CHANNEL MORPHOLOGY OF COTTONWOOD CREEK NEAR COTTONWOOD, CALIFORNIA, FROM 1940 TO 1985

By *William F. McCaffrey, James C. Blodgett,* and *John L. Thornton*

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CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer to use metric (International System) units, the conversion factors for inch-pound units used in this report are listed below.

Multiply inch-pound unit	By	To obtain metric unit
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
statute mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
cubic yard (yd^3)	0.7645	cubic meter (m^3)

Degrees Fahrenheit can be converted to degrees Celsius by using the formula:

$$\text{Temp °C} = (\text{temp °F} - 32)/1.8.$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NVGD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

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ABSTRACT

Proposed construction of two dams on Cottonwood Creek has caused concern that the resulting modification of streamflow will alter downstream channel morphology. Baseline information on the present channel is based on streamflow data obtained from 1940 to 1985, field surveys made during 1982-83, and aerial photographs taken between 1940-84. Cottonwood Creek has an alluvial channel that consists of a braided inner main channel within a broader flood channel. No clear topographic break exists between the main and flood channels. The main channel is subject to large and rapid position shifts within the flood channel, which meanders within the valley fill. The flood-channel position has remained relatively stable since 1940.

Data obtained for Cottonwood Creek describe main channel characteristics of bankfull discharge, channel slope, mean streambed elevation, bed-material size, sinuosity, and lateral migration.

Bankfull discharge has been estimated at 20,000 cubic feet per second with a return interval of 1.8 years. The mean slope for Cottonwood Creek is 0.0017, and the mean slope for South Fork Cottonwood Creek is 0.0020. No correlation was established between the mean low-flow bed elevation and the 1-, 3-, and 7-day maximum discharges. Fluctuations of bed elevation appear to be random changes associated with local bed-form movement and channel braiding. The mean streambed elevation at the station Cottonwood Creek near Cottonwood appears to have been in equilibrium since 1942 with no apparent trend of aggradation or degradation.

Mean size of bed material, obtained by the point-count method, ranged from 39.6 to 82.3 millimeters. Mean grain size obtained by sieve analysis ranged from 3.0 to 24.3 millimeters. Sinuosity for the low-flow channel ranged from 1.04 to 1.47 from 1940 to 1984. The mean sinuosity in 1984 was 1.21. Cumulative lateral migration for Cottonwood Creek during this period decreased in the upstream direction; cumulative migration for South Fork Cottonwood Creek was relatively constant. The cause of the difference in migration trend between Cottonwood Creek and South Fork Cottonwood Creek is possibly related to the width of the flood channel. Net lateral migration for Cottonwood Creek during this period has been predominantly towards the right bank, whereas the net lateral migration for South Fork Cottonwood Creek has no apparent trend.

INTRODUCTION

Two multipurpose dams for flood control and irrigation have been proposed by the U.S. Army Corps of Engineers within the drainage of Cottonwood Creek in Shasta and Tehama Counties of northern California. Information is needed on the possible effects of dam construction on channel morphology downstream from the damsites and, in particular, the effects of reduced bed load and peak streamflows on channel alignment. The U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, investigated channel form and migration of Cottonwood Creek and South Fork Cottonwood Creek (fig. 1), so that future studies may evaluate the possible effects of the proposed dams.

Purpose and Scope

This report presents baseline information on channel form as described by bankfull discharge, channel slope, mean streambed elevation, bed-material size, sinuosity, and lateral migration. The reaches studied include Cottonwood Creek downstream from the proposed Dutch Gulch damsite and South Fork Cottonwood Creek downstream from the proposed Tehama damsite (fig. 2).

Work for this study was accomplished in two phases. The first phase, which consisted of surveys of channel profiles, cross sections (fig. 2), and high-water levels, was done in 1982 and 1983; samples of bed material also were collected. The second phase, a study of channel pattern and lateral migration that used aerial photographs for 1940-84, was done between 1984 and 1986. Streamflow data were obtained from several gaging stations operated for various periods from 1940 to 1985.

Approach

Cottonwood Creek was divided into six consecutive reaches, and South Fork Cottonwood Creek was divided into three consecutive reaches (fig. 2 and table 1). Various reaches were selected on the basis of gaging-station locations and cross sections where additional streamflow data were obtained.

The sinuosity and lateral migration of the Cottonwood Creek channel pattern were determined from aerial photographs taken in 1940, 1952, 1966, 1972, 1979, and 1984. The six sets of aerial photographs divided the 44-year time span into five intervals: 1940-52, 1952-66, 1966-72, 1972-79, and 1979-84. All aerial photographs provided information on the channel position at times of low flow.

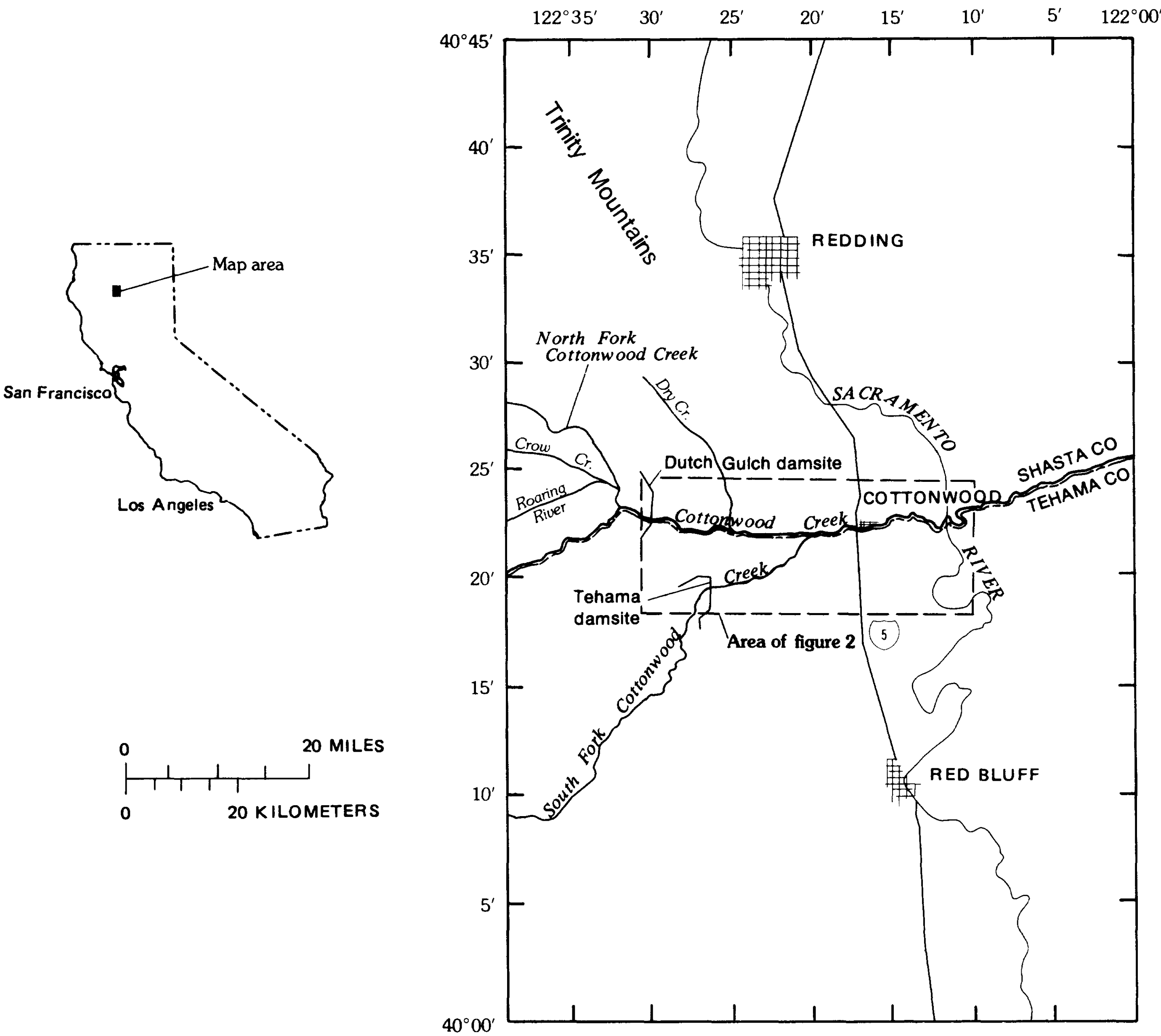
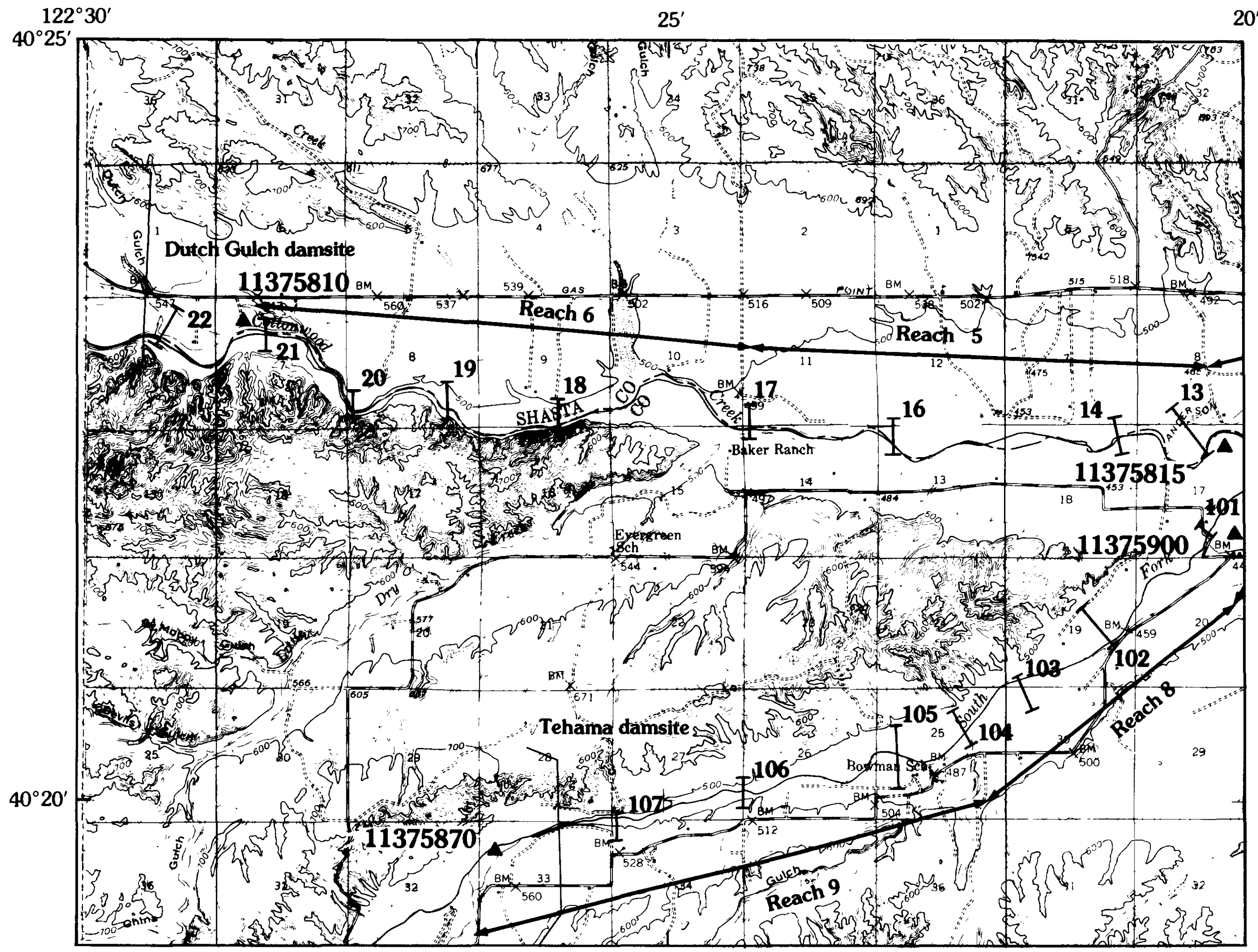


FIGURE 1.—Index map of study area.



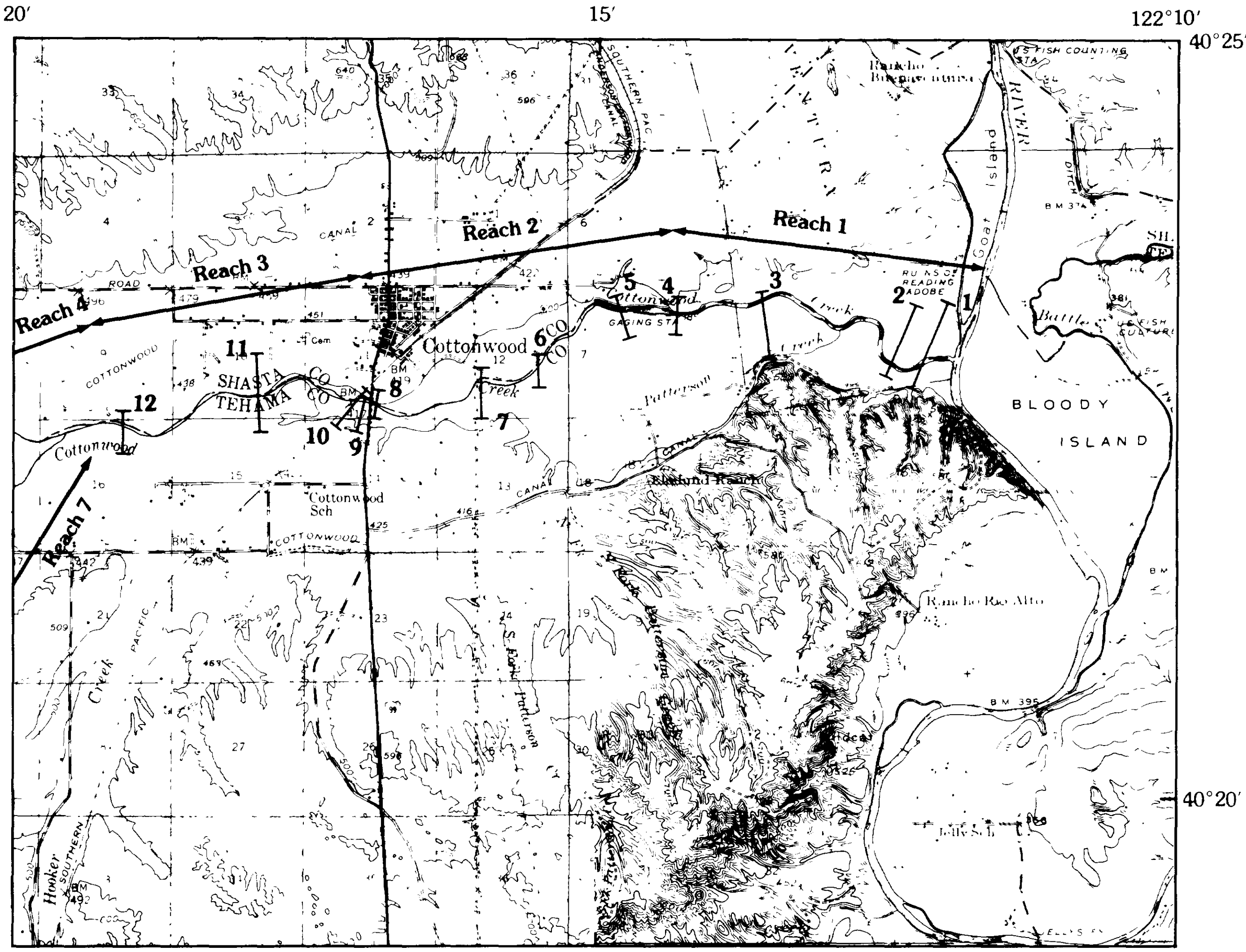
Base from U.S. Geological Survey
French Gulch, 1945, Ono, 1952; 1:62,500,
Cottonwood, Gulch, Hooker, Mitchell, Olinda,
1965; 1:24,000

0 1 2 3 4 MILES

0 1 2 3 4 KILOMETERS

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

FIGURE 2.– Location of gaging stations and cross sections.



EXPLANATION

5 ├───┤ CROSS SECTION AND NUMBER

11375810 ▲ GAGING STATION AND NUMBER

Reach 2 ◄───► REACH AND NUMBER

FIGURE 2. – Continued.

A photomosaic was created for each of the 6 years, and the position of the low-flow channel centerline was transferred onto an overlay, which was then reproduced at a common scale. Channel and valley lengths for each reach and the areas covered by the lateral shift between channel centerlines on successive overlays were determined with a digitizer. The length and area data thus measured were used to calculate sinuosity and lateral migration. Estimates of lateral migration are not intended to represent the volume of channel erosion but to indicate the amount and rate of channel movement. The data for Cottonwood Creek and for South Fork Cottonwood Creek have been treated as separate systems to detect differences between the two stream channels.

Table 1. - Description of study reaches on Cottonwood Creek

[Location of reaches shown in figure 2. Numbers in parentheses are U.S. Geological Survey gaging-station numbers]

Reach	Description
	Main channel of Cottonwood Creek
1	Mouth of Cottonwood Creek to station Cottonwood Creek near Cottonwood (11376000).
2	Station Cottonwood Creek near Cottonwood to old Highway 99 bridge.
3	Old Highway 99 bridge to cross section 12.
4	Cross section 12 to station Cottonwood Creek above South Fork, near Cottonwood (11375815).
5	Station Cottonwood Creek above South Fork, near Cottonwood to cross section 17.
6	Cross section 17 to station Cottonwood Creek near Olinda (11375810).
	South Fork Cottonwood Creek
7	Cross section 12 to station South Fork Cottonwood Creek at Evergreen Road, near Cottonwood (11375900).
8	Station South Fork Cottonwood Creek at Evergreen Road, near Cottonwood to cross section 104.
9	Cross section 104 to station South Fork Cottonwood Creek near Olinda (11375870).

Previous Investigations

Streamflow and geology at the two proposed damsites are described in reports by the U.S. Army Corps of Engineers (1977; 1980; 1983). Ground-water characteristics in the Cottonwood basin are described by Bryan (1923), Pierce (1983), Fogelman and Evenson (1985), and Evenson and Kinsey (1985). Faulting in the Cottonwood Creek area was evaluated by Harlan Miller Tait Associates (1984). Stream-terrace deposits along Cottonwood Creek were studied by Steele (1979). The use of aerial photographs in the study of stream patterns has been described by Brice (1977, 1982); he also discusses some common errors and problems associated with the use of aerial photographs in studies of stream patterns.

PHYSICAL SETTING

The Cottonwood Creek drainage basin is in the northern end of the Sacramento Valley (fig. 1). The stream flows eastward from the Trinity Mountains through foothills to the Sacramento River. The study area consists of the lower reaches of Cottonwood Creek extending upstream from the mouth to Dutch Gulch and up South Fork Cottonwood Creek to the mouth of Dry Creek (fig. 2). The lower reaches of Cottonwood Creek define the Shasta-Tehama County line. The town of Cottonwood is situated on the left bank and along Interstate Highway 5 (fig. 1), between the cities of Redding and Red Bluff. Access to most sections of the stream channel is restricted due to the private ownership of lands adjacent to the creek.

The Cottonwood Creek drainage basin has a total relief of 7,747 feet. In the study area, Cottonwood Creek rises 153 feet in 17 miles from its mouth on the Sacramento River. Topographic relief along the lower reaches of Cottonwood Creek is 300 feet or less. South Fork Cottonwood Creek rises 70 feet in 6.6 miles from its confluence with Cottonwood Creek. The drainage area of Cottonwood Creek upstream from the station Cottonwood Creek near Cottonwood (11376000) is 927 mi^2. The station is located 2.5 miles upstream from the creek mouth. Above the confluence with Cottonwood Creek, South Fork Cottonwood Creek drains 397 mi^2 and Cottonwood Creek drains 478 mi^2.

The climate in the study area is characterized by hot dry summers and cool moist winters. Mean annual temperature is 62 °F and ranges from a winter low of 5 °F to a summer high of 110 °F (U.S. Army Corps of Engineers, 1977, p. 6). Precipitation varies considerably from place to place within the basin and from year to year. Annual precipitation ranges from 25 inches at lower elevations to 70 inches at higher elevations. Average annual precipitation for the entire basin is 36.6 inches (U.S. Army Corps of Engineers, 1977, p. 6).

Cottonwood Creek is a braided channel with perennial streamflow. Channel width generally ranges from 50 to 150 feet at times of low flow. The channel boundaries are in most places alluvium and consist of unconsolidated sand, gravel, and cobbles. The flood plain has a variable width which generally broadens to a wide, poorly defined plain in the downstream direction.

Natural riparian vegetation along the lower reaches of Cottonwood Creek is oak-grassland and chaparral. Some areas adjacent to the lower reaches are under cultivation for pasture. Vegetation along the streambanks is sparse and, where present, may inhibit migration of the stream. Denser vegetation is found along the margins of the flood plain.

SURFICIAL GEOLOGY AND MINING

The area surrounding Cottonwood Creek has been classified as a dissected upland. This upland, which fringes the Sacramento Valley, is underlain principally by structurally deformed, poorly consolidated to unconsolidated continental deposits of Pliocene and Pleistocene age (Poland and Evenson, 1966). Cottonwood Creek and its tributaries have downcut into the partly consolidated deposits developing a pronounced dendritic pattern. The regional geology has been compiled by Strand (1962) and summarized by Hackel (1966) and the U.S. Army Corps of Engineers (1983).

Principal Geologic Units

The Cottonwood Creek streambed lies on the Pliocene Tehama Formation. In some reaches the upper part of the formation is exposed to the stream channel and consists of a series of poorly consolidated, poorly sorted, sand and sandy clay interbeds with occasional gravel lenses (Anderson and Russell, 1939, p. 233; U.S. Army Corps of Engineers, 1983, p. E-2). Marliave (1932) noted that these beds are resistant enough to deflect flow of the Sacramento River in a reach just downstream from the mouth of Cottonwood Creek; it is inferred that these beds, where exposed, could also affect the location of the Cottonwood Creek channel.

The Pleistocene Red Bluff Formation lies unconformably above the Tehama Formation and is differentiated from the Tehama Formation by its coarser clast size and reddish stain (Anderson and Russell, 1939, p. 235). However, Steele (1979, p. 14) indicated that these formations may be indistinguishable in some locations. The Red Bluff Formation is found primarily north of Cottonwood Creek and on the higher elevations of the interfluves away from the streambanks and flood plain (Strand, 1962; Steele, 1979). The Red Bluff Formation is poorly indurated and offers little resistance to stream erosion (Marliave, 1932, p. 465).

Most land adjacent to the flood plain in the study area has been mapped by Steele (1979) as a sequence of four erosional or "strath" river terraces. The erosional terraces are abandoned flood plains developed primarily on beds of the Tehama Formation. The terrace surfaces consist of a thin veneer of unconsolidated stream sediments that seldom exceed a thickness greater than the depth of flood scour (Steele, 1979, p. 21).

Regional Structure

Structural deformation in the area of Cottonwood Creek exerts some influence on the stream-channel characteristics. The Tehama Formation and, to a lesser extent, the Red Bluff Formation have been deformed since deposition. Following the deposition of the Red Bluff Formation, episodic uplift of the northern Sacramento Valley caused Cottonwood Creek to erode its channels, dissecting the uplands and leaving a series of "ingrown" meanders in the foothills west and south of the study area (Steele, 1979, p. 72). The distribution of terrace deposits along South Fork Cottonwood Creek indicates that the channel has shifted 1.9 miles to the north-northwest (Steele, 1979, p. 74).

Fault mapping by Helley and others (1981) in the vicinity of Cottonwood Creek suggests the possibility that the Battle Creek fault extends west of the Sacramento River along Cottonwood Creek and South Fork Cottonwood Creek. This fault extension may exert some control on the drainage pattern and location of Cottonwood Creek (Helley and others, 1981, p. 1).

Mining

Between 1890 and 1942, 13 placer gold-mining operations were worked along Cottonwood Creek and its tributaries in Shasta County (Lydon and O'Brien, 1974). The early mining operations used hydraulic-mining techniques; later operations used dredges. The dredging operations ceased in 1942 (Lydon and O'Brien, 1974), after excavating 390,500 yd^3 of gravel on the Roaring River and Crow Creek--both tributaries to Cottonwood Creek and approximately 2 miles upstream from the Dutch Gulch damsite. Vast deposits of dredge tailings are still found along the stream channels of North Fork and Middle Fork Cottonwood Creek, Roaring River, Crow Creek, and Dry Creek (fig. 1).

During periods of flooding, these tailings may be washed into Cottonwood Creek and transported to the Sacramento River. Given the volume of material mined and the recency of that mining, remnants of mine tailings are probably still stored in the Cottonwood Creek channel. Gilbert (1917, p. 46) found that mining debris in the Sierra Nevada was stored in temporary deposits on the alluvial plain at the mountain front and in stream channels 20 years after the cessation of mining operations there.

Since 1961, the Anderson-Cottonwood Concrete Products plant has excavated sand and gravel from a pit on the north side of the Cottonwood Creek flood plain at Cottonwood (fig. 1). During winter months the pit is allowed to flood (Lydon and O'Brien, 1974) and acts as a sediment trap.

CHANNEL MORPHOLOGY

Natural stream channels are commonly classified on the basis of characteristic channel patterns as straight, sinuous, meandering, and braided. These common patterns are manifestations of channel adjustment to cross section, discharge, and slope. There are no sharp boundaries between characteristic channel patterns, but rather the patterns represent a continuous spectrum of possible patterns. Cottonwood Creek can be described as a braided point-bar channel pattern according to a descriptive scheme developed by Brice (1982). Brice based his classification on 14 properties, all of which are readily discernible from aerial photographs except for flow habit, bed material, and bank material.

Stream braiding is the process in which the coarser bedload is deposited within the stream channel, forming bars which redirect the streamflow towards either outside bank, and the scouring of a new thalweg. A braided stream is characterized by anabranching of streamflow about bars built upon the alluvial bed. The branching may occur rapidly and result in frequent changes in the location of the thalweg. This is a normal process for braided streams, such as Cottonwood Creek, and serves to distinguish braided channels from straight and meandering channels.

Twenty-eight cross sections (fig. 2) were surveyed along Cottonwood Creek and South Fork Cottonwood Creek. These cross-sections show the high width-to-depth ratio which characterizes the Cottonwood Creek channel. When viewed sequentially (figs. 3 and 4), the cross sections illustrate the branching of the main channel into multiple channels, a characteristic of a braided stream.

The braided channel pattern of Cottonwood Creek and South Fork Cottonwood Creek within the study area is contained within a larger sinuous flood channel. The flood-channel position is relatively stable while the main stream channel is braided and migrates within the flood channel, similar to that described for the Yuba River by Gilbert (1917, p. 60). Characteristics of the Cottonwood Creek channel described in this study are, therefore, those of the main channel and not the flood channel. The main-channel properties described in the following sections of this report are bankfull discharge, channel slope, mean streambed elevation, bed-material size, sinuosity, and lateral channel migration.

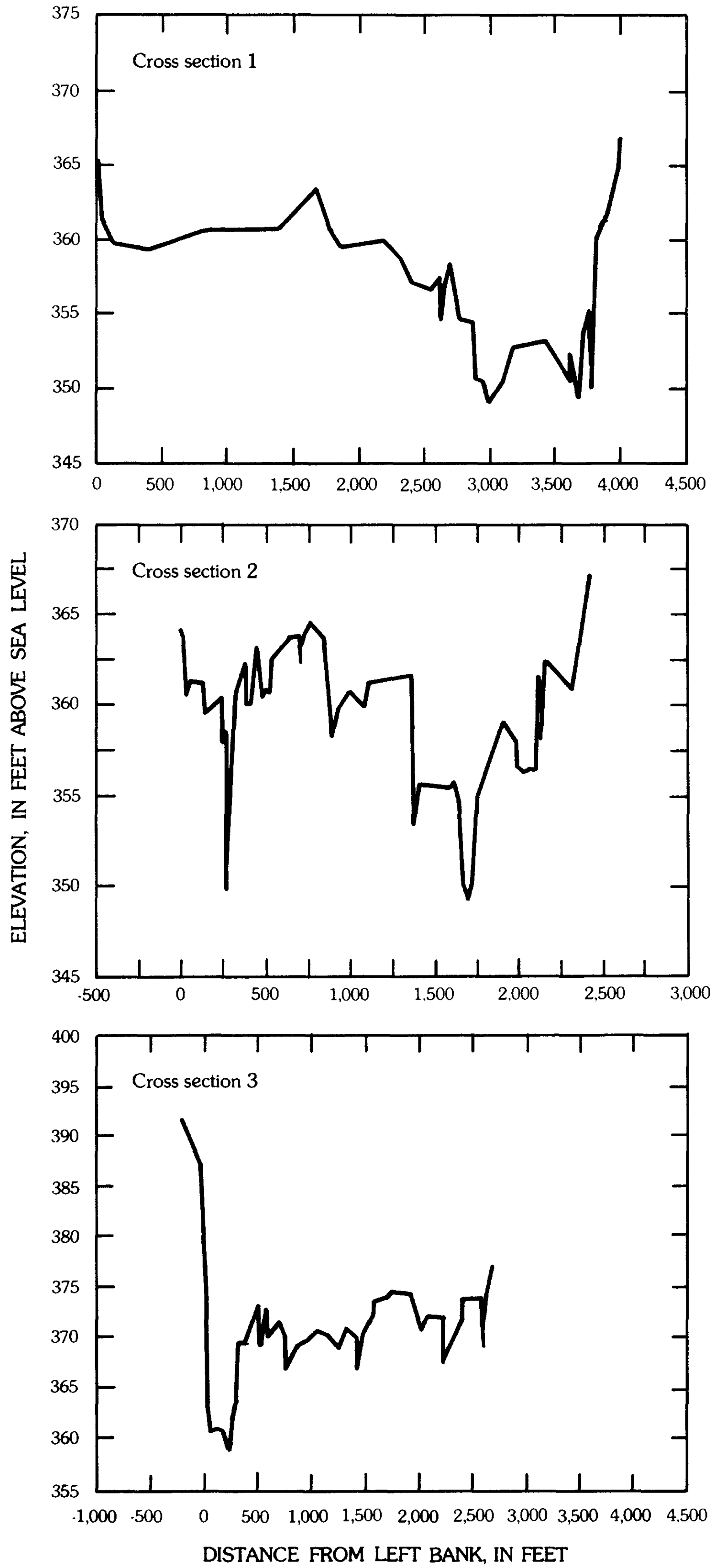


FIGURE 3.– Cross sections of Cottonwood Creek.

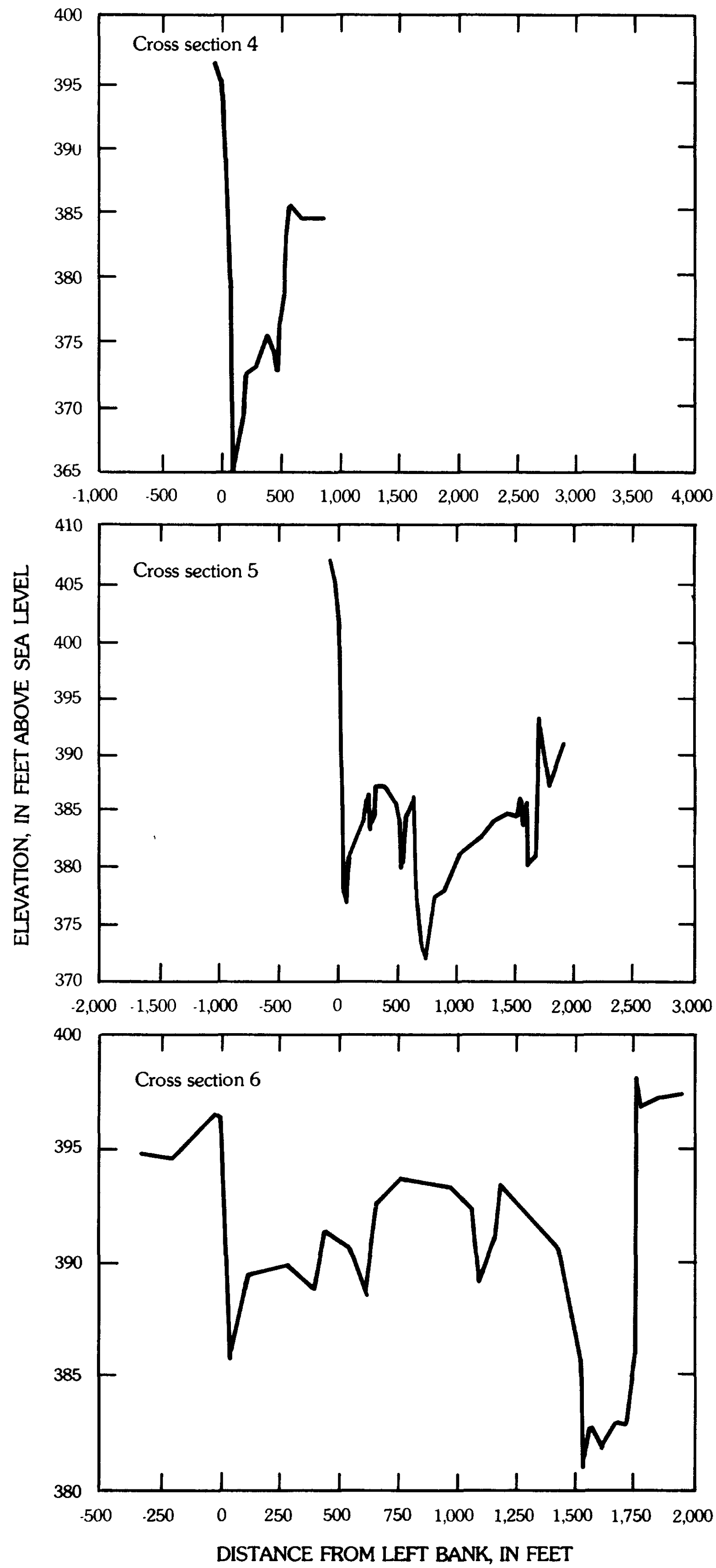


FIGURE 3.— Cross sections of Cottonwood Creek— Continued.

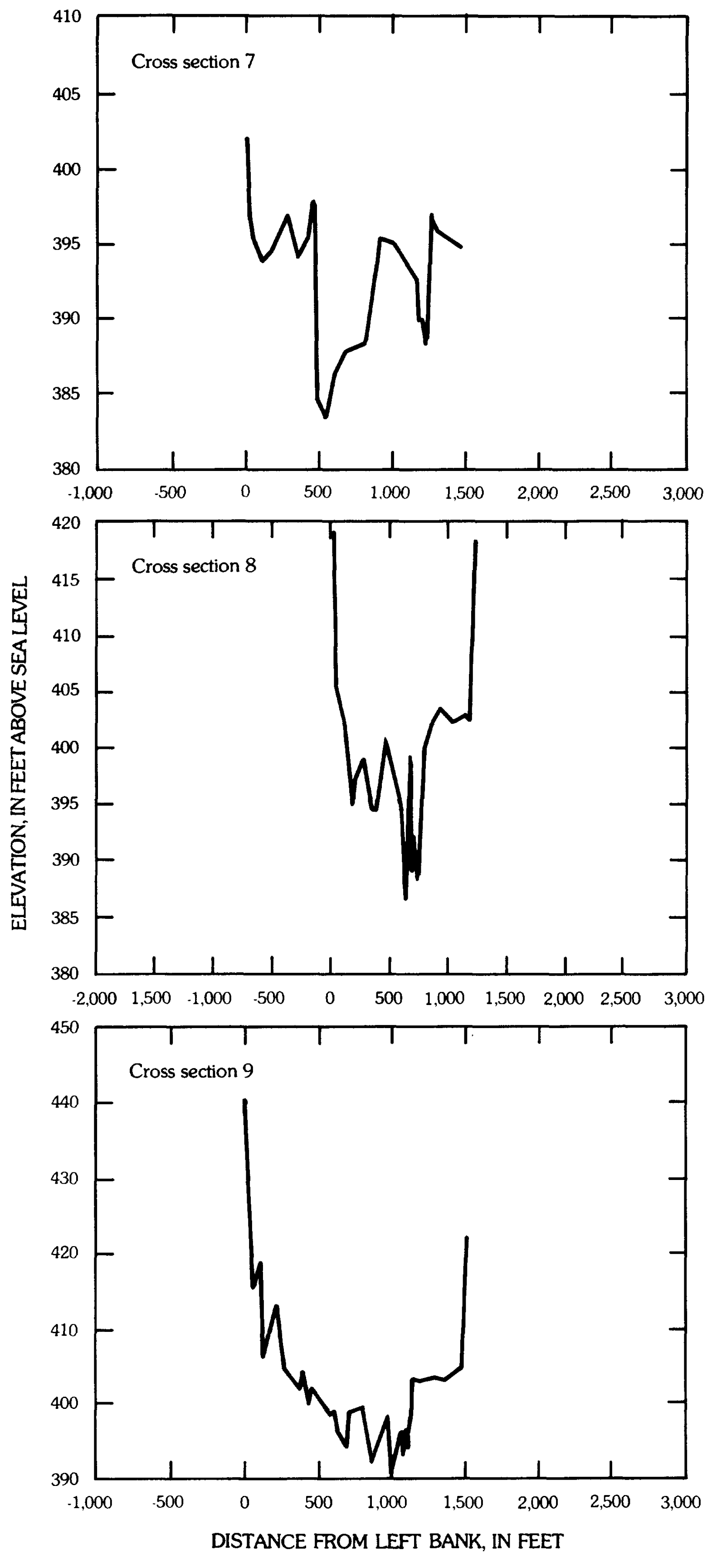


FIGURE 3.– Cross sections of Cottonwood Creek– Continued.

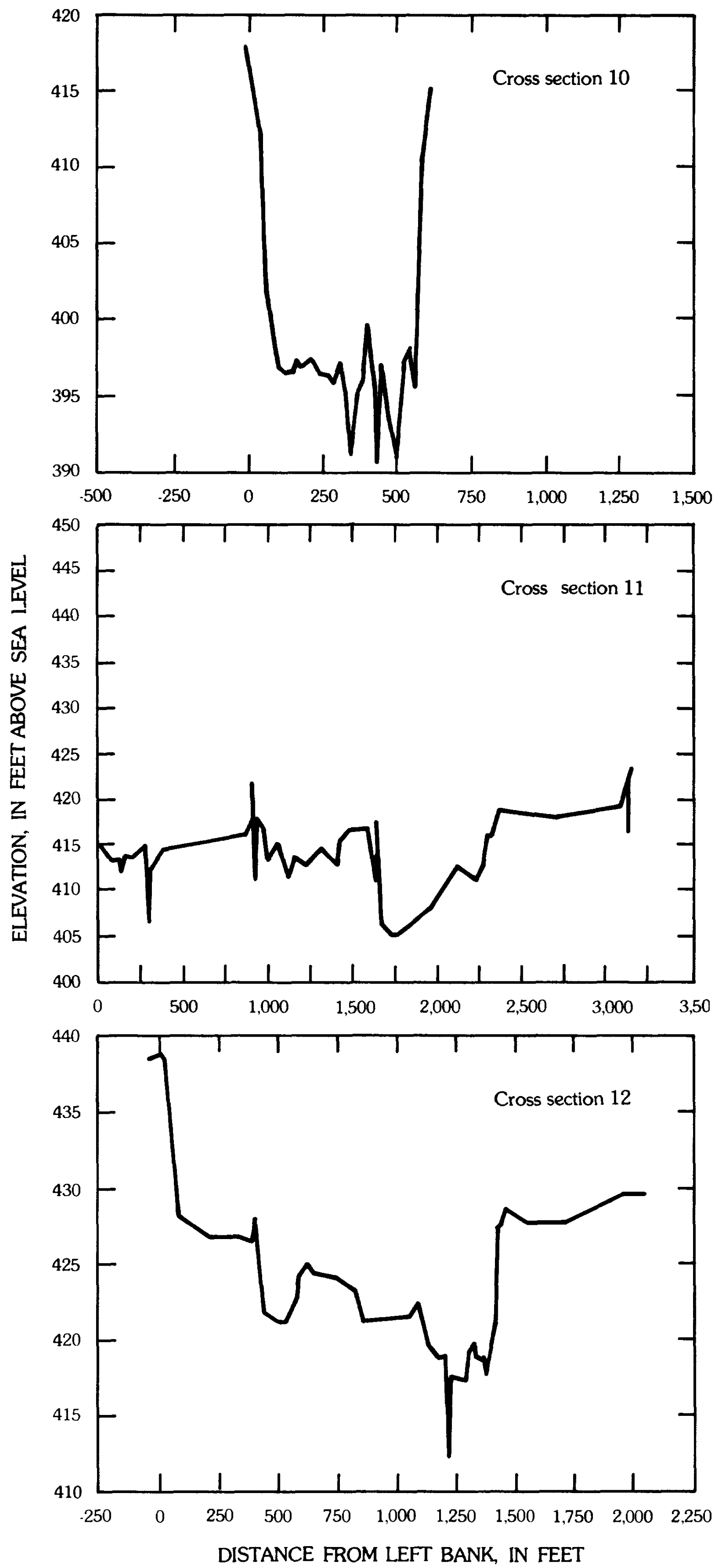


FIGURE 3.— Cross sections of Cottonwood Creek— Continued.

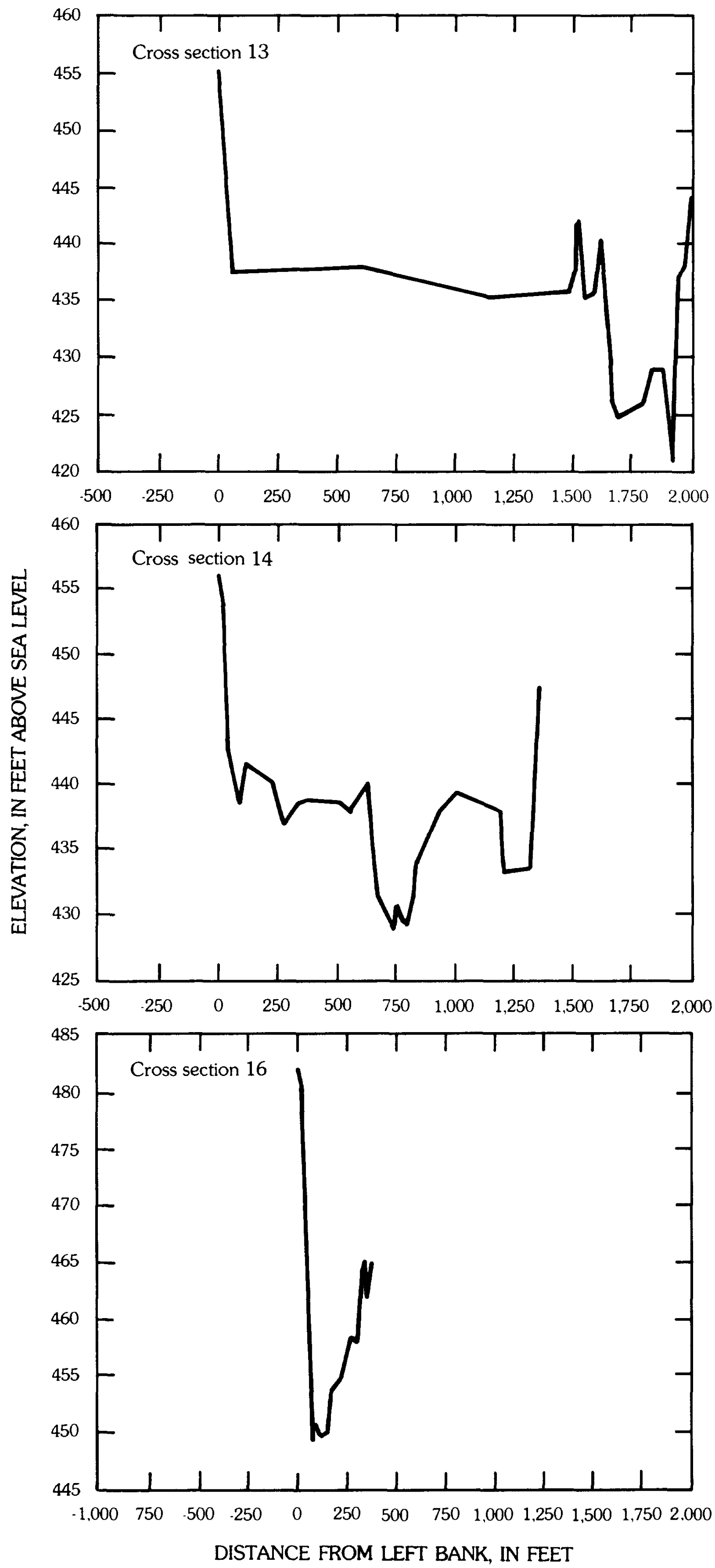


FIGURE 3.— Cross sections of Cottonwood Creek— Continued.

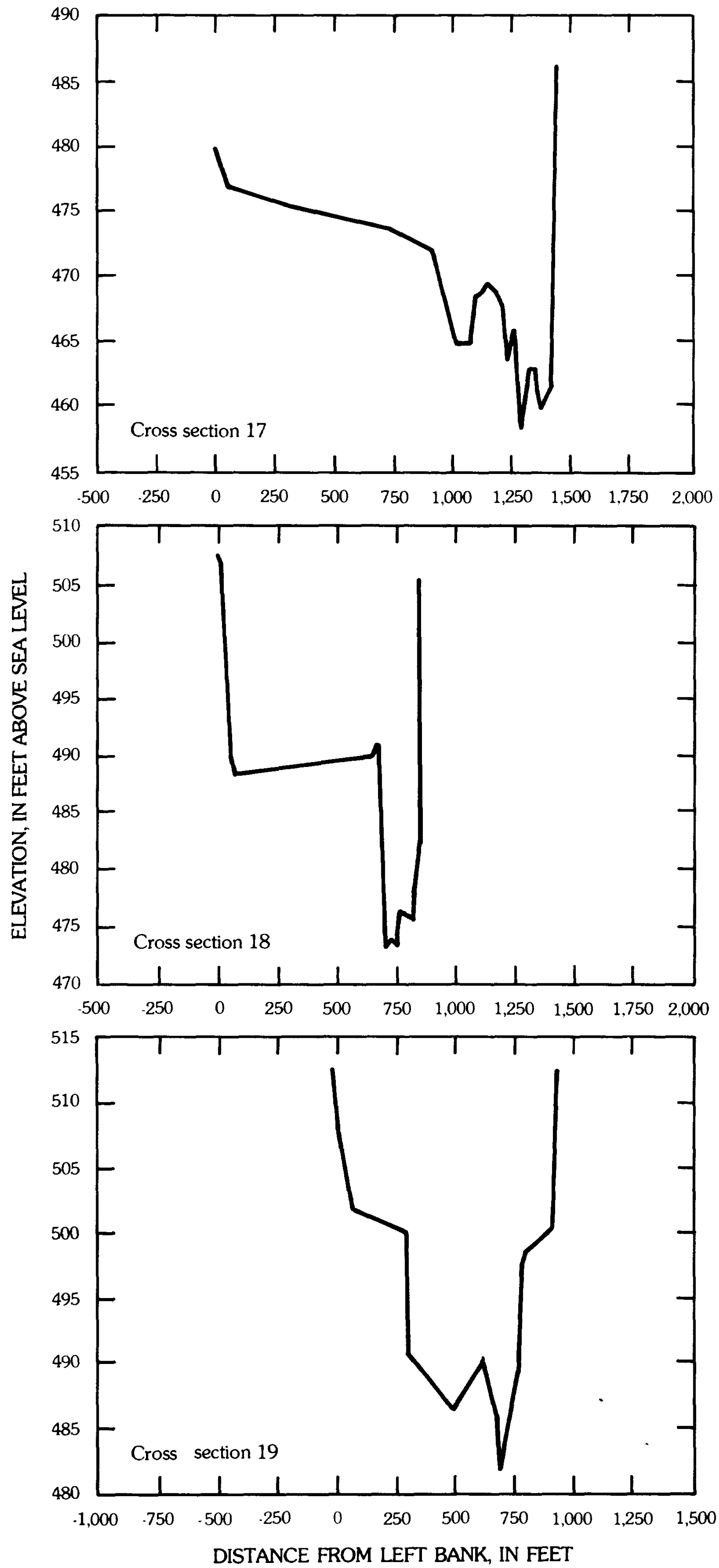


FIGURE 3.— Cross sections of Cottonwood Creek— Continued.

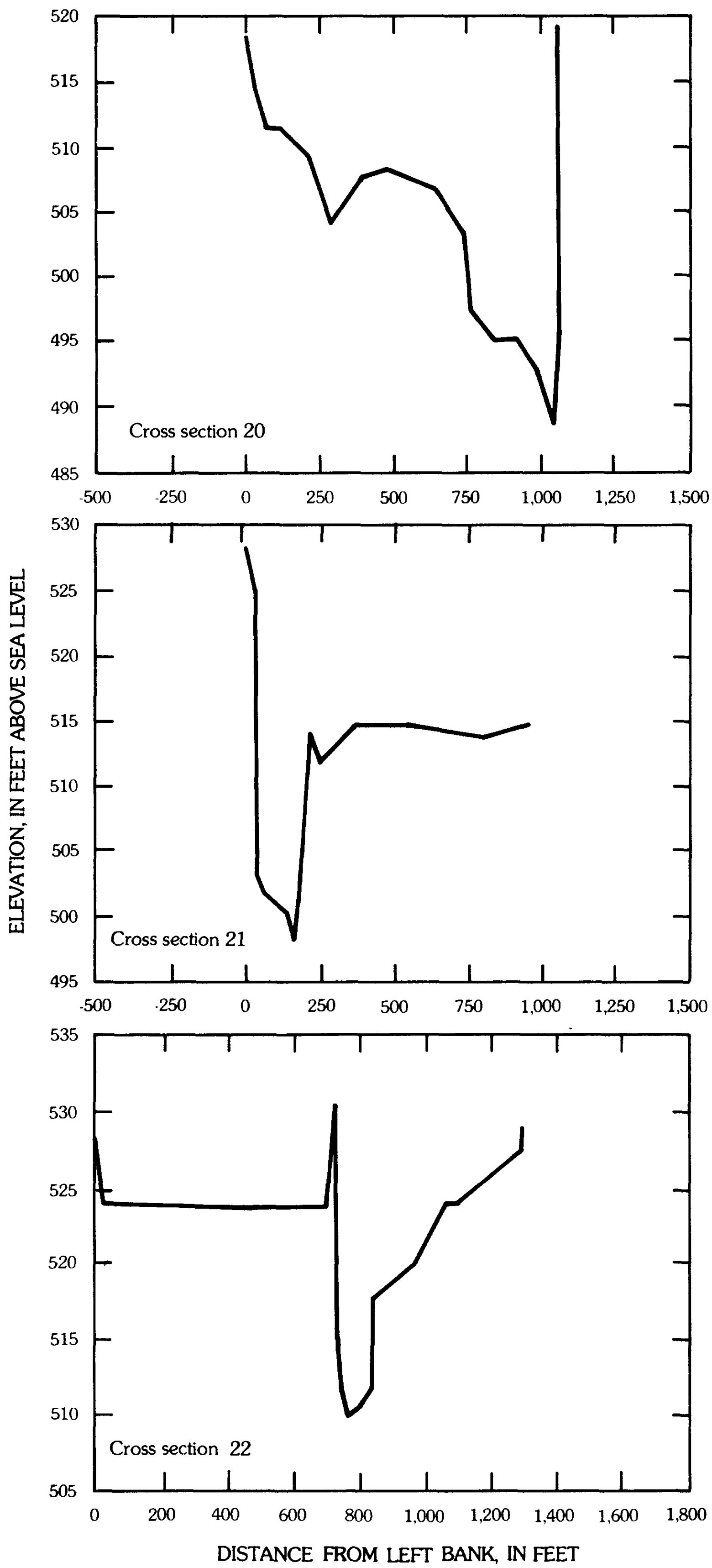


FIGURE 3.— Cross sections of Cottonwood Creek— Continued.

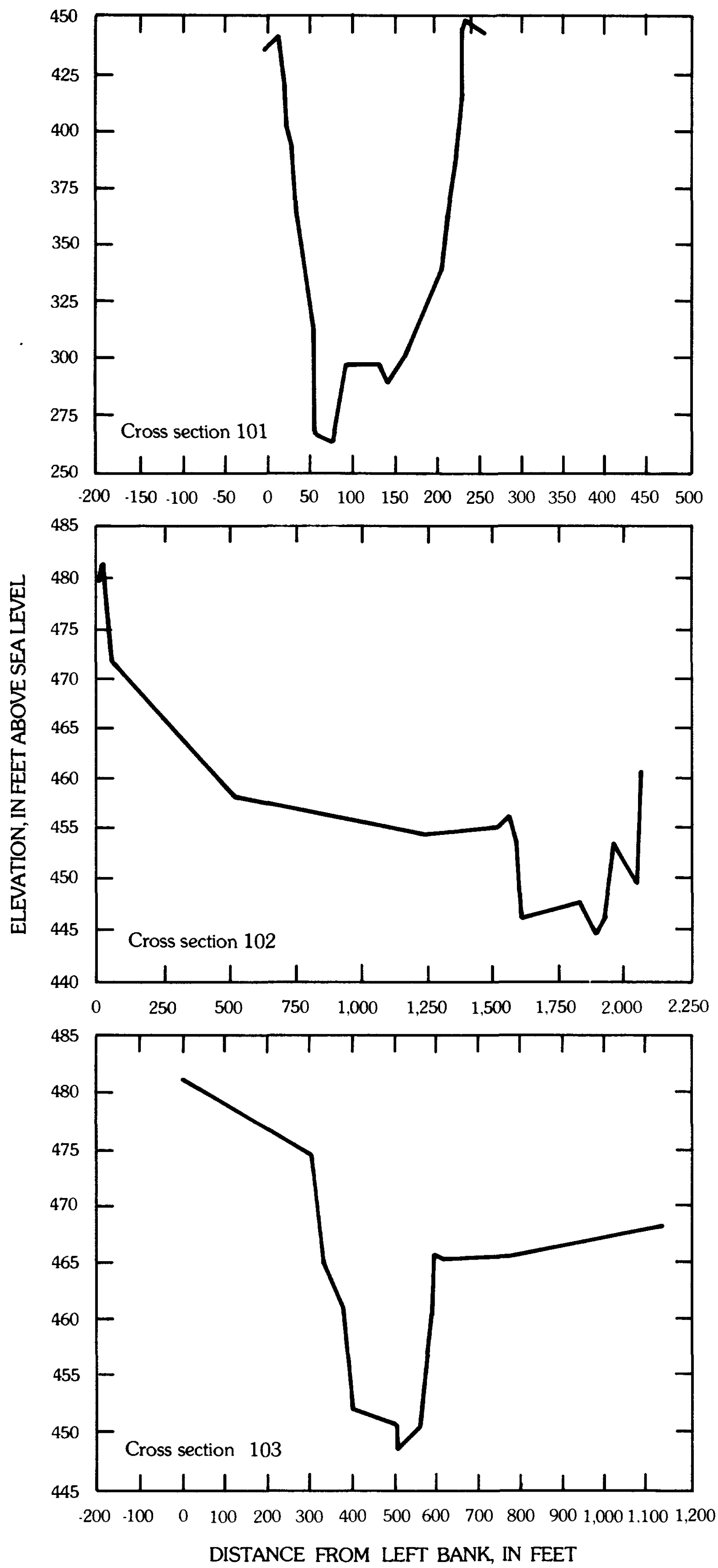


FIGURE 4.—Cross sections of South Fork Cottonwood Creek.

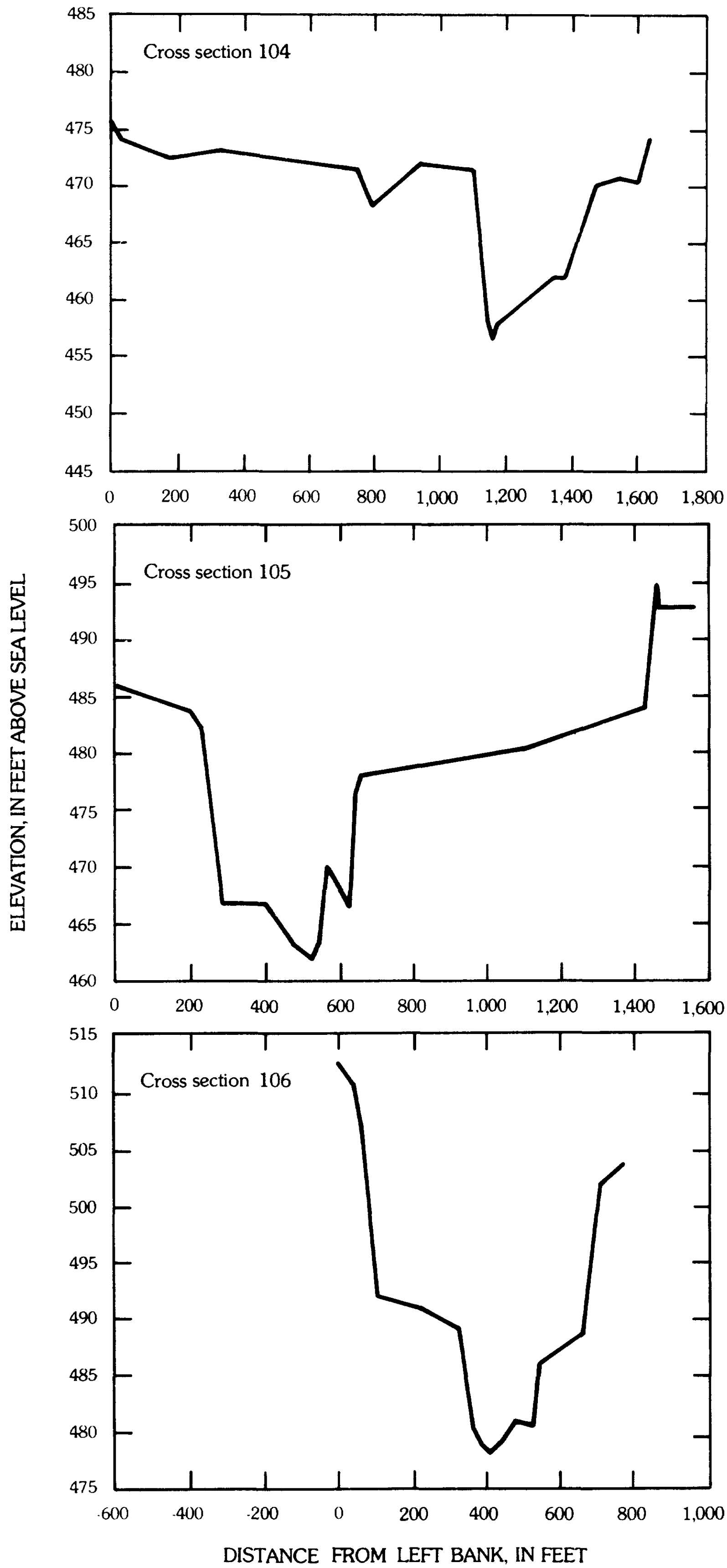


FIGURE 4.—Cross sections of South Fork Cottonwood Creek— Continued.

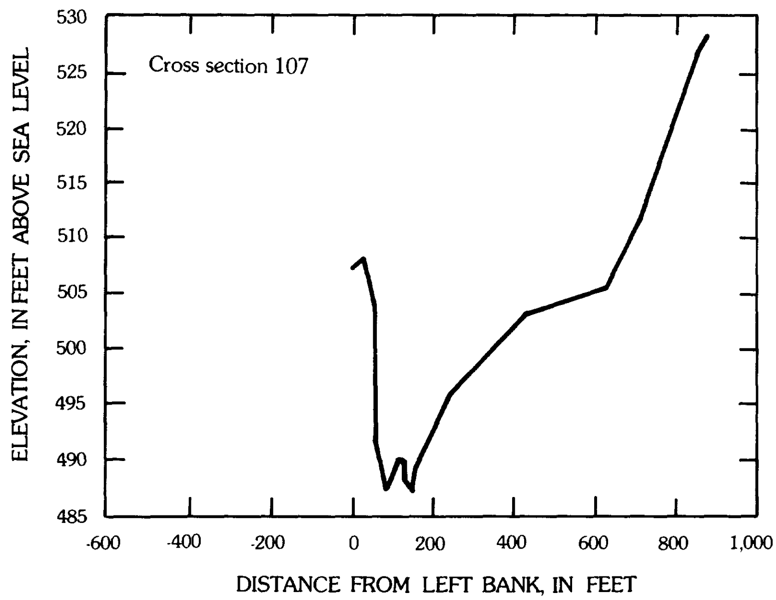


FIGURE 4.—Cross sections of South Fork Cottonwood Creek— Continued.

Bankfull Discharge

Channel pattern is commonly adjusted to the bankfull stream discharge. The annual peak discharge that occurs most frequently was used to estimate the bankfull discharge. Based on 43 years of record the most frequently occurring peak discharge at the station Cottonwood Creek at Cottonwood has a value of 20,000±2,000 ft^3/s (fig. 5). This discharge, used as an estimate of the bankfull discharge, has a recurrence interval of 1.8 years, which is within the range of recurrence intervals for bankfull discharge presented by Leopold and others (1964, p. 321) and Williams (1978, p. 1152). This figure is in close agreement with flow-frequency data presented by the U.S. Army Corps of Engineers (1977).

The bankfull discharge and the corresponding surface-water level are important factors in defining height of the flood plain as well as in classifying the channel type. The Cottonwood Creek flood plain is poorly defined and difficult to differentiate from the main stream channel, especially along the lower reaches where there are no well-defined banks or levees separating the main channel from the broad, sparsely vegetated alluvial surface of sand and cobbles adjacent to the stream, which is better described as a flood channel (Gilbert, 1917, p. 55). High-water elevations of the 1983 flood, the largest on record for Cottonwood Creek, were within the limits of the flood channel.

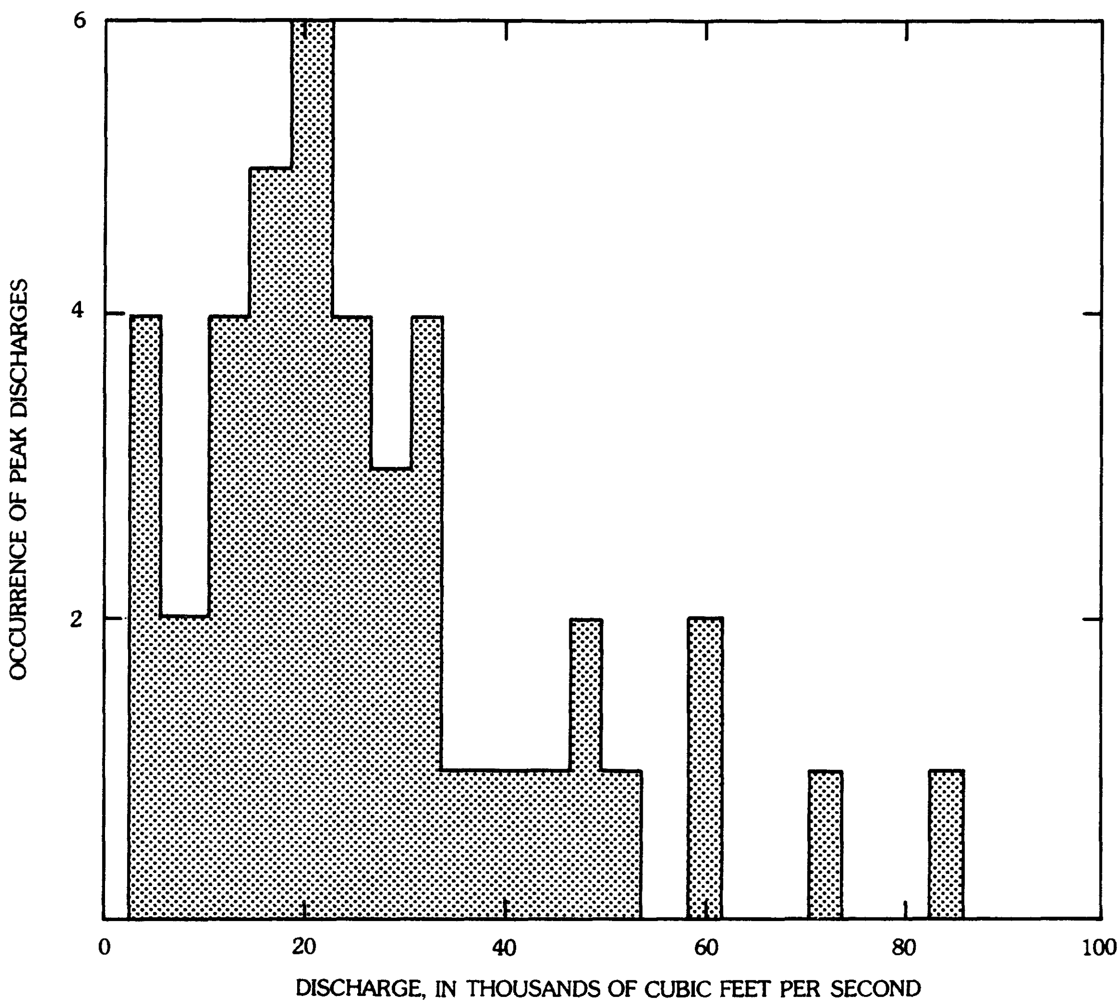


FIGURE 5.–Histogram showing peak discharges for Cottonwood Creek.

Channel Slope

Elevations of the channel thalweg and the high-water levels attained by the January and March 1983 floods are shown in table 2. The average slope for each reach obtained from this survey is shown in table 3. The mean bed slope is 0.0017 over the length of the six reaches on Cottonwood Creek. The mean slope of the three reaches along South Fork Cottonwood Creek is slightly greater at 0.0020. The greatest fluctuations in slope occurred between the mouth of Cottonwood Creek and its confluence with South Fork.

The average channel slopes for reaches 1 through 3 (fig. 2) were plotted against the estimated bankfull discharge of 20,000 ft^3/s for the station Cottonwood Creek near Cottonwood. These data plot within the zone characterized by braided channels as defined by Leopold and Wolman (1957, fig. 46). This agrees with the classification of the Cottonwood Creek channel obtained by using Brice's (1982) classification scheme.

Table 2. - Thalweg and water-surface elevations for 1983 floods of January 26 and March 1 in study area

[Cross-section locations are shown in figure 2]

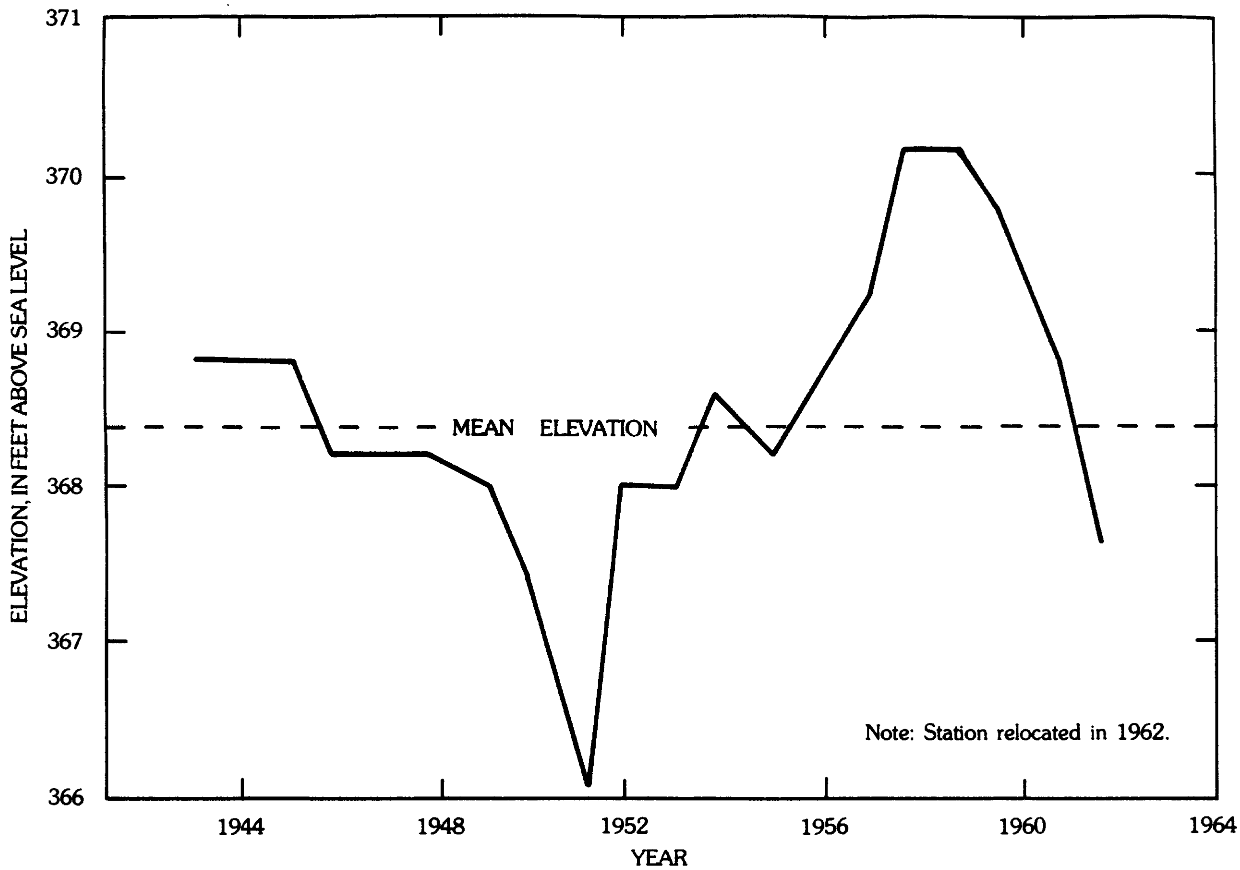
Cross section No.	Distance upstream from mouth (feet)	Elevation (feet above sea level)		
		Thalweg	January 26	March 1
		Cottonwood Creek		
1	1,640	348.7	363.4	366.0
2	2,900	348.9	364.2	--
3	9,930	358.9	--	376.8
4	13,500	364.3	384.0	385.4
5	15,700	371.4	388.4	389.4
6	20,300	380.9	392.9	396.0
7	22,800	383.1	--	--
8	27,600	387.8	404.4	409.8
9	27,900	391.1	--	--
10	28,300	390.9	--	--
11	32,700	404.4	--	415.8
12	38,900	413.9	429.4	429.9
13	45,500	421.2	439.0	441.5
14	50,200	428.6	443.8	--
15	(Not surveyed)	--	--	--
16	60,600	449.3	464.4	--
17	66,300	458.4	475.1	--
18	75,700	472.8	487.9	--
19	80,600	481.7	502.5	--
20	85,100	488.6	507.7	--
21	90,300	498.4	515.2	518.2
22	95,500	509.4	525.7	--
		South Fork Cottonwood Creek		
101	5,330	426.0	443.8	444.2
102	11,500	443.6	455.1	--
103	16,200	448.1	467.4	--
104	19,300	455.3	472.1	--
105	22,400	461.5	477.3	--
106	29,500	477.4	492.0	--
107	34,900	487.2	504.5	--
108	40,950	501.3	515.3	516.7
109	45,050	--	--	525.7

Table 3. - Average channel slopes for reaches of Cottonwood Creek, 1983

Reach	Slope
Cottonwood Creek	
1	0.0014
2	.0017
3	.0023
4	.0011
5	.0018
6	.0017
Mean	.0017
South Fork Cottonwood Creek	
7	0.0020
8	.0021
9	.0020
Mean	.0020
Mean for all reaches	.0018

Mean Streambed Elevation

Data describing the annual mean low-flow streambed elevation for 42 years at the station Cottonwood Creek near Cottonwood (11376000) are shown in figure 6. These elevations were calculated following the procedure used by Hickey (1969). A break in the data is shown for 1962 when the station was moved a short distance downstream. Attempts were made to relate mean low-flow bed elevation with 1-, 3-, and 7-day maximum stream discharges; however, no relations were indicated. Fluctuations of annual mean bed elevation seem to be random changes associated with local bed-form movement and channel braiding. The mean bed elevation seems to be in dynamic equilibrium through the period; no long-term trend of aggradation or degradation of the channel was detected.



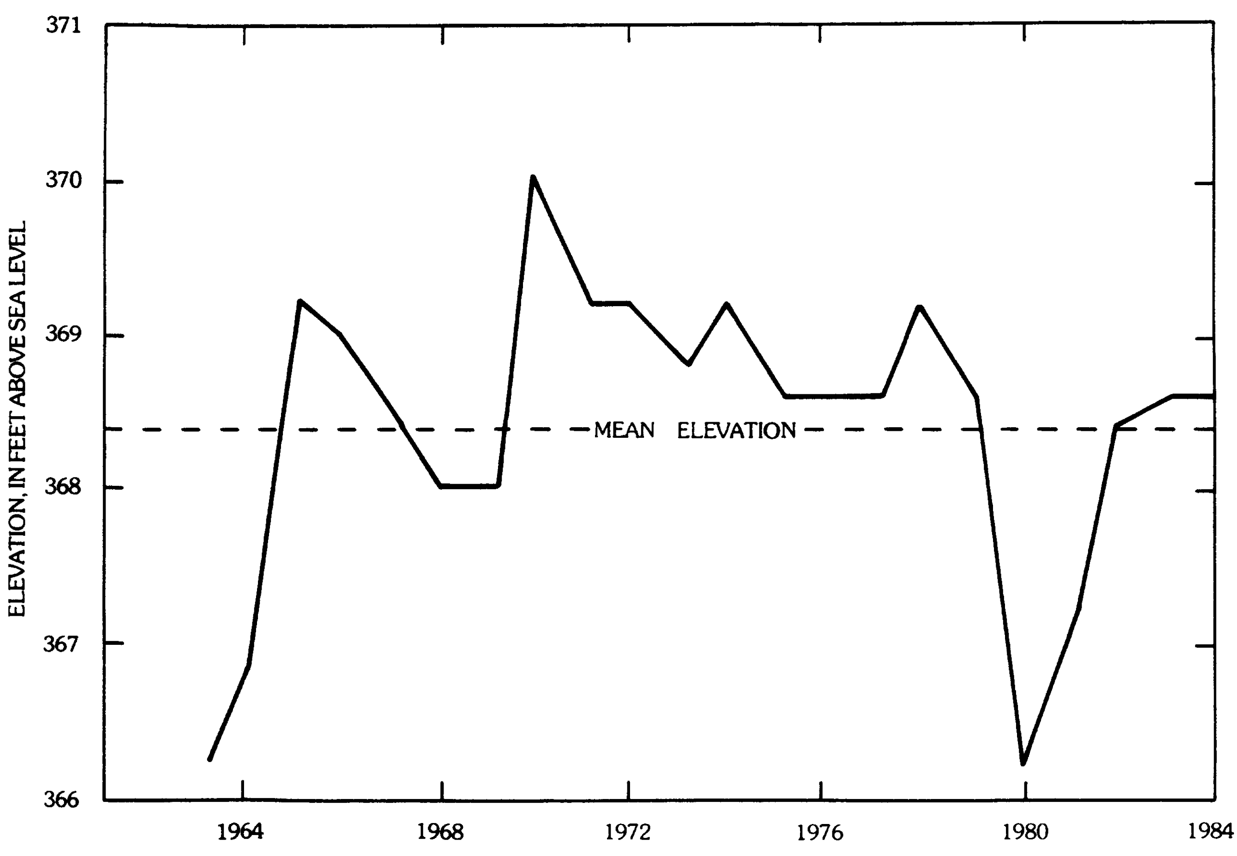


FIGURE 6.—Annual mean streambed elevation at station Cottonwood Creek near Cottonwood, 1943–84.

Bed-Material Size

The amount and size of bed material available to a stream as bedload directly affect channel slope; generally, coarser bed material is indicative of a steeper slope. With the absence of well-defined banks, no distinctions were made between bed and bank samples within the flood channel. Thirty-three samples of bed and bank material were collected and analyzed by two methods: the coarser fraction was analyzed using the point-count method; the finer fraction was analyzed using sieves. No appropriate method is known to merge the data obtained by the two methods; therefore, the actual relative amount of coarse to fine material could not be determined accurately. The data are presented to characterize the average clast sizes in the streambed that may be available for transport. The data in table 4 indicate that the bed and banks are composed of very coarse material. The mean grain size obtained by the point-count method ranged from 39.6 to 82.3 mm; the mean grain size of sieved samples ranged from 3.0 to 24.3 mm. In all cases the percent of silt and clay by weight for each sieved sample was less than 3 percent of the total sample.

The sorting, which is a measure of the spread in grain-size distribution, was calculated using the Trask formula with values greater than one indicating poorly sorted sediment. The data show that the sediments in samples collected from Cottonwood Creek and South Fork Cottonwood Creek are comparable in size, whereas samples collected from Cottonwood Creek have a slightly broader range of sizes. The sieve data, when compared with 15 sets of sieve data from terrace deposits in the drainage presented by Steele (1979, p. 89), show the channel deposits to be slightly coarser than the terrace deposits. Mean grain sizes obtained by Steele (1979) ranged from 0.3 to 9.5 mm.

Sinuosity

The sinuosity of Cottonwood Creek was calculated using the ratio of low-flow channel centerline length to the straight valley distance, according to the definition by Leopold and others (1964). Sinuosity was calculated for each year of photographic coverage, and the data obtained for each reach and the mean values for the year are tabulated in table 5.

Sinuosity values for Cottonwood Creek are low, ranging from 1.04 to 1.47. The mean sinuosity for all reaches of Cottonwood Creek gradually increased from 1.16 in 1940 to 1.21 in 1972 and has remained relatively constant since then. This apparent trend is small and may reflect errors in the data. The mean sinuosities for South Fork Cottonwood Creek are slightly lower than those for Cottonwood Creek. The low sinuosities are attributed, at least in part, to the low silt-clay content of the bed and bank material and the consequent low cohesion. Schumm (1963) demonstrated that sinuosity tends to increase with increasing silt-clay content of the bed and bank material.

Table 4. - Sediment-size distribution at cross sections for Cottonwood Creek, 1983

Cross section No.	Mean (millimeters)	Median (millimeters)	Sorting	Skewness
		Point-count data		
1--------	61.0	54.9	1.40	1.92
11--------	61.0	57.9	1.67	1.73
13--------	70.1	67.1	1.40	2.38
14--------	70.1	61.0	1.83	2.05
17--------	76.2	73.1	1.62	.30
19--------	64.0	54.9	1.71	2.86
20--------	82.3	79.2	1.59	1.10
21--------	54.9	54.9	1.42	.37
22--------	61.0	54.9	1.64	1.57
102A-------	39.6	42.7	1.36	.19
102B-------	67.1	57.9	1.35	1.70
103--------	42.7	39.6	1.54	.66
104--------	61.0	57.9	1.60	1.57
105--------	67.1	54.9	1.72	2.68
106A-------	70.1	57.9	1.66	1.69
106B-------	42.7	42.7	1.36	1.13
107--------	61.0	54.9	1.57	1.75
		Sieve-analysis data		
1A-------	19.7	21.1	1.09	0.14
1B-------	3.7	5.3	2.03	.29
3--------	3.0	5.3	2.21	.52
5--------	4.9	8.6	2.37	.54
7A-------	4.9	4.6	1.30	-.03
7B-------	24.3	34.3	1.35	.65
11--------	21.1	26.0	1.66	.52
13--------	9.8	22.6	2.36	.64
17--------	5.7	21.1	3.39	.71
19--------	5.3	10.6	2.21	.60
21--------	4.9	8.0	2.24	.46
101--------	17.1	21.1	1.35	.38
103--------	5.7	8.6	2.06	.44
105--------	7.5	11.3	1.89	.56
107--------	4.9	7.5	2.15	.49

Table 5. - Sinuosity by stream reach for Cottonwood Creek, 1940-84

Reach	1940	1952	1966	1972	1979	1984	Mean
			Cottonwood Creek				
1	1.12	1.30	1.32	1.25	1.25	1.36	1.27
2	1.24	1.17	1.23	1.29	1.30	1.22	1.24
3	1.24	1.24	1.27	1.34	1.47	1.24	1.30
4	1.08	1.21	1.16	1.22	1.12	1.11	1.15
5	1.19	1.14	1.14	1.18	1.23	1.34	1.20
6	1.25	1.23	1.24	1.26	1.25	1.27	1.25
Mean	1.19	1.22	1.23	1.26	1.27	1.26	--
			South Fork Cottonwood Creek				
7	1.11	1.08	1.07	1.09	1.06	1.04	1.08
8	1.10	1.14	1.16	1.16	1.10	1.16	1.14
9	1.10	1.10	1.10	1.10	1.09	1.11	1.10
Mean	1.10	1.11	1.11	1.12	1.08	1.10	--
Mean for all reaches	1.16	1.18	1.19	1.21	1.21	1.21	--

The mean sinuosity for Cottonwood Creek is relatively low when compared with other streams. Sinuosities calculated by Brice (1982, p. 24-25) for 46 streams in the United States have values ranging from 1.05 to 2.8. Braided stream channels according to Brice (1982, p. 6) have low sinuosities. Four river reaches classified by Brice as braided point-bar types all have sinuosities of 1.2. The mean sinuosities for Cottonwood Creek, which are close to this value, support the classification of Cottonwood Creek as a braided point-bar type. A disadvantage in the interpretation of sinuosity, however, is that constancy in sinuosity through time is no indication of lateral stability, for a stream may maintain the same value of sinuosity while changing the location and geometry of its bends.

Lateral Migration

Time-sequential aerial photographs of Cottonwood Creek taken between 1940 and 1984 show the position of the main channel has shifted frequently back and forth across the flood channel. The sideward shift in channel location is termed lateral migration; lateral migration values for the nine reaches for 1940-84 are given in table 6 and are summarized graphically in figure 7. Lateral migration may be expressed either as net migration or as cumulative migration. Net migration represents the average trend of channel migration to the right or left from the initial thalweg position during an interval of time. Cumulative migration represents the total displacement of the channel from its initial position in a reach during a specific period of observation. The total cumulative and net migration values shown in table 6 are the summation of values across the line for each reach.

Cumulative migration does not imply towards which bank the channel thalweg is migrating. The cumulative migration is calculated by dividing the summation of the land areas (designated the migration area) between successive channel positions, as shown on the aerial photographs, by the mean channel length for the reach during the same period of observation. The mean channel length is defined as the mean of the channel lengths at the start and end of each period. The dimension thus determined is designated the cumulative migration area:

$$\text{Cumulative migration} = \text{migration area/mean channel length.} \qquad (1)$$

An assumption was made in the analysis of cumulative migration that the channel shifted continuously in only one direction during a period of observation; reversals in the direction of shift were not recorded. This assumption results in a minimum value for cumulative migration. The shorter the time interval between successive aerial photographic coverage of a channel, the greater the accuracy of the resulting migration data. For example, comparison of the channel position for reach 1 in 1940 with that in 1984 would yield a cumulative migration of 648 feet. The total cumulative migration for reach 1, using the summation of values for each of the five time intervals in this study, is 1,802 feet.

The data in table 6 indicate that cumulative migration tends to decrease in the upstream direction along Cottonwood Creek. The trend of total cumulative migration for 1940-84 as shown in figure 33 also shows a decrease with distance upstream. The total cumulative migration data for South Fork Cottonwood Creek, when compared with the migration of Cottonwood Creek, appear to be relatively constant in the upstream direction (table 6). Differences in the observed amount of cumulative migration may be related to the width of the flood channel. Where the flood channel is sufficiently broad, meander bends can form in the alluvial flood channel. Cutoffs of these bends resulted in very large values for the migration area, hence large values for the cumulative migration. Meander bends in the main channel are less frequent as the flood channel narrows in the upstream direction. Therefore, as the flood-channel width decreases, the cumulative migration decreases. The flood-channel width along South Fork Cottonwood Creek remains fairly constant with the result that the cumulative migration also is relatively constant.

Table 6. - Lateral migration for reaches of Cottonwood Creek, 1940-84

[Stream channel shifts to the left of original centerline are designated as negative (-) values; those to the right are positive (+) values]

Reach	1940-52	1952-66	1966-72	1972-79	1979-84	Total
			Cumulative migration, in feet			
Cottonwood Creek						
1------	331	512	288	311	360	1,802
2------	196	287	122	359	357	1,321
3------	214	200	83	214	477	1,188
4------	69	156	65	141	220	651
5------	80	182	113	170	296	841
6------	115	65	47	79	86	392
South Fork Cottonwood Creek						
7------	43	140	39	113	127	462
8------	83	85	42	76	117	403
9------	95	110	102	53	51	411
			Net migration, in feet			
Cottonwood Creek						
1------	-105	+152	-57	+161	+37	+188
2------	-84	+9	+64	+199	+85	+273
3------	+179	-41	-31	-23	+73	+157
4------	+12	+122	+3	+141	-220	+58
5------	-21	+146	+5	+36	+80	+246
6------	-42	+10	0	-55	-6	-93
South Fork Cottonwood Creek						
7------	+16	+72	+15	+20	-101	+22
8------	+1	+12	-15	-12	-41	-55
9------	-62	+53	-39	+39	+13	+4

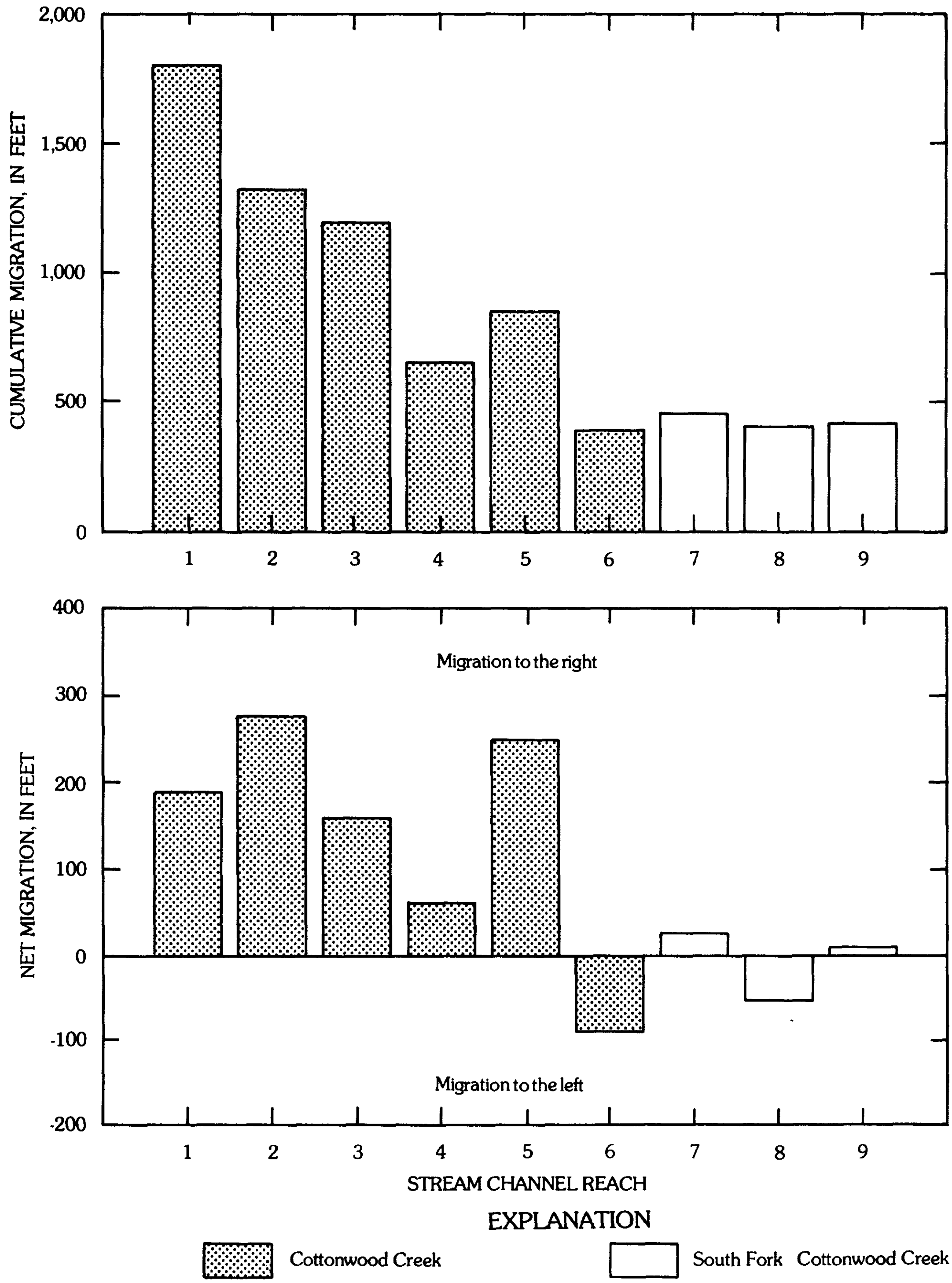


FIGURE 7.– Cumulative and net migration of Cottonwood Creek between 1940 and 1984.

Net migration represents the extent of channel displacement to the right or left of the initial channel position during a time interval. The assignment of positive and negative values to the migration areas has been made to connote a left- or right-shift direction away from the initial channel position in a time interval. When viewed in the downstream direction, left shifts have been defined as negative and right shifts as positive. The net shift may be equal to zero, indicating no net change in channel position, or less than zero, indicating a net shift towards the left bank, while the cumulative migration may be some value greater than zero. The net migration is calculated by dividing the algebraic summation of the migration areas between successive channel positions by the mean channel length for the reach during the period of observation:

$$\text{Net migration} = \Sigma\text{migration area/mean channel length.} \qquad (2)$$

The total net migration data (table 6 and fig. 7) show that the predominant shift of the Cottonwood Creek channel has been towards the right bank since 1940; reach 6 is the only exception to the trend for Cottonwood Creek. South Fork Cottonwood Creek, however, shows no trend of total net migration towards either bank during this period.

SUMMARY

The channel pattern for Cottonwood Creek is classified as a braided point-bar type. Cottonwood Creek is similar in form to the Yuba River, both having a larger sinuous flood channel that contains a main stream channel, which is braided and migrates within the flood channel. The bankfull discharge near the town of Cottonwood has been estimated to be 20,000 ft^3/s. The stage height of the bankfull discharge was used to establish a distinction between the main channel and the poorly defined flood plain. The bankfull discharge and the mean channel slope of 0.0017 plotted within the zone characterized by braided channels. A study of the mean streambed elevation at the station Cottonwood Creek near Cottonwood showed no long-term trend of aggradation or degradation, which can be interpreted to indicate that the mean streambed elevation in the vicinity of the station is in dynamic equilibrium. Fluctuations in channel-bed elevation probably are related to local bed-form movement and channel braiding. The bed-material size of Cottonwood Creek is very coarse. Deposition of the coarse material in the stream channel causes redirection of streamflow and the consequent development of a new thalweg. The mean sinuosity for Cottonwood Creek is low but increased from 1.16 to 1.21 during 1940-72. This increase may not be significant, because it is only marginally above the probable error in the data. The sinuosities for Cottonwood Creek approximate the sinuosities for braided stream channels.

Lateral migration for Cottonwood Creek has been expressed in two ways, cumulative migration and net migration. The cumulative migration indicates a decreasing trend in the upstream direction for Cottonwood Creek and probably is related to the decreasing width of the flood channel in the same direction. Cumulative migration for South Fork Cottonwood Creek was relatively constant, as was the flood-channel width. The net migration for Cottonwood Creek has been predominantly towards the right bank; South Fork Cottonwood Creek has no apparent trend.

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