the reservoir plus part of the suspended- sediment discharge of the stream in the upper 2 square miles of the drainage area. All the bedload discharge and part of the suspended-sediment discharge from the upper 2 square miles of the area were probably trapped in the two upstream reservoirs during 1956–59; beginning in 1960, sediment from some of the downstream area was trapped by the new structures.

Flocculation of fine sediments probably is not a significant cause of deposition in K–79 Reservoir. The runoff from the area is dilute and is not conducive to rapid flocculation. Detention time for most runoff is only a few hours. Even for the 20-foot rise of July 30, 1957, when the total inflow was 270 acre-feet, the detention time was short; more than 50 percent of the total inflow was discharged from the reservoir during the first 6 hours of the rise, and about 90 percent was discharged during the first 24 hours. Thus, the combination of dilute waters and short detention time probably prevents significant deposition caused by flocculation of sediment. A considerable part of the clay-size material in the reservoir deposits was probably transported to and deposited in the reservoir as soil aggregates or floccules of silt or sand size; during the preparation and analysis of the sample for particle-size distribution, the aggregates are destroyed, and the particles composing the aggregate become discrete.

SUSPENDED SEDIMENT—KIOWA CREEK AT KIOWA AND AT ELBERT

During periods of flow at the Elbert and Kiowa sites, suspended-sediment samples were collected with a U.S. DH–48 sampler by wading during minor stream rises and with a U.S. D–49 sampler suspended from a reel mounted on a cable car during major rises. In addition, samples were obtained with automatic samplers during major rises at both sites. Because of the lack of flow at Elbert during the past few years, the channel has become rather heavily vegetated. (See figs. 14, 15.) The investigational site at Kiowa and the stream reach downstream from the site are shown in figures 16 and 17. The gaging station and sediment station are at a cableway that spans a narrow artificial channel having nearly vertical banks. The artificial channel, about 800 feet long and on the average about 80 feet wide, was constructed to divert flow from an eroding stream meander. Figure 18 shows the general plan of the site.

FIGURE 14.—Cableway across Kiowa Creek at Elbert.

FIGURE 15.—Kiowa Creek channel upstream from cableway at Elbert.

FIGURE 16.—Kiowa Creek channel at Kiowa. Channel is about 80 feet wide in this reach. Gage house and cableway are in background.

FIGURE 17.—Kiowa Creek channel about half a mile downstream from cableway at Kiowa and immediately upstream from bridge on State Route 86.

On Kiowa Creek, maximum suspended-sediment concentration usually either precedes or coincides with maximum water discharge. Figures 19–24 show some typical stage hydrographs and suspended-sediment concentration curves for selected rises on Kiowa Creek. When maximum concentration precedes maximum water discharge, the maximum suspended-sediment discharge may also precede maximum water discharge.

The data in tables 6 and 7 indicate that very little of the water and sediment transported at Kiowa is from the part of the basin upstream from Kiowa Creek at Elbert; nearly all the suspended-sediment discharge at Kiowa is apparently from West Kiowa Creek and from Kiowa Creek basin between Elbert and Kiowa. For the period April–September 1956, the suspended-sediment discharge at Kiowa was about 64,700 tons; for the same period, Kiowa Creek at Elbert had no flow. For the 1957 water year, the water discharge at Kiowa was about 2,590 cfs-days, and the sediment discharge was about 100,000 tons; for the same period, the water discharge at Elbert was about 65 cfs-days, and the sediment discharge was about 1,360 tons. For the 1961 water year, the sediment discharge was about 3,880 tons at Kiowa and about 1.6 tons at Elbert.

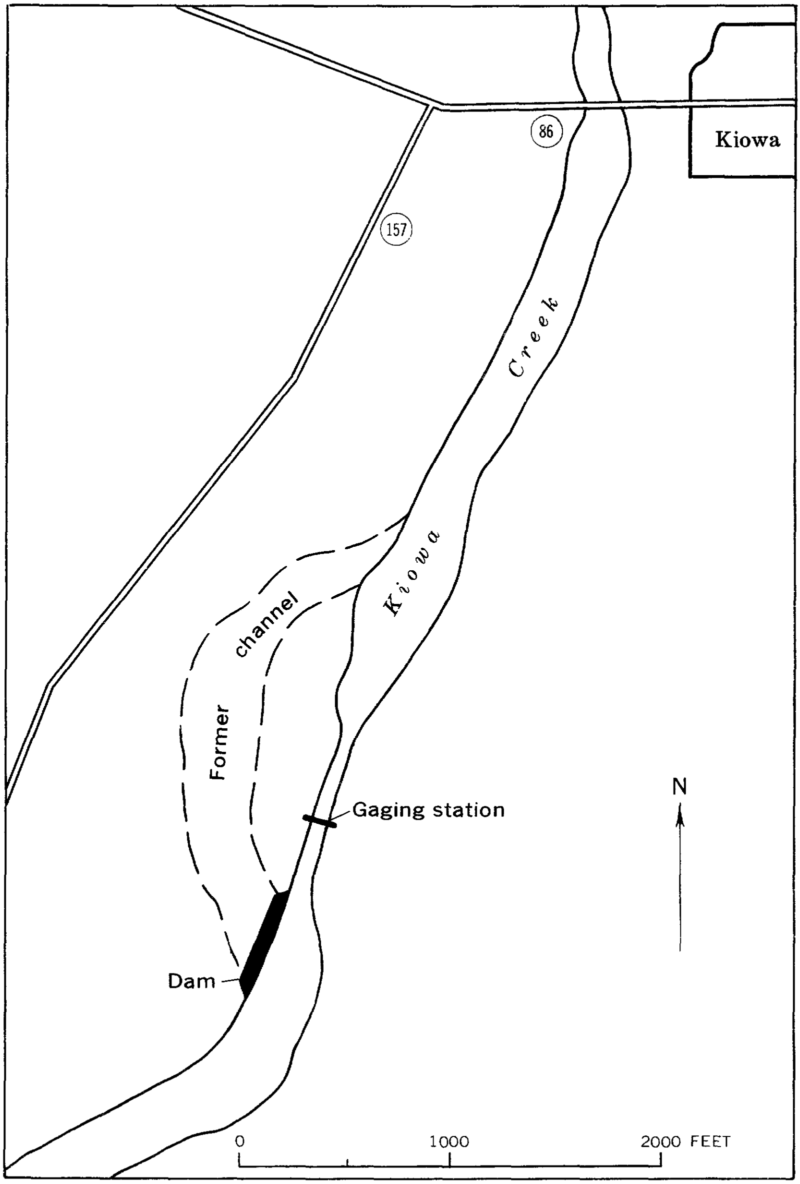

FIGURE 18.—Map showing location and general plan of Kiowa Creek in the vicinity of Kiowa, Colo.

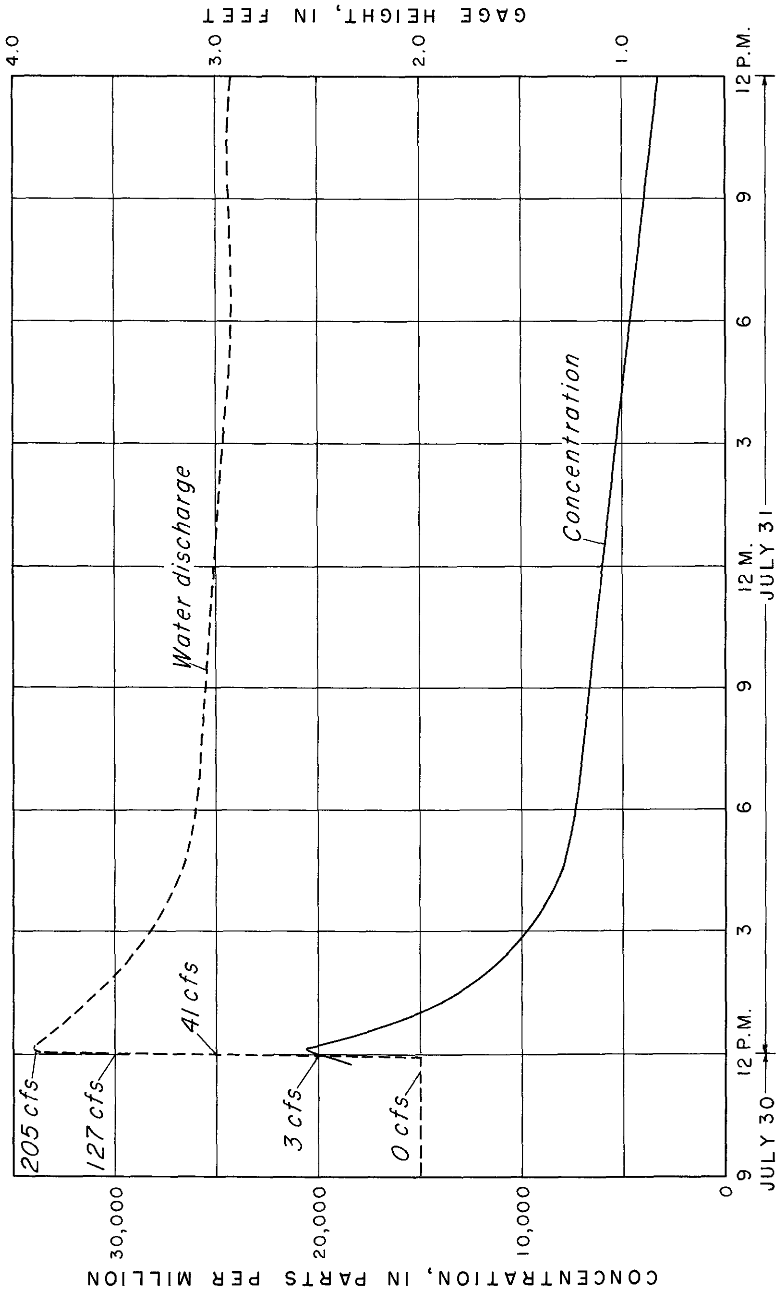

Figure 19.—Hydrograph and suspended-sediment concentration curve, Kiowa Creek at Elbert, July 30–31, 1957.

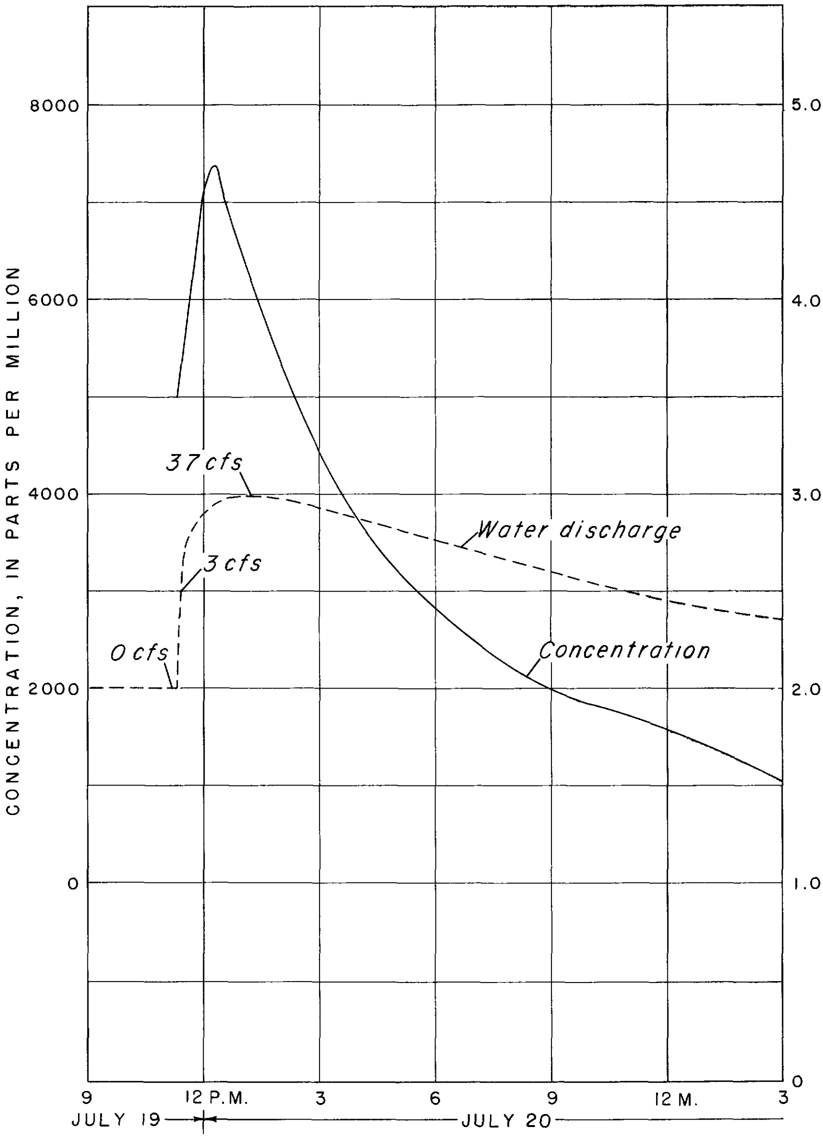

Figure 20.—Hydrograph and suspended-sediment concentration curve, Kiowa Creek at Elbert, July 19–20, 1958.

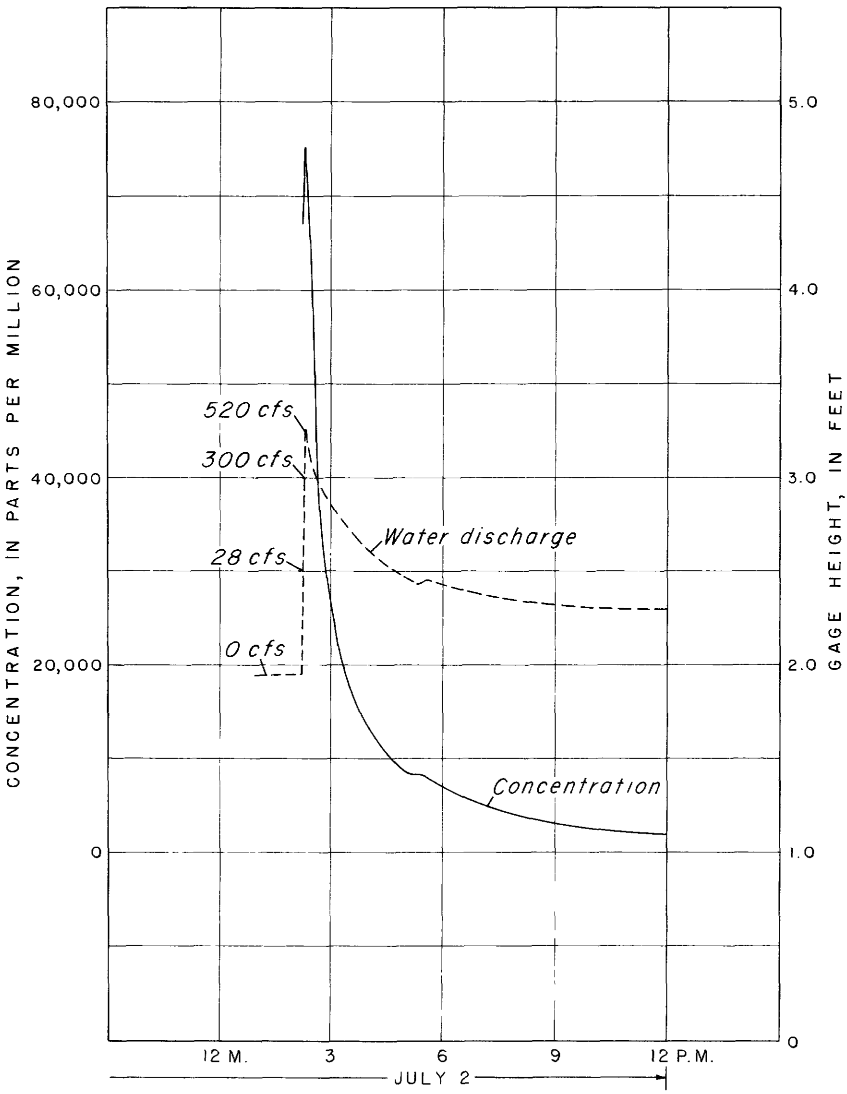

Figure 21.—Hydrograph and suspended-sediment concentration curve, Kiowa Creek at Kiowa, July 2, 1956.

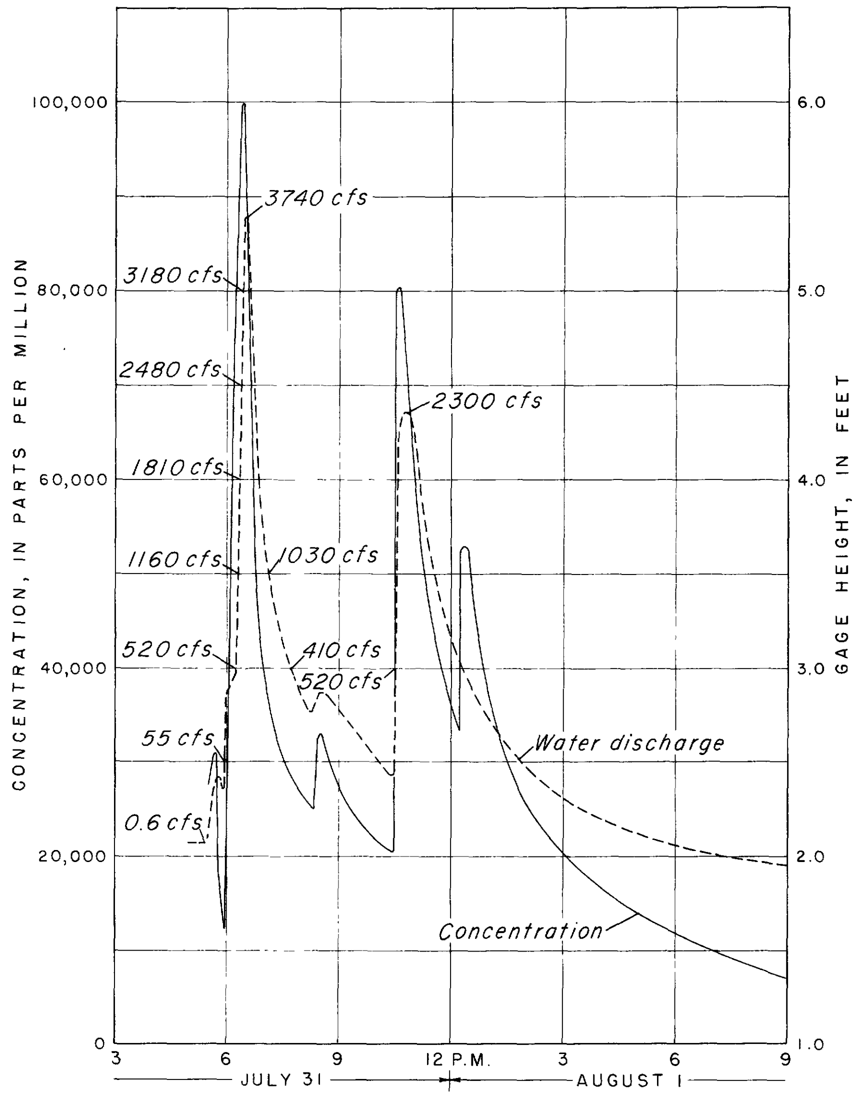

FIGURE 22.—Hydrograph and suspended-sediment concentration curve, Kiowa Creek at Kiowa, July 31 and August 1, 1956.

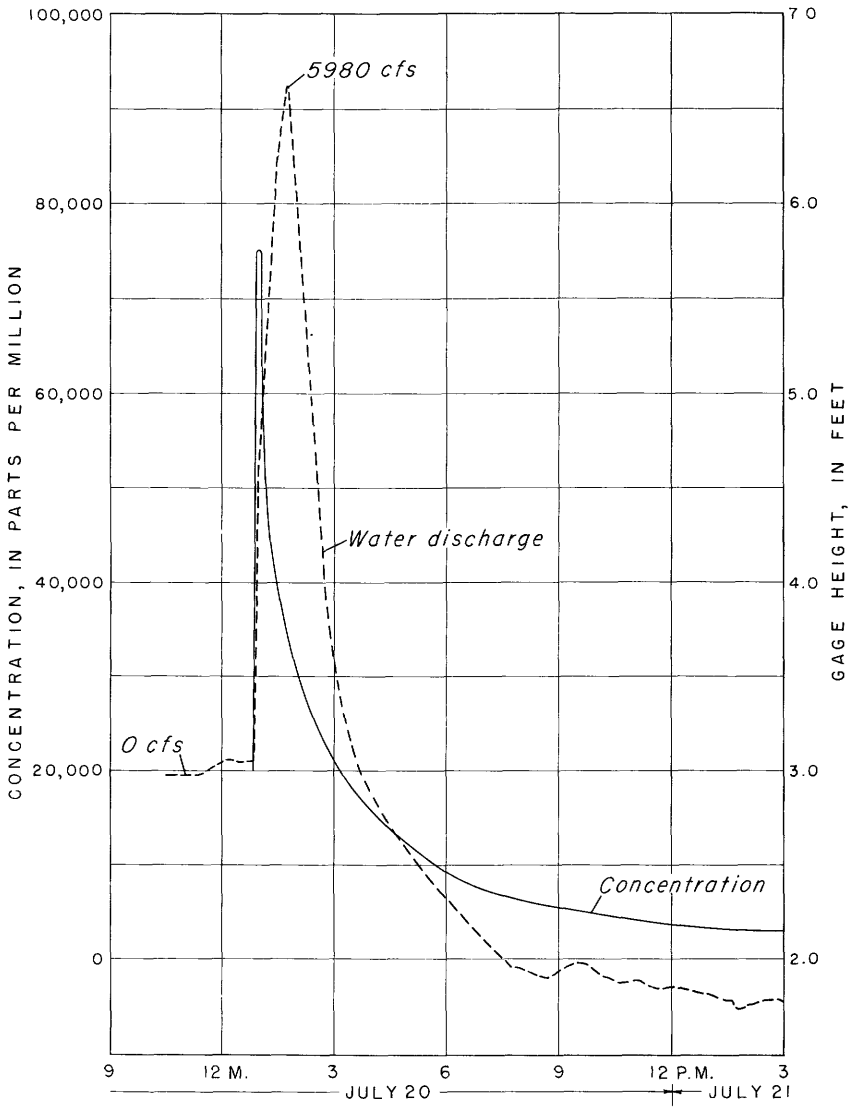

FIGURE 23.—Hydrograph and suspended-sediment concentration curve, Kiowa Creek at Kiowa, July 20, 1957.

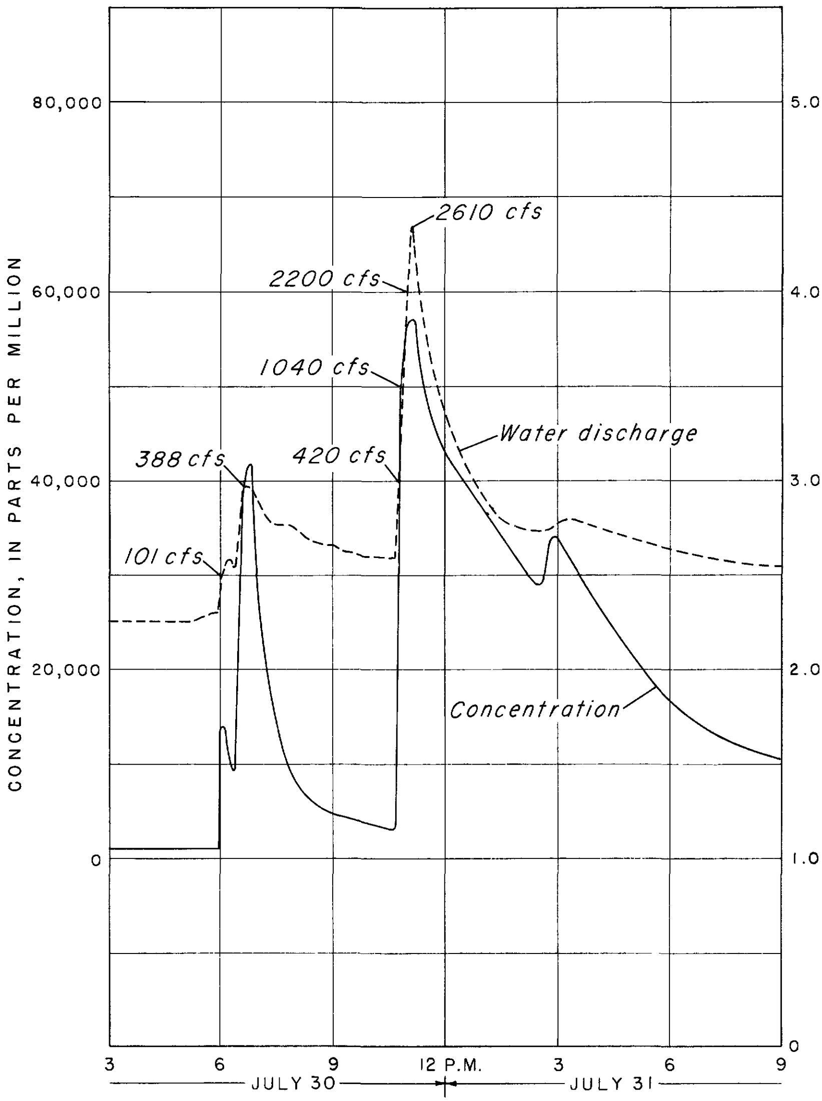

FIGURE 24.—Hydrograph and suspended-sediment concentration curve, Kiowa Creek at Kiowa, July 30–31, 1957.

TABLE 6.—*Monthly and annual summary of water and suspended-sediment discharge, October 1956–September 1961, Kiowa Creek at Elbert, Colo.*

Month	Water discharge (cfs-days)	Runoff (acre-feet)	Suspended sediment				
			Discharge (tons)	Daily discharge (tons)		Concentration (ppm)	
				Maximum	Minimum	Weighted	Maximum observed
1956							
October	0	0	0				
November	0	0	0				
December	0	0	0				
1957							
January	0	0	0				
February	0	0	0				
March	0	0	0				
April	0	0	0				
May	0	0	0				
June	0	0	0				
July	59.3	118	1,326.1	1,320	0	8,280	
August	5.5	11	35.4	31	0	2,380	
September	0	0	0				
Water year 1957	64.8	129	1,361.5	1,320	0	7,780	19,600
October	0	0	0				
November	0	0	0				
December	0	0	0				
1958							
January	0	0	0				
February	0	0	0				
March	0	0	0				
April	0	0	0				
May	0	0	0				
June	0	0	0				
July	9.3	18.4	130	112	0	5,080	
August	0	0	0				
September	.2	.4	3.2	2.0	0	5,930	
Water year 1958	9.5	18.8	133.2	112	0	5,200	6,280
Water year 1959	0	0	0				
1959							
October	0	0	0				
November	0	0	0				
December	0	0	0				
1960							
January	0	0	0				
February	0	0	0				
March	398.1	790	4,390.8	1,400	0	4,080	
April	11.5	23	2.8	0.4	[1]	90	
May	20.6	41	13.1	8.2	[1]	236	
June	1.8	3.6	[1]	[1]	0		
July	0	0	0				
August	0	0	0				
September	0	0	0				
Water year 1960	432.0	858	4,406.7	1,400	0	3,780	6,860
October	0	0	0				
November	0	0	0				
December	0	0	0				
1961							
January	0	0	0				
February	0	0	0				
March	0	0	0				
April	.7	1.4	[1]	[1]	0	5	
May	.2	.4	[1]	[1]	0	74	
June	0	0	0				
July	.2	.4	.1	0.1	0	241	
August	2.4	4.8	1.4	1.4	0	218	
September	.2	.4	[1]	[1]	0	74	
Water year 1961	3.7	7.4	1.6	1.4	0	160	990

[1] Less than 0.05 ton.

TABLE 7.—*Monthly and annual summary of water and suspended-sediment discharge, April 1956–September 1961, Kiowa Creek at Kiowa, Colo.*

Month	Water discharge (cfs-days)	Runoff (acre-feet)	Suspended sediment				
			Discharge (tons)	Daily discharge (tons)		Concentration (ppm)	
				Maximum	Minimum	Weighted mean	Maximum observed
1956							
April	0	0	0	--------	--------	--------	--------
May	89.4	177	8,401	8,400	0	33,600	--------
June	5.1	10	730	370	0	51,100	--------
July	284.7	565	44,601	43,000	0	55,900	--------
August	117.6	233	11,001	11,000	0	33,400	--------
September	0	0	0	--------	--------	--------	--------
April 1–September 30	496.8	985	64,733	43,000	0	46,500	56,600
October	0	0	0	--------	--------	--------	--------
November	.8	1.6	[1]	[1]	0	--------	--------
December	3.1	6.1	1	[1]	0	119	--------
1957							
January	7.1	14	3	[1]	0	156	--------
February	15.6	31	8	[1]	[1]	190	--------
March	29.7	59	31	--------	--------	387	--------
April	344.8	684	2,080	--------	--------	2,230	--------
May	720.4	1,430	22,537	12,000	1	11,600	--------
June	238.5	473	853	400	[1]	1,320	--------
July	1,088.2	2,160	71,113	33,000	0	24,200	--------
August	134.3	266	3,649	2,600	0	10,100	--------
September	10.1	20	3	[1]	0	110	--------
Water year 1957	2,592.6	5,140	100,278	33,000	0	14,300	73,300
October	44.3	87.9	60.8	3.0	1.0	508	--------
November	93.1	184.7	106.8	12	.6	428	--------
December	66.9	132.7	27.8	1.0	.6	154	--------
1958							
January	46.5	92.2	24.8	.8	.8	198	--------
February	47.3	93.8	82.0	14	[1]	642	--------
March	127.4	252.7	278.3	53	1.4	809	--------
April	161.4	320.1	466.0	100	3.0	1,070	--------
May	166.5	330.2	1,932.6	763	.4	4,300	--------
June	29.0	57.5	240.0	112	0	3,070	--------
July	6.9	13.7	37.0	34	0	1,990	--------
August	.7	1.4	14.0	13	0	7,410	--------
September	.4	.8	3.4	2.2	0	3,150	--------
Water year 1958	790.4	1,570	3,273.5	763	0	1,530	19,700
October	0.6	1.2	0.1	--------	--------	62	--------
November	3.0	6.0	1.0	--------	--------	123	--------
December	6.2	12	2.0	--------	--------	119	--------
1959							
January	9.3	18	2.0	--------	--------	80	--------
February	32.5	64	24	--------	--------	274	--------
March	56.8	113	107	--------	--------	698	--------
April	164.4	326	332	--------	--------	748	--------
May	158.3	314	334	--------	--------	781	--------
June	14.4	29	21	9	--------	736	--------
July	.5	1.0	15	9	--------	11,100	--------
August	0	0	0	--------	--------	--------	--------
September	0	0	0	--------	--------	--------	--------
Water year 1959	446.0	884	838.1	--------	--------	697	10,200
October	0	0	0	--------	--------	--------	--------
November	.1	.2	[1]	[1]	0	--------	--------
December	4.3	8.5	2	[1]	[1]	172	--------

See footnote at end of table.

TABLE 7.—*Monthly and annual summary of water and suspended-sediment discharge, April 1956–September 1961, Kiowa Creek at Kiowa, Colo.*—Con.

Month	Water discharge (cfs-days)	Runoff (acre-feet)	Suspended sediment				
			Discharge (tons)	Daily discharge (tons)		Concentration (ppm)	
				Maximum	Minimum	Weighted mean	Maximum observed
1960							
January	12.8	25	4	(1)	(1)	116	----------
February	14.7	29	12	----------	(1)	302	----------
March	2,363.0	4,690	50,325	16,500	(1)	7,890	----------
April	352.2	698	956	260	3	1,000	----------
May	211.6	420	231	53	(1)	404	----------
June	2.9	5.8	1	(1)	0	128	----------
July	0	0	0	----------	----------	----------	----------
August	0	0	0	----------	----------	----------	----------
September	0	0	0	----------	----------	----------	----------
Water year 1960	2,961.6	5,880	51,531	16,500	0	6,440	19,800
October	3.9	7.7	2.0	2	0	190	----------
November	0	0	0	----------	----------	----------	----------
December	1.6	3.2	.1	(1)	0	741	----------
1961							
January	6.2	12	.5	(1)	(1)	39	----------
February	42.0	83	4.5	(1)	(1)	40	----------
March	112.2	223	105.7	14	(1)	349	----------
April	62.2	123	20.3	2	(1)	121	----------
May	94.0	186	45.0	13	(1)	177	----------
June	96.1	191	193	40	0	744	----------
July	380.9	756	3,258	780	0	3,170	----------
August	89.1	177	158.7	20	0	660	----------
September	85.0	169	88.5	13	(1)	386	----------
Water year 1961	973.2	1,930	3,876.3	780	0	1,480	10,600

[1] Less than 0.5 ton.

No quantitative data are available on water seepage from the channel nor on aggradation or degradation on Kiowa Creek. Field reconnaissance during low-discharge periods in July and August 1959 indicated little water seepage from the channel of West Kiowa Creek at estimated discharges of 0.5–1.1 cfs; however, detailed observations were not made throughout the length of West Kiowa Creek in 1959. Flow in Kiowa Creek upstream from Elbert was usually restricted to a reach extending from a seepage zone about one-fourth mile upstream from K–79 Reservoir to about 1 mile downstream from the reservoir. No flow occurred at the gaging station at Elbert during the summer of 1959. From the mouth of West Kiowa Creek to a point immediately upstream from the mouth of one of the two large tributaries that enter between Elbert and Kiowa, very minor flow was continuous during July and August. Surface flow disappeared into the bed at this point, reappeared in a short reach about 2½ miles downstream, disappeared into the bed at the mouth of the largest tributary between Elbert and Kiowa, and reappeared as surface flow about 2 miles downstream. Figure 25 shows reaches of Kiowa Creek in which surface flow was observed on July 21, August 10, and August 24, 1959; flow in West

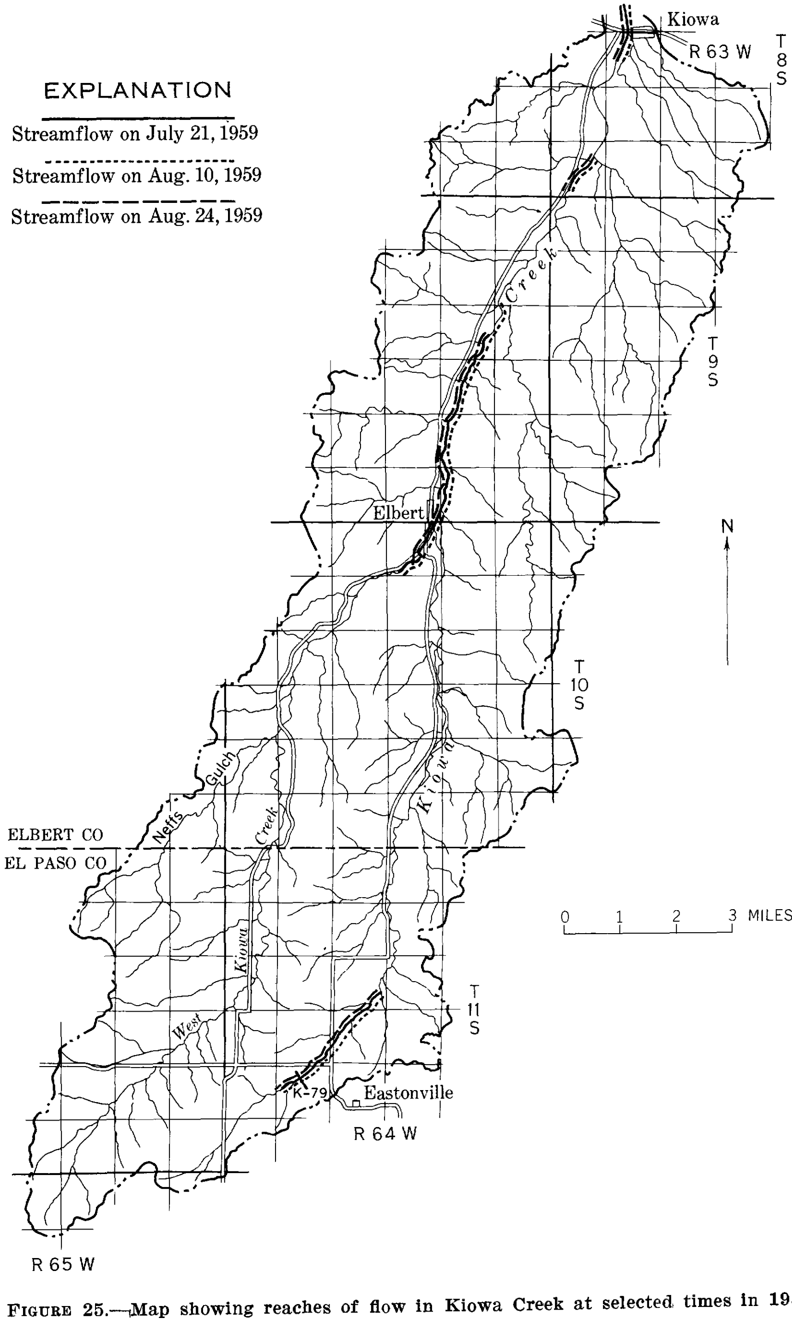

FIGURE 25.—Map showing reaches of flow in Kiowa Creek at selected times in 1959.

Kiowa Creek is shown only for a short reach upstream from Elbert. During the summer of 1960, observations of surface flow in Kiowa Creek and in West Kiowa Creek were made. In general, the reaches of surface flow during low-flow periods in 1960 were about the same as in 1959. Figure 26 shows stream reaches in which surface flow was observed on July 11, August 2, and September 9. Changes in main-channel gradient at confluences with major tributaries and for some distance downstream from them may explain the termination of surface flow immediately upstream from the mouth of each of the two major tributaries between Elbert and Kiowa.

Other evidence of water seepage from the channel of Kiowa Creek is obtained by comparison of discharge from K–79 Reservoir and discharge at Elbert. For example, a major storm of July 30, 1957, resulted in a total discharge of 270 acre-feet from K–79 Reservoir, whereas the total discharge of Kiowa Creek at Elbert was only about 129 acre-feet. During the summers of 1956 and 1957, many discharges from K–79 Reservoir ranged from about 1.0 to 15.0 acre-feet; none of these small discharges reached the gaging station at Elbert. The assumptions are made that runoff was limited to the K–79 drainage area and that no additional runoff was contributed by the drainage area between K–79 and Elbert; however, additional runoff probably entered Kiowa Creek between K–79 Reservoir and the gaging station at Elbert. Water seepage from the channel between the gaging station at Elbert and the gaging station at Kiowa also are probably significant. A total discharge of about 18 acre-feet at Elbert resulted from a local storm on July 19–20, 1958; only about 1.5 acre-feet passed the gaging station at Kiowa, and some of this may have been contributed by tributaries entering Kiowa Creek between Elbert and Kiowa.

Table 8 is a summary of periods of significant water and sediment discharges for K–79 Reservoir, Kiowa Creek at Elbert, and Kiowa Creek at Kiowa. For the period April 1956–September 1961, the summary includes about 98 percent of the suspended-sediment discharge from K–79 Reservoir, 100 percent of that from Kiowa Creek at Elbert, and about 98 percent of that from Kiowa Creek at Kiowa. The data indicate that most of the discharge from K–79 Reservoir does not reach Elbert and that the suspended-sediment discharge at Elbert is insignificant compared to the discharge at Kiowa. The drainage area upstream from Kiowa Creek at Elbert comprises about 25 percent of the drainage area upstream from Kiowa Creek at Kiowa; however, the suspended-sediment discharge of Kiowa Creek at Elbert was less than 3 percent of the suspended-sediment discharged at Kiowa. If sediment discharges for March 22–31, 1960, are excluded, the suspended-sediment discharge at Elbert was less than 1 percent of that at Kiowa during the period 1956–61.

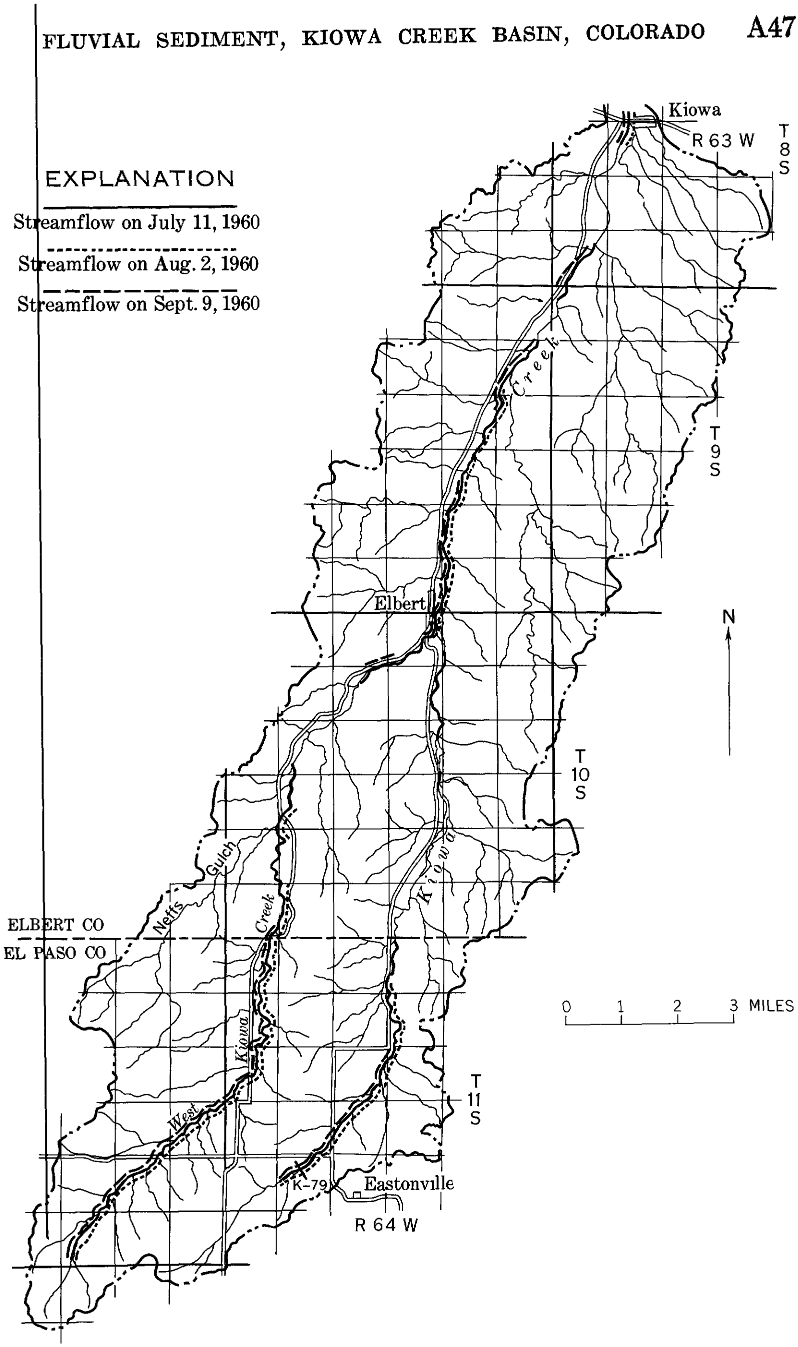

FIGURE 26.—Map showing reaches of flow in Kiowa Creek at selected times in 1960.

TABLE 8.—*Summary of periods of significant discharge at K–79 Reservoir near Eastonville, Kiowa Creek at Elbert, and Kiowa Creek at Kiowa*

Date	K–79 Reservoir (outflow)		Kiowa Creek at Elbert		Kiowa Creek at Kiowa	
	Water discharge (cfs-days)	Sediment discharge (tons)	Water discharge (cfs-days)	Sediment discharge (tons)	Water discharge (cfs-days)	Sediment discharge (tons)
1956						
May 23	0	0	0	0	89	8,400
June 28	0	0	0	0	4.4	360
July 2	0	0	0	0	20	1,600
July 16–17	4.0	24.5	0	0	0	0
July 31	0	0	0	0	264	43,000
Aug. 1–2	2.1	9.1	0	0	117	11,000
1957						
May 9	0	0	0	0	189	12,000
May 15–June 13	2.3	4.6	0	0	627	10,900
June 14–15	5.9	30.4	0	0	40	80
July 10–11	6.8	27.8	0	0	0	0
July 20	.6	2.0	.1	1.4	419	33,000
July 21–22	0	0	0	0	96	5,600
July 23–24	3.0	12.7	.1	.3	69	480
July 25–29	0	0	0	0	165	4,050
July 30–Aug 1	136	1,600	64.1	1,355	378	28,160
Aug. 2	---	---	0	0	5.8	14
Aug. 3	---	---	.3	3.6	48	2,600
Aug. 4	---	---	.2	.8	32	870
Aug. 6–7	2.8	12.5	0	0	3.5	3
1958						
Mar. 21–22	5.5	7.6	0	0	22	71
May 8–9	1.2	1.8	0	0	41	440
May 15–16	.9	1.5	0	0	45	1,030
July 19			1.0	18	2.6	4.2
July 20	3.6	7.2	8.3	112	2.6	4.2
July 21			0	0	2.6	3.2
July 22	---	---	0	0	3.4	3.7
July 23	---	---	0	0	1.8	3.6
Sept. 5	---	---	.1	2.0	.2	2.2
Sept. 6	---	---	.1	1.2	0	0
Sept. 9–10	6.4	14.8	0	0	0	0
1959						
Mar. 22–30	---	---	0	0	35.8	65
Apr. 1–30	6.4	0.7	0	0	164.4	332
May 1–30	2.6	.1	0	0	158.3	334
June 1–4	.2	.1	0	0	13.2	17
July 16–17	9.8	35.6	0	0	.5	15
Aug. 4–5	.8	.7	0	0	0	0
Sept. 9	.4	.3	0	0	0	0
1960						
Mar. 19–21	---	---	.2	.4	229	1,670
Mar. 22–31	40.3	56.5	397.9	4,390.4	2,073	48,577
Apr. 1–12	13.0	1.2	5.9	1.6	236.6	886
Apr. 13–30	5.6	.3	5.6	1.2	115.6	70
May 5–8	3.5	1.2	6.4	8.8	38.8	76
May 9–15	2.9	.1	2.1	.2	43.0	25
May 16–20	1.5	.1	7.4	3.7	100	119
July 2	1.5	4.2	0	0	0	0
Oct. 19	.3	(1)	0	0	3.6	2
1961						
Feb. 1–28	---	---	0	0	42	4.5
Mar. 1–5	---	---	0	0	27.6	45
Mar. 6–31	---	---	0	0	84.6	61
Apr. 1–May 13	1.1	1.0	.7	(1)	68	21.9
May 14–19	1.4	.6	.2	(1)	44.7	34
June 1–4	1.6	.7	0	0	26.9	78
June 5–8	.4	.1	0	0	33.3	94
June 9–16	.5	.1	0	0	31.7	20
July 7–8	.1	0	.1	(1)	3.5	5
July 11–12	.04	0	0	0	98	940
July 13–14	.04	0	0	0	20.5	11
July 28–31	.1	0	.1	.1	250	2,300
Aug. 1–4	.5	.1	0	0	29.2	50
Aug. 8	.6	.1	0	0	1.2	.2

See footnote at end of table.

TABLE 8.—*Summary of periods of significant discharge at K–79 Reservoir near Eastonville, Kiowa Creek at Elbert, and Kiowa Creek at Kiowa*—Con.

Date	K–79 Reservoir (outflow)		Kiowa Creek at Elbert		Kiowa Creek at Kiowa	
	Water discharge (cfs-days)	Sediment discharge (tons)	Water discharge (cfs-days)	Sediment discharge (tons)	Water discharge (cfs-days)	Sediment discharge (tons)
Aug. 12–16	.2	0	2.3	1.4	16.1	19
Aug. 17	.8	.2	0	0	7.0	11
Aug. 30–31	.1	0	0	0	20.7	75
Sept. 1–4	.4	(1)	.1	(1)	26.6	43
Sept. 5–10	.3	(1)	0	0	17.7	16
Sept. 11–30	1.0	(1)	.1	(1)	40.7	30

1 Less than 0.05 ton.

The very low suspended-sediment discharge at Elbert compared to the suspended-sediment discharge at Kiowa can be attributed partly to the progress of completion of detention structures in the basin. (See fig. 27.) Initial emphasis was on the completion of detention structures in the drainage area of Kiowa Creek upstream from Elbert; by January 1, 1957, runoff from nearly 60 percent of this area was partly controlled. On the same date, runoff from only about 7 percent of the remaining 75 percent of the drainage area upstream from Kiowa was controlled; by January 1, 1958, 14 percent was controlled; by January 1, 1959, 53 percent was controlled, although most of the structures completed during 1958 were not completed until early fall; and by January 1, 1960, about 60 percent was controlled. The combined drainage area upstream from dams completed in Kiowa Creek basin between January 1, 1955, and January 1, 1960, is about 65.6 square miles. The combined storage capacity of the reservoirs is about 3,080 acre-feet, of which about 720 acre-feet is allotted to sediment pool.

The control of runoff from 60 percent of the drainage area of Kiowa Creek upstream from Elbert was probably one of the major reasons for the disproportionately low sediment discharge at Elbert during 1956–59. The detention structures decrease the peak discharge and spread out the period of water discharge in the main stem of the stream; consequently, water seepage from the channel becomes greater than it would be without the controlled discharge into the main stem. Water seepage from the channel is probably appreciable in a wide sandy reach of Kiowa Creek from about 2 to 5 miles south of Elbert. For example, on July 16–17, 1959, K–79 Reservoir discharged about 20 acre-feet of water into Kiowa Creek, and other drainage areas in upper Kiowa Creek basin contributed an unknown quantity of water to the stream; although a considerable part of this water was observed to have entered the sandy reach of the stream, none of the water reached the downstream end as surface flow.

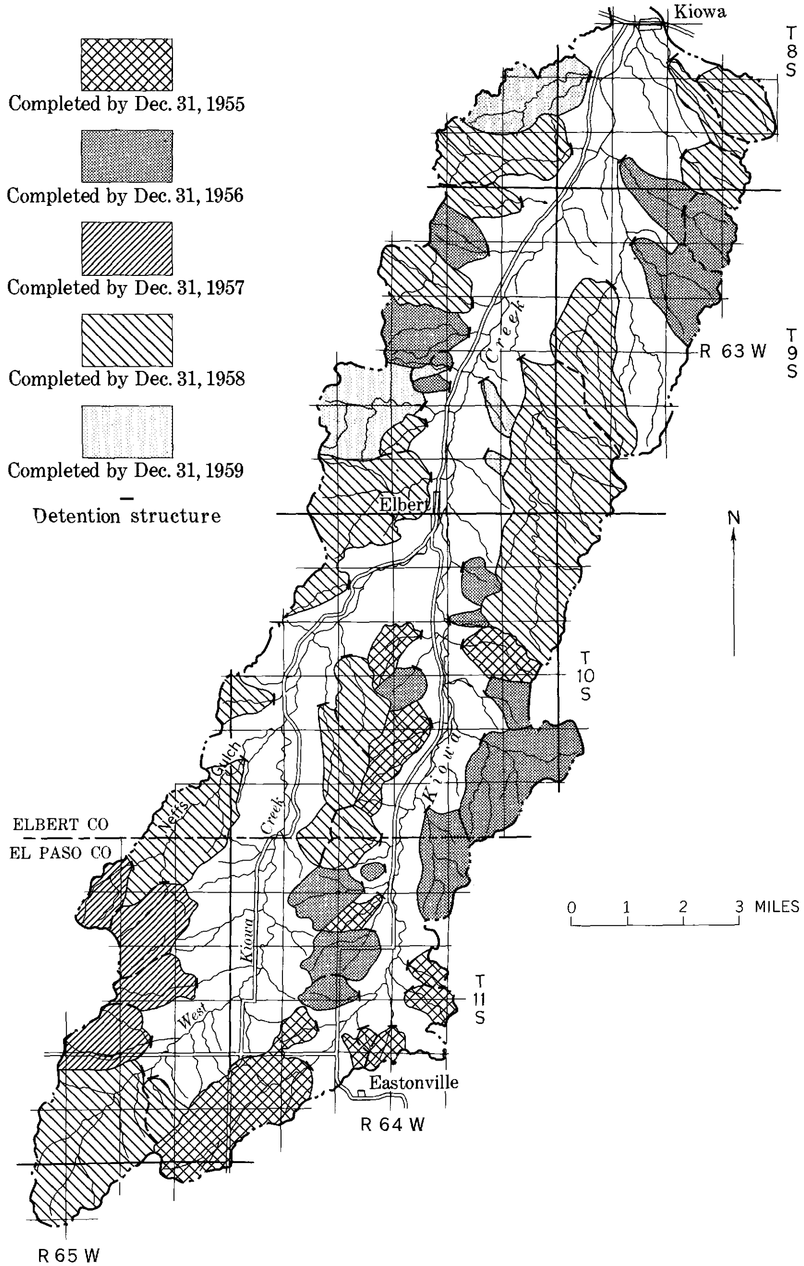

FIGURE 27.—Map showing location of detention structures and associated subbasins in Kiowa Creek basin upstream from Kiowa.

The trap efficiency of the different reservoirs probably varies, but the reservoirs significantly reduce the suspended-sediment concentration of water discharged into the main stem of Kiowa Creek. Therefore, the deposition of sediment in the reservoirs, the control of discharge from 60 percent of the drainage area during most of the period of investigation, and the concomitant conditions conducive to water seepage from the channel are probably responsible for the low sediment discharge of Kiowa Creek at Elbert.

The effect of the completion of many detention structures in 1958 in the West Kiowa Creek drainage area and in Kiowa Creek basin between Elbert and Kiowa became apparent during the summer runoff season in 1959. Between June 10 and September 15, 1959, only one minor flow occurred at Kiowa Creek at Kiowa; this flow, on July 16–17, was mainly from a small tributary about 1 mile upstream from the gaging station. Precipitation during the period and during the entire year was slightly below or near normal, but it was considerably higher than in 1956. Although differences in rainfall intensity-duration relationships may have had some effect on the differences between sediment discharges in 1956 and in 1959, the very low water and sediment discharges at the Kiowa station during 1959–61 can be attributed partly to the increased control of runoff between 1956 and 1959.

Limited information indicates that structural and land-treatment measures—such as stabilization structures, erosion-control structures, terraces, range improvement, and field diversions—completed since 1955 have resulted in some decrease in runoff and in sediment discharge from the area. The detention structures probably have been much more effective than the other measures in reducing the sediment discharge of Kiowa Creek.

Figure 28 shows the relation between water discharge and suspended-sediment discharge at Kiowa Creek at Elbert. A much greater number of sediment-discharge measurements would be required to establish the relation accurately. Figure 29 shows the relation between water discharge and suspended-sediment discharge at Kiowa Creek at Kiowa for the period 1956–61. Although sediment discharge shows a poor correlation with water discharges of less than about 20 cfs, it shows a fairly good positive correlation with water discharges of more than about 20 cfs.

Because the data on streamflow and sediment transport obtained during 1956–61 were representative of a period of extensive implementation of structural controls and land-treatment practices in Kiowa Creek basin, they are of limited use in estimating either past sedimentation conditions or in predicting future sedimentation conditions. No pretreatment data are available for comparison with data obtained since 1956. However, the data obtained at Kiowa Creek at Elbert are probably fairly representative of future sedimentation conditions in the basin. Most of the data at Elbert were collected after the completion of nearly all the major structural controls in this part of the basin and during years when precipitation ranged from

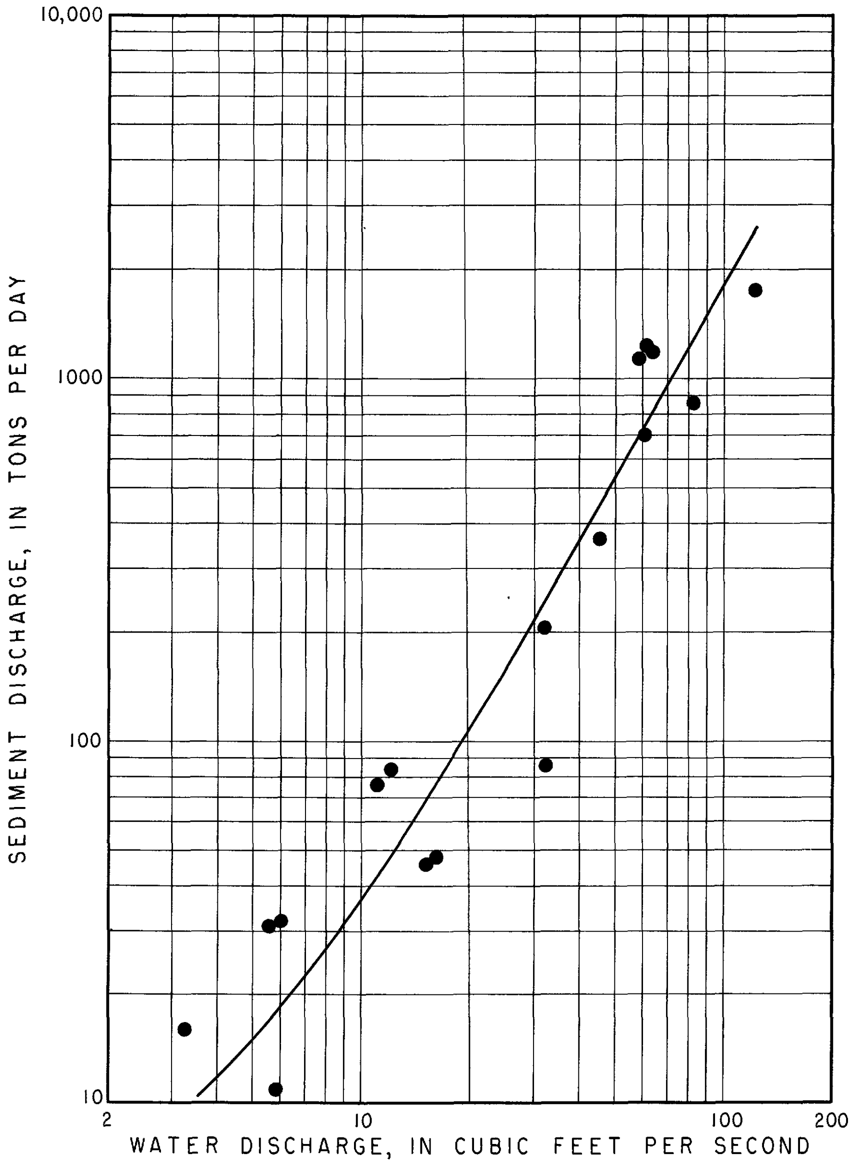

FIGURE 28.—Relation of water discharge to suspended-sediment discharge, Kiowa Creek at Elbert.

much below normal to much above normal. Further, the data obtained at Kiowa Creek at Kiowa between April 1956 and September 1958 may be somewhat representative of pretreatment conditions in the basin. During this period, only a few structural controls existed in the drainage areas of West Kiowa Creek and Kiowa Creek between Elbert and Kiowa.

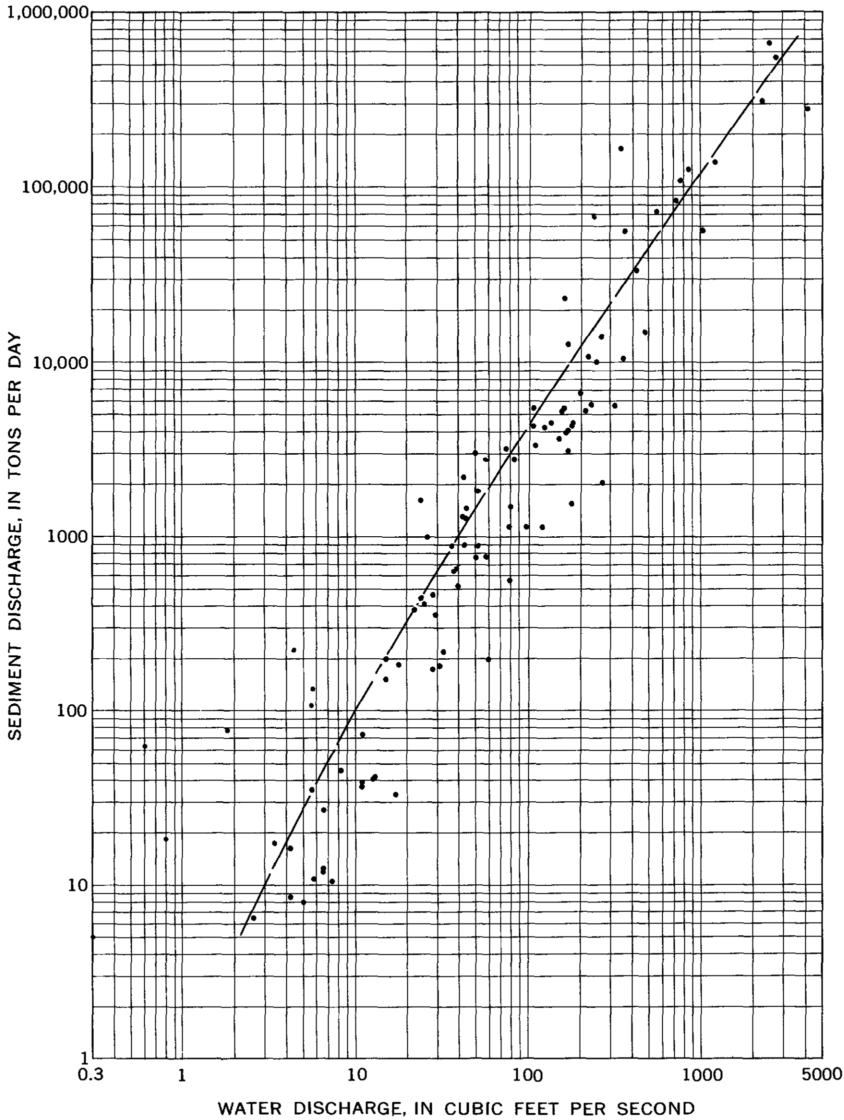

FIGURE 29.—Relation of water discharge to suspended-sediment discharge, Kiowa Creek at Kiowa.

Figure 30 shows the percentages of sand, silt, and clay in suspended-sediment samples from Kiowa Creek at Kiowa and at Elbert. The percentage of sand at Kiowa may occasionally be somewhat higher than would be expected for most reaches of Kiowa Creek. At Kiowa, suspended-sediment samples were obtained from a narrow, constricted artificial channel. During moderate or high water discharge, channel characteristics are conducive to extremely turbulent flow (fig. 31). Observations by field personnel indicate that during some periods of moderate to high discharge, the sandfill is completely removed and the bedrock forms the streambed. During these periods, nearly all the sediment transported through this constricted section may be in suspension, and only a thin layer of very coarse material may move as bedload along the bedrock channel bottom.

Tables 9 and 10 show the particle-size distribution of suspended-sediment samples collected at Kiowa Creek at Elbert and at Kiowa Creek at Kiowa, respectively, from April 1956 to September 1961.

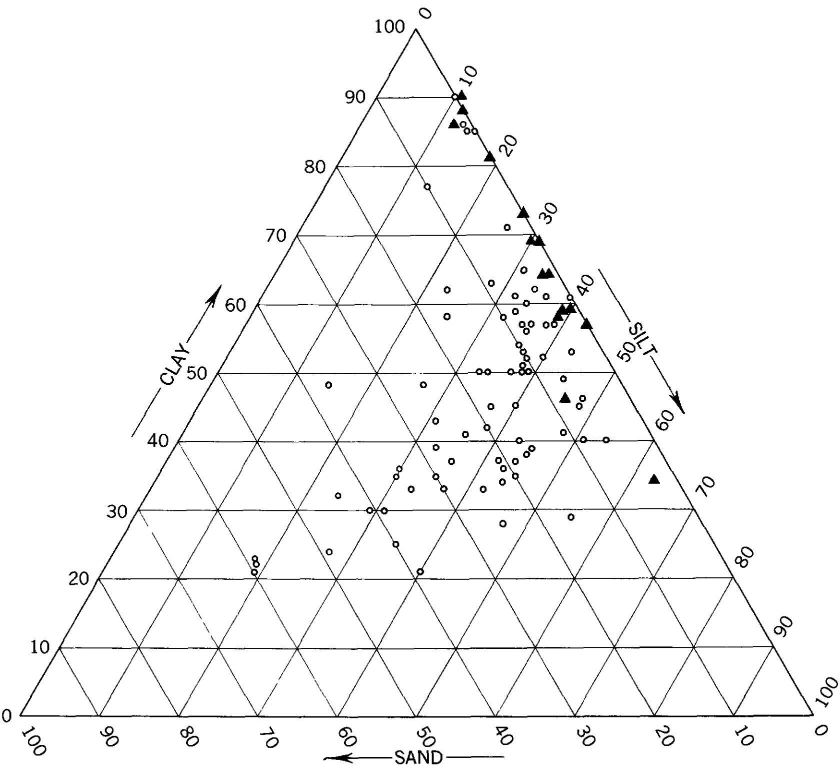

FIGURE 30.—Percentage of sand, silt, and clay in suspended sediment, Kiowa Creek at Elbert and Kiowa Creek at Kiowa. O, at Kiowa; ▲, at Elbert.

TABLE 9.—*Particle-size analyses of suspended sediment, Kiowa Creek at Elbert*

[Methods of analysis: P, pipet; S, sieve; N, in native waters; W, in distilled water; C, chemically dispersed; M, mechanically dispersed; V, visual accumulation tube]

Date	Time	Water discharge (cfs)	Water temperature (°F)	Suspended sediment											Methods of analysis
				Concentration (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size, in millimeters									
						0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	
1957															
July 31	6:00 a.m.	62	----	7,270	5,160	59	73	87	96	97	100	----	----	----	SPWCM
Do	6:45	59	53	7,200	4,830	56	69	80	90	95	100	----	----	----	SPWCM
Do	6:45 a.m.	59	53	7,200	5,700	40	57	74	85	88	100	----	----	----	SPNM
1958															
July 20	6:20 a.m.	12	----	2,580	1,740	81	88	----	99	----	----	----	----	----	PWCM
Do	8:25 a.m.	5.5	----	2,070	2,330	79	86	----	92	----	98	98	98	100	VPWCM
1960															
Mar. 23	4:05 p.m.	83	----	3,870	4,030	56	64	76	90	96	99	100	----	----	VPWCM
Mar. 24	5:00 p.m.	121	----	5,340	5,830	49	59	70	86	93	99	100	----	----	VPWCM
Mar. 25	2:50 p.m.	45	57	2,970	3,450	55	64	74	84	92	98	99	100	----	VPWCM
Do	4:15	60	55	4,330	3,770	47	58	70	80	88	97	98	99	100	VPWCM
Do	4:15 p.m.	60	55	4,330	2,960	18	34	54	73	88	97	98	99	100	VPN
Mar. 26	5:30 p.m.	64	54	6,860	8,420	39	46	56	68	81	92	95	97	98	VPWCM
Mar. 27	8:45 a.m.	34	39	2,250	2,890	54	59	71	82	91	98	99	100	----	VPWCM
Mar. 28	3:20 p.m.	15	54	1,140	2,980	56	69	81	90	96	99	100	----	----	VPWCM
Do	4:40 p.m.	16	57	1,120	2,670	61	69	80	88	95	----	----	----	----	PWCM
Mar. 29	1:45 p.m.	5.8	----	732	1,090	70	81	89	95	98	----	----	----	----	PWCM
1961															
Aug. 16	5:40 p.m.	32	56	992	3,230	79	90	94	98	99	100	----	----	----	PWCM

TABLE 10.—*Particle-size analyses of suspended sediment, Kiowa Creek at Kiowa*

[Methods of analysis: P, pipet; S, sieve; N, in native waters; W, in distilled water; C, chemically dispersed; M, mechanically dispersed; V, visual accumulation tube]

Date	Time	Water discharge (cfs)	Water temperature (°F)	Suspended sediment: Concentration (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size, in millimeters: 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	2.000	Methods of analysis
1956																	
May 23	1:40 a.m.	0.6	50	42,900	5,780	46	57	70	82	92	96	98	100				SPWCM
Do	2:14	848	48	51,800	4,000		33		52		75	80	89	99	100		SPWCM
Do	2:15	757		51,600	4,550		34		54		78	84	93	99	100		SPWCM
Do	2:55	718		41,600	2,660		35		52		70	73	82	95	99	100	SPWCM
Do	4:55	42		20,900	3,730		50		67		83	86	93	98	99	100	SPWCM
Do	8:30	24	55	6,860	1,360		63		80		91	93	96	99	100		SPWCM
Do	1:45 p.m.	8.2	74	2,060	2,470	49	62	74	83	91	96	97	99	100			SPNM
June 27	11:40	170		65,500	2,210		37		53		79	85	93	100			SPWCM
Do	11:55	163		50,060	7,690		45		69		93	96	99	100			VPWCM
June 28	12:45 a.m.	24	55	24,800	5,270		54		78		94	96	98	100			VPWCM
Do	4:15	.3	53	6,380	3,000		71		92		100						PWCM
July 2	2:25 p.m.	366		54,900	7,050		35		51		80	88	97	99	100		VPWCM
Do	5:05	5.8	52	8,480	4,720		62		82		96	97	98	100			SPWCM
July 31	6:25	2,520		90,000	3,650		33		48		70	78	89	96	99	100	SPWCM
Do	8:55	170		27,900	5,080	42	50	59	70	80	87	92	98	100			VPWCM
Do	9:45	50		22,800	5,540		58		76		90	92	94	97	99	100	SPWCM
Aug. 1	12:30 a.m.	848		52,000	3,040		33		48		64	68	79	95	99	100	SPWCM
Do	9:20	22		6,350	3,060		71		89		97	98	99	100			SPWCM
Do	11:35	333		57,700	3,610		39		59		84	88	95	99	100		SPWCM
Do	12:05 p.m.	292		45,800	3,630		36		50		66	69	72	86	97	99	SPWCM
1957																	
Mar. 12	3:10 p.m.	0.8	51	329	1,240	41	53	64	77	90	96	98	99	100			SPWCM
Apr. 11	11:45 a.m.	6.6	47	1,510	1,890	34	41	51	60	75	89	95	100				VPWCM
May 9	10:25 a.m.	160	43	12,600	5,840	44	52	63	72	80	90	96	99	100			VPWCM
Do	10:25	160	43	12,600	6,120	29	39	55	68	78	91	96	99	100			VPNM
Do	11:25	156	44	12,300	5,880	42	51	61	70	79	89	95	99	100			VPWCM
Do	6:25 p.m.	43	47	7,670	4,810	51	60	68	76	84	94	98	99	100			VPWCM
May 10	1:45 p.m.	11	55	1,260	820	51	57	69	77	88	93	97	100				VPWCM
May 13	9:50 a.m.	29	45	4,540	3,890	37	45	54	64	72	82	87	95	99	100		VPWCM
Do	9:50 a.m.	29	45	4,540	3,940	26	37	49	60	67	79	84	94	98	100		VPNM
May 15	3:32 p.m.	110	33	11,200	5,000	30	38	44	52	65	83	92	98	100			VPWCM
May 16	12:20 p.m.	51	42	6,380	5,940	32	39	48	58	71	86	93	98	100			VPWCM
May 17	5:55 p.m.	249	60	14,900	8,570	25	28	39	47	58	75	85	95	100			VPWCM
Do	5:55 p.m.	249	60	14,900	8,590	18	26	35	45	57	76	86	96	100			VPNM
May 18	9:55 a.m.	67	62	4,250	3,980	44	54	63	72	79	90	94	99	100			VPWCM
Do	3:25 p.m.	224	68	17,600	6,200		50		68		88	92	97	100			VPWCM

May 31	9:05 p.m.	226	48	19,800	4,670	35	40	48	56	67	83	90	96	99	100		VPWCM
Do	9:05 p.m.	226	48	19,800	4,560	22	29	43	54	68	84	91	96	99	100		VPNM
June 1	5:28 a.m.	6.6	45	6,140	4,670	24	36	48	58	69	79	86	95	100			VPWCM
July 20	1:20 p.m.	2,690	47	73,300	4,340		25		36		60	73	90	99	100		VPWCM
Do	2:30 p.m.	4,090		26,800	7,190	34	42	51	61	70	80	86	95	100			VPWCM
Do	2:30	4,090		26,800	7,400	24	33	45	58	70	80	86	95	100			VPNM
July 20	6:18 p.m.	150	59	8,960		49	57	65	74	85	92	96	100				VPWCM
July 21	7:55 a.m.	28	51	2,290	2,470	54	62	67	71	77	85	89	97	100			VPWCM
July 22	4:55 p.m.	556	42	46,200	6,230	32	37	45	53	64	81	91	97	100			VPWCM
Do	4:55 p.m.	556	42	46,200	6,570	19	27	36	47	59	79	91	97	100			VPNM
July 23	6:10 p.m.	75	58	15,500	4,130		49		68		93	96	99	100			VPWCM
Do	6:44 p.m.	59	58	17,900	6,170	51	61	73	84	92	97	99	100				VPWCM
July 30	6:36 p.m.	421	68	29,600	4,100		37		51		73	80	92	100			VPWCM
Do	11:20 p.m.	2,200		50,400	5,990		45		66		85	89	96	100			VPWCM
July 31	12:12 a.m.	1,190	58	41,600	6,610	43	52	62	74	84	92	95	98	100			VPWCM
Do	1:50 p.m.	79	84	6,980	4,570		65		82		96	97	99	100			VPWCM
1958																	
May 9	9:05 a.m.	39	50	5,150	3,140	43	50		73		89	95	100				VPWCM
May 15	7:45 p.m.	106	50	19,100	7,090	34	40		62		87	91	96	99	100		VPWCM
Do	7:45 p.m.	106	50	19,000	7,170	19	29		57		87	91	96	99	100		VPN
May 16	11:05 a.m.	18	68	3,810		47	56		77		94	96	99	100			VPWCM
June 5	7:05 a.m.	15		4,930	4,690	50	59		78		92	94	98	100			VPWCM
June 6	10:30 p.m.	50	57	13,600	7,750	37	46		69		94	98	100				VPWCM
Aug. 20	1:45 a.m.	4.2	55	19,700	5,440	71	85		99		100						VPWCM
Do	2:35 a.m.	1.8	55	16,100	5,800	72	85		97		99	99	99	100			VPWCM
Do	4:15 a.m.	.8	55	8,340	2,110	78	90		98		100						VPWCM
1959																	
July 16	7:05 p.m.	1.8	63	9,760	7,660	74	86		98		99	100					VPWCM
1960																	
Mar. 21	12:25 p.m.	274	32	3,170	1,650	20	23	28	31	34	41	51	73	96	100		VPWCM
Mar. 22	10:25 a.m.	182		3,140	2,200	29	32	38	44	50	56	64	76	90	100		VPWCM
Mar. 23	1:03 p.m.	215		8,840	4,550	21	24	29	34	42	51	60	79	95	100		VPWCM
Mar. 24	12:45 p.m.	322		6,510	4,090	29	33	39	45	54	66	75	86	95	100		VPWCM
Do	5:35 p.m.	1,060	38	19,800	5,560	17	21	24	28	34	40	44	58	87	99	100	VPWCM
Mar. 25	10:25 a.m.	50	47	5,680	6,740	30	35	41	48	56	65	71	81	95	100		VPWCM
Do	6:15 p.m.	366		10,700	6,840	26	30	35	38	50	61	68	84	97	100		VPWCM
Do	6:15 p.m.	366		10,700	7,010	13	21	28	37	48	61	68	84	97	100		VPN
Mar. 26	9:00 p.m.	476		11,500	5,380	26	30	35	42	51	59	65	76	94	100		VPWCM
Mar. 27	3:15 p.m.	122	60	3,500	6,850	37	41	48	55	64	77	84	93	99	100		VPWCM
Mar. 28	2:35 p.m.	79	56	2,660	4,190	34	39	45	52	61	72	80	92	99	100		VWPCM
Mar. 29	5:05 p.m.	59	47	1,260	1,220	46	50	58	64	73	84	92	99	100			VPWCM
Mar. 30	3:55 p.m.	31		2,170	1,960	20	22	26	31	35	41	47	57	73	83	92	SVPWCM
1961																	
July 11	7:15 p.m.	233	46	9,040	7,360	41	48	54	59	61	63	66	75	93	100		VPWCM
Do	4:35 p.m.	340		18,100	6,160	44	53	64	74	84	90	94	97	100			VPWCM
July 12	9:05 a.m.	33	70	2,340	3,210	69	77	77	83	85	90	92	95	100			VPWCM
July 28	8:15 p.m.	240		10,600	5,540	42	48	57	64	72	75	79	85	90	100		VPWCM
July 29	8:10 a.m.	98	60	4,280	4,600	51	58	68	73	78	83	87	93	98	100		VPWCM
Aug. 30	11:55 p.m.	78	57	5,400	12,000	49	61	74	83	89	93	96	99	100			VPWCM

FIGURE 31.—Turbulent flow at gaging section, Kiowa Creek at Kiowa.

BED MATERIAL

Information on the particle size and specific gravity of the material forming the streambed is necessary for computing total sediment discharge of sand-bed streams or for accurately estimating the movement of the bed material under specific flow conditions.

Tables 11 and 12 show the particle-size distribution of bed-material samples collected at Kiowa Creek at Elbert and at Kiowa Creek at Kiowa, respectively, from April 1956 to September 1961. Figure 32 is a diagrammatic summary of the data shown in these tables. Also

TABLE 11.—*Particle-size analyses of bed material, Kiowa Creek at Elbert*

[Methods of analysis: S, sieve; V, visual accumulation tube]

Date	Number of sampling points	Water discharge (cfs)	Bed material									Methods of analysis
			Percent finer than indicated size, in millimeters									
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.000	
1956												
May 9	9	0	4	7	13	37	70	87	98	100	-------	SV
1958												
July 20	9	12	5	7	9	19	47	73	93	99	100	SV
1960												
Mar. 25	8	45	-------	0	2	23	61	83	97	100	-------	SV
Do	13	60	-------	0	3	23	57	78	94	99	100	SV
Mar. 26	11	64	0	1	4	24	57	76	93	99	100	SV
Mar. 27	9	22	0	1	2	21	58	82	97	100	-------	SV
Mar. 28	9	15	3	4	5	21	49	67	87	96	100	SV
Mar. 29	5	5.8	1	1	2	18	53	76	93	100	-------	SV
May 17	3	3.2	1	1	3	17	58	78	96	100	-------	SV
1961												
Aug. 16	9	32	6	7	10	24	48	70	89	98	100	SV

TABLE 12.—*Particle-size analyses of bed material, Kiowa Creek at Kiowa*

[Methods of analysis: S, sieve; V, visual accumulation tube]

Date	Number of sampling points	Water discharge (cfs)	Bed material										Methods of analysis
			Percent finer than indicated size, in millimeters										
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.000	32.000	
1956													
May 23	4	8.2	0	1	6	44	81	93	99	100	------	------	SV
June 28	1	------	------	0	12	63	89	98	100	------	------	------	SV
July 2	1	------	0	1	7	46	84	95	99	100	------	------	SV
Aug. 1	1	22	------	0	1	24	62	81	92	100	------	------	SV
Do	5	9.0	------	0	5	39	76	90	97	99	100	------	SV
1957													
Mar. 12	6	.8	2	5	14	46	79	91	98	100	------	------	SV
Apr. 11	8	6.6	1	3	12	42	73	87	96	100	------	------	SV
May 9	3	160	------	0	4	33	76	90	97	100	------	------	SV
Do	3	156	0	1	8	46	88	96	99	100	------	------	SV
Do	1	43	------	0	4	31	70	88	96	99	100	------	SV
May 10	2	11	------	0	6	44	82	94	98	100	------	------	SV
May 13	3	29	------	0	8	42	76	89	97	100	------	------	SV
May 15	2	110	0	1	8	50	92	96	99	100	------	------	SV
May 16	3	51	0	1	11	60	92	100	------	------	------	------	V
May 17	2	249	------	0	11	48	78	88	96	100	------	------	SV
May 18	3	67	------	0	10	40	73	90	98	100	------	------	SV
June 1	18	6.6	0	1	9	41	75	89	96	99	99	100	SV
July 20	15	117	------	0	3	23	47	62	83	96	99	100	SV
July 21	14	28	------	0	6	42	72	86	96	99	100	------	SV
July 23	2	59	------	0	7	38	69	86	98	100	------	------	SV
1958													
Aug. 20	2	4.2	------	0	3	33	71	85	93	100	------	------	SV
1959													
Apr. 2	2	[1]11	1	2	9	40	78	93	99	100	------	------	SV
June 2	1	[1]3.4	1	1	9	40	77	91	98	100	------	------	SV
July 15	8	0	------	0	8	38	70	87	97	100	------	------	SV
July 16	1	1.8	0	1	7	38	73	88	98	100	------	------	SV
1960													
Mar. 25	12	223	------	0	7	38	73	89	98	100	------	------	SV
Do	8	366	------	0	2	20	62	85	96	100	------	------	SV
Mar. 26	7	476	------	0	2	30	73	92	99	100	------	------	SV
Mar. 27	7	122	------	0	5	43	76	90	99	100	------	------	SV
Mar. 28	21	79	------	0	6	45	80	92	99	100	------	------	SV
Apr. 13	13	11	------	0	9	45	75	89	98	99	100	------	SV
Apr. 18	6	6.6	------	0	10	44	77	90	98	100	------	------	SV
Apr. 20	6	3.4	------	0	9	42	76	90	98	100	------	------	SV
May 7	5	31	0	2	12	55	84	94	99	100	------	------	SV
May 17	6	15	------	0	9	42	74	88	98	100	------	------	SV
May 22	6	5.0	------	0	10	46	76	90	98	100	------	------	SV
1961													
July 11	7	233	------	0	8	41	75	91	98	99	100	------	SV
July 12	6	33	------	0	7	44	76	89	98	100	------	------	SV
July 30	17	122	------	0	5	37	74	89	98	99	100	------	SV
Aug. 7	------	.5	------	0	8	39	72	88	97	100	------	------	SV
Aug. 30	26	78	------	0	8	44	77	91	99	100	------	------	SV
Aug. 31	19	11	0	1	8	42	73	88	97	100	------	------	SV

[1] Daily mean discharge.

shown in figure 32 is a point representing the average particle-size distribution of bed-material samples collected by Vanoni (written commun.) in an 8,000-foot reach of Kiowa Creek about 2 miles upstream from Elbert. The samples obtained by Vanoni were representative of the upper 4 feet of bed material in this reach; with one exception, samples obtained since 1956 by the Geological Survey were obtained from the upper 3 inches or less of bed material at the Elbert and Kiowa gaging stations. The relative coarseness of the samples obtained by Vanoni may be explained by the greater depth of sampling if it is assumed that the bed material becomes progressively coarser with increasing depth. On July 15, 1959, samples of the upper 2 feet

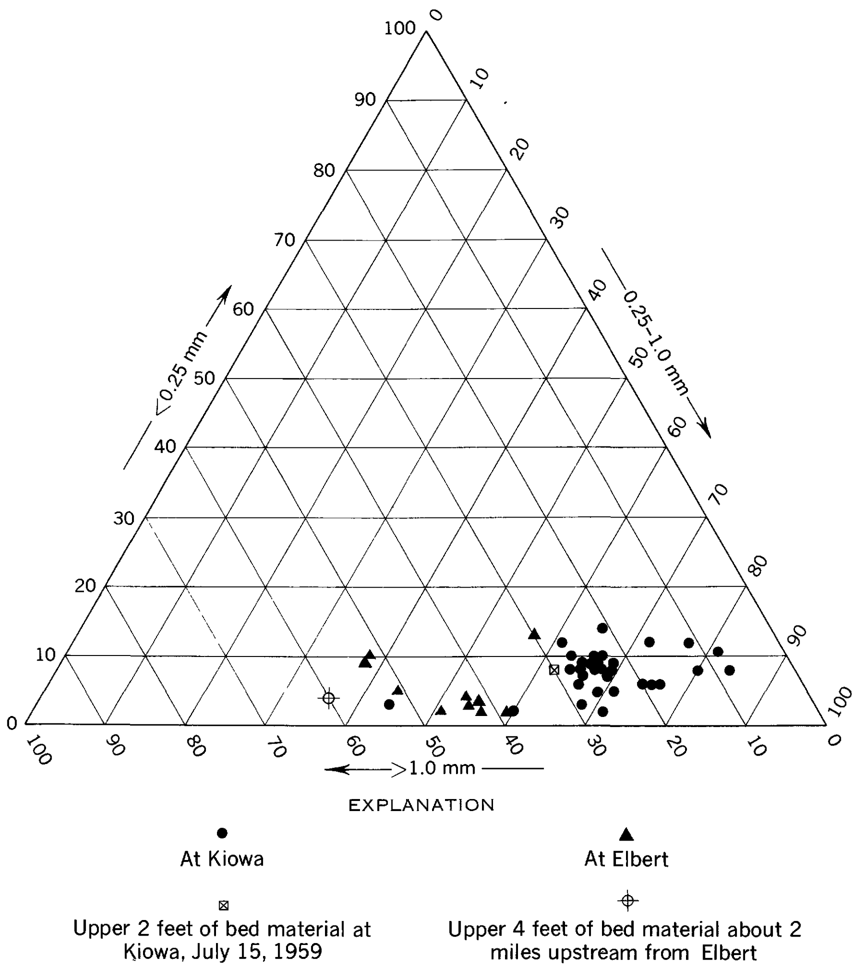

FIGURE 32.—Particle-size distribution of bed material, Kiowa Creek at Elbert and Kiowa Creek at Kiowa.

of bed material were obtained during a period of no flow at the Kiowa gaging section; however, the particle-size distribution of this material was almost the same as the particle-size distribution of surface material collected during a period of flow on the following day. Figure 33 shows depth to bedrock and thickness of sandfill on July 21, 1959, at different sections of the 800-foot artificial channel in which the Kiowa gaging station is located. The depth to bedrock was relatively shallow and uniform across the upstream end of this channel. At and near the gaging section, the bedrock surface was somewhat deeper near the center of the channel than near the banks. Maximum depth to bedrock was somewhat greater at and near the gaging station than near the upstream end of this reach. At the downstream end of the 800-foot reach, the maximum depth to bedrock was nearly 6 feet below

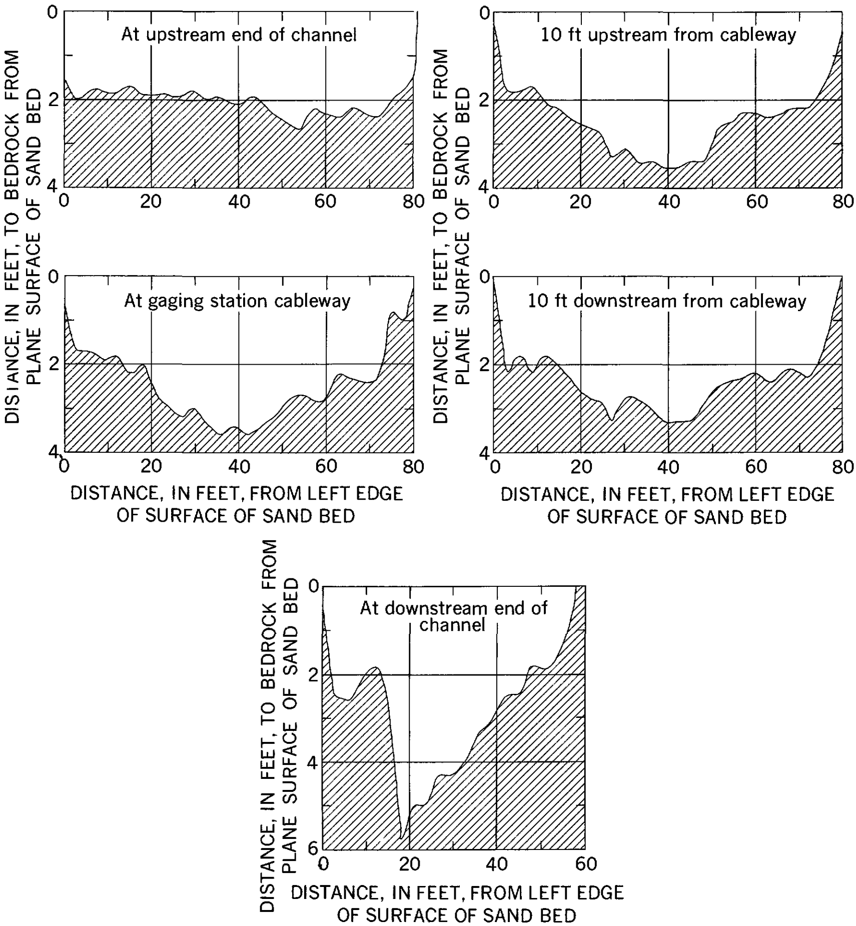

FIGURE 33.—Bedrock profiles across the channel of Kiowa Creek at Kiowa.

the surface of the level sandfill. If, as field observations indicate, this reach scours to bedrock during some periods of high discharge, an estimated 8,000 tons of sand is removed from the reach. Scour probably begins at the downstream end of the reach and progresses upstream; no observations have been made to determine if scour to bedrock progresses all the way to the upstream end of the reach.

The thickness of sand-and-gravel channel deposits in other reaches of Kiowa Creek was not determined. However, Vanoni (written commun.) sampled bed material to a depth of 10 feet at three channel cross sections of Kiowa Creek upstream from Elbert. The material obtained at depths of 0–4 feet had a "geometric mean sieve size" of 1.06 mm; the material at depths of 8–10 feet had a geometric mean sieve size of 1.47 mm.

TOTAL SEDIMENT DISCHARGE

Some methods for computing total sediment discharge have been discussed in detail by Colby and Hembree (1955) and by Hubbell and Matejka (1959).

Computation of total sediment discharge by the modified Einstein procedure requires concurrent determinations of suspended-sediment characteristics, bed-material characteristics, and hydraulic characteristics such as water discharge, cross-sectional area of flow, mean velocity of flow, and mean depth of flow. Because very rapid changes in stage and flow conditions are characteristic of Kiowa Creek and because applicable concurrent data on both sediment and hydraulic characteristics are difficult to obtain, few determinations of total sediment discharge of Kiowa Creek at Kiowa have been made.

A method for approximating unmeasured sediment discharge from mean velocity and concentration of suspended sand was devised by Colby (1957). Results of computations of unmeasured sediment discharge by the Colby method and of total sediment discharge by the modified Einstein method for Kiowa Creek at Kiowa are shown in the following table:

Date	Discharge (cfs)	Measured suspended sediment		Total sediment discharge—modified Einstein method (tons per day)	Unmeasured sediment discharge—Colby method (tons per day)
		Concentration (ppm)	Discharge (tons per day)		
May 23, 1956	158	24,000	10,240	15,920	3,200
May 17, 1957	249	14,900	10,000	21,200	4,900
March 25, 1960—11:30 a.m.	254	5,680	3,900	9,380	3,200
March 25, 1960—7:25 p.m.	472	11,000	14,000	32,300	6,600

The data in the table indicate a large difference between unmeasured sediment discharges computed by the two methods. For example, on May 17, 1957, unmeasured sediment discharge as indicated by the modified Einstein method was 11,200 tons per day (total sediment discharge minus measured suspended-sediment discharge); unmeasured sediment discharge computed by the Colby method was only 4,900 tons per day.

Current methods for computing total sediment discharge and unmeasured sediment discharge may give unreliable results, and the reliability of the results is extremely difficult to evaluate. Nevertheless, the computations indicate that the unmeasured sediment discharge is a significant part of the total sediment discharge of Kiowa Creek at Kiowa. The ratio of measured sediment discharge to unmeasured sediment discharge may be somewhat higher at the Kiowa gaging section than in most of the natural channel reaches.

MAJOR SOURCES OF SEDIMENT

No data are available on the relative magnitude of sheet erosion, gully erosion, and channel erosion in Kiowa Creek basin. Also, inadequate quantitative data are available on precipitation intensity, soil characteristics, and vegetation density and characteristics as related to erosional characteristics and rates in Kiowa Creek basin. Field observations suggest that sheet erosion, gully erosion, and main-stem channel erosion probably rank in that order as contributors of sediment to Kiowa Creek.

Measurements made on aerial photographs indicate that the headcut of numerous gullies advanced significantly between 1937 and 1951. Poor definition in some of the photographs and distortions and slight differences in scale between photographs may have resulted in some error in the measurements. Headcut advances of about 60–440 feet were measured; drainage areas upstream from the headcuts ranged from about 30 to 200 acres. Figure 34 shows the magnitude of headcut advance of selected gullies in Kiowa Creek basin. For the nine gullies measured, drainage from about 1,050 acres resulted in a combined headcut advance of about 2,700 feet. Accurate determination of width and depth of gullies could not be made from the aerial photographs. However, if an average width of 10 feet, an average depth of 5 feet, and an average volume weight of 100 pounds per cubic foot of removed material are assumed, about 6,750 tons of material was removed by headcut advances in the nine gullies between 1937 and 1951. These headcut advances were the largest and most obvious advances discernible on photographs of the entire area, and they probably represent the maximum rates of gully growth to be expected in the area.

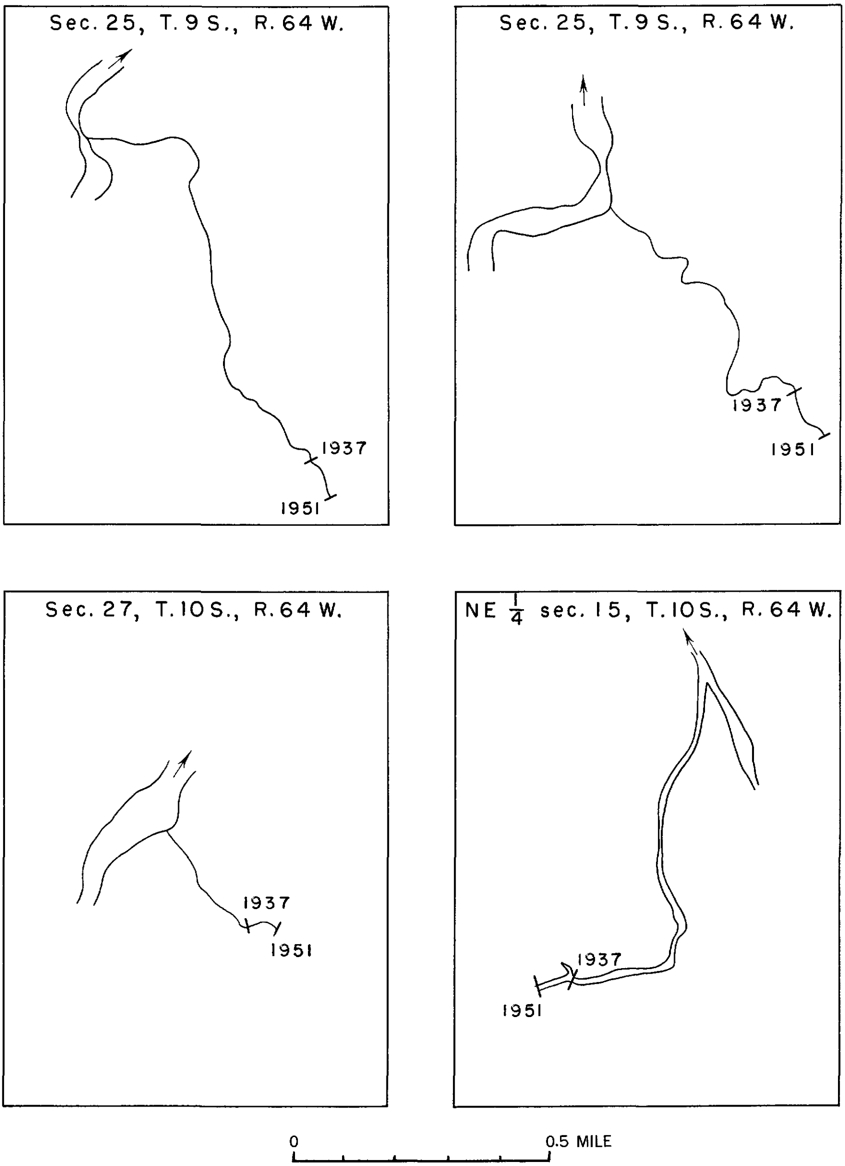

FIGURE 34.—Maps showing location and extent of selected gully-headcut advances between 1937 and 1951. Arrow indicates direction of streamflow.

Comparison of 1937 and 1951 aerial photographs revealed only a few places where the channel had changed or shifted noticeably. (See fig. 35.) Abandonment of some stream meanders shown in figure 35 may have been artificially induced. Abandonment of main-stem

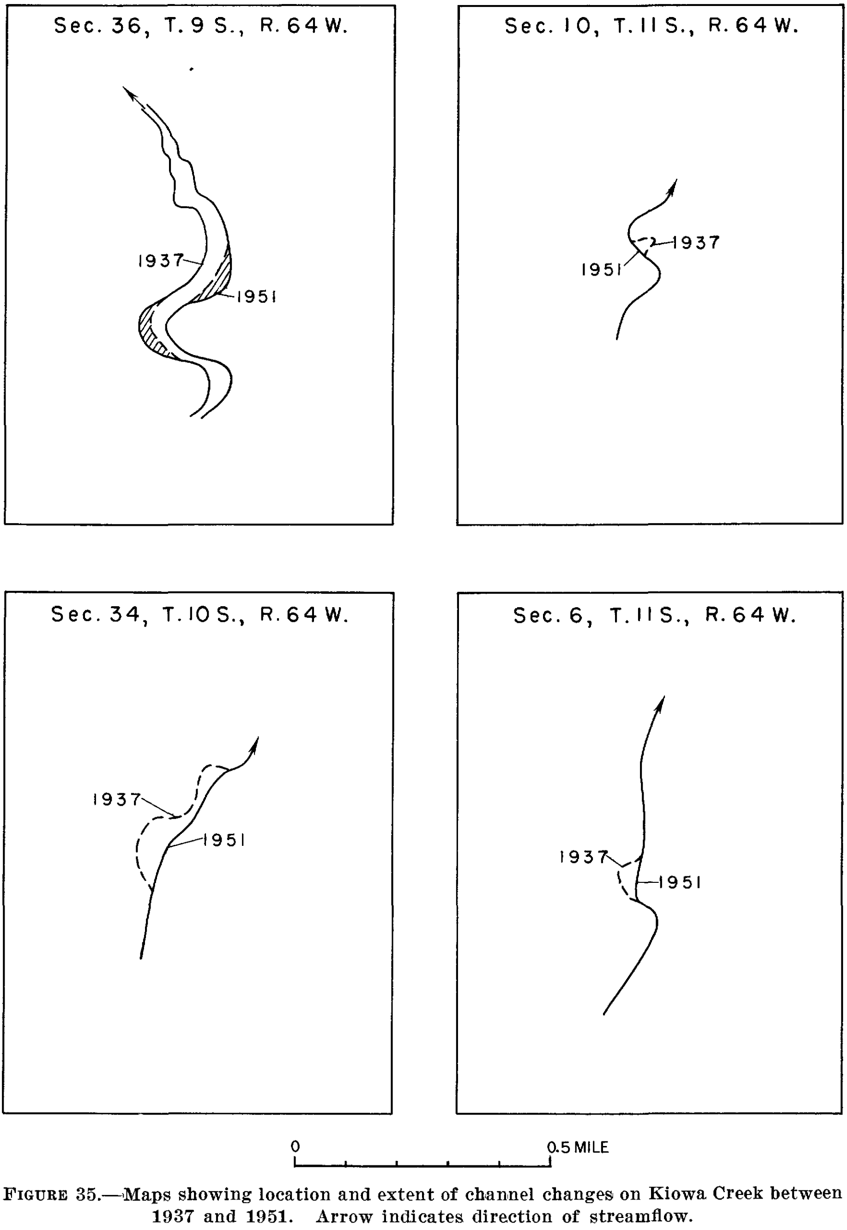

FIGURE 35.—Maps showing location and extent of channel changes on Kiowa Creek between 1937 and 1951. Arrow indicates direction of streamflow.

meanders and formation of new channels probably have a minor influence on the long-term sediment discharge of Kiowa Creek; bank slump and erosion throughout long reaches of the stream probably have a much greater influence.

CONCLUSIONS

From May 1955 to September 1961, investigations of runoff and fluvial sediment have been made at three sites in Kiowa Creek basin. The investigations have resulted in the following conclusions:

1. Both the water discharge and the sediment discharge of Kiowa Creek at Elbert and at Kiowa have been significantly affected by upstream development since 1955.
2. Detention structures have probably been more effective than land-treatment measures in reducing the sediment discharge of Kiowa Creek at Elbert and at Kiowa.
3. Water seepage from the channel is appreciable in certain reaches of Kiowa Creek upstream from Elbert and between Kiowa and Elbert.
4. Sediment is necessarily deposited in reaches of the stream where surface flow disappears during many runoff periods. The magnitude of deposition has not been determined.
5. The lack of significant flow in Kiowa Creek upstream from Elbert has resulted in the channel's becoming heavily vegetated with both perennial and annual forms in many reaches. The channel vegetation is conducive to water seepage from the channel and to sediment deposition in these reaches.
6. Sediment deposition in K–79 Reservoir and discharge from the reservoir may have been affected significantly by two upstream reservoirs.
7. For the period April 1956–August 1957, trap efficiency of K–79 Reservoir was about 65 percent. Most of the deposition in the reservoir and the sediment discharge from the reservoir resulted from the intense storm of July 30, 1957.
8. Flocculation of sediment probably had only a minor effect on sediment deposition in K–79 Reservoir.
9. The total sediment discharge is significantly greater than the suspended-sediment discharge during periods of significant flow at Kiowa Creek at Kiowa. Because the site at Kiowa is in an atypical reach of Kiowa Creek, sediment-transport characteristics at the site may also be atypical.
10. Information obtained since 1956 is not adequate for accurate evaluation of sources of fluvial sediment in the basin.

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