ASSESSMENT OF HYDRAULIC CHANGES ASSOCIATED WITH REMOVAL OF CASCADE DAM, MERCED RIVER, YOSEMITE VALLEY, CALIFORNIA

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CONVERSION FACTORS

For readers who prefer the International System of Units (SI) to inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply	By	To obtain
ft (foot)	0.3048	meter
ft/ft (foot per foot)	1.00	meter per meter
ft^3/s (cubic foot per second)	0.02832	cubic meter per second
inch	25.40	millimeter
lb/ft^2 (pound per square foot)	4.882	kilogram per square meter
lb/ft^3 (pound per cubic foot)	16.02	kilogram per cubic meter
mi (mile)	1.609	kilometer
mi^2 (square mile)	2.59	square kilometer

DEFINITION OF TERMS

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 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 Sea Level Datum of 1929.

ASSESSMENT OF HYDRAULIC CHANGES ASSOCIATED WITH REMOVAL OF CASCADE DAM, MERCED RIVER, YOSEMITE VALLEY, CALIFORNIA

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ABSTRACT

The National Park Service is considering plans to remove Cascade Diversion Dam on the Merced River in Yosemite National Park. This dam was constructed in 1917 to impound water for the intake structure that diverts flows to a powerhouse located about 1 mile downstream. This study evaluates the possible channel changes that would be caused by removal of the dam and intake structure.

The diversion dam is located at a natural break in the Merced River gradient. The pool upstream from the dam provides sufficient storage to reduce erosive forces on the State Highway 140 embankment caused by inflow to the dam. A rockfall near the downstream side of the dam has deposited large boulders in the channel that tend to stabilize the channel boundary.

Large floods on the Merced River occurred in December 1937, November 1950, and December 1955. These floods, which have a recurrence interval of about 40 years, caused the deposition of sediment in the pool upstream from the dam and inundation of State Highway 140 near the right abutment of the dam. Sediment deposited during the 1937 flood was removed in 1938 to a depth about 2.5 feet below the dam crest. Field surveys in April 1988 indicate that the pool and backwater extend upstream from the dam about 550 feet. The surveys indicate that the channel curvature causes impinging flows on the State Highway 140 embankment upstream from the dam. Also, the channel thalweg is about 10 feet lower than the toe of the present rock riprap bank protection along the State Highway 140 embankment.

Removal of the dam will cause several channel changes at the site, including possible scour of the channel bed at the dam to a depth 20 feet lower than the present dam crest. Bed and associated bank shear stresses six times greater than presently occur could cause increased erosion of the State Highway 140 embankment. Other possible changes include lateral movement of the channel alignment in the reach upstream from the dam causing impinging flows against the State Highway 140 embankment and exposure of the toe of the existing rock riprap placed along road fill.

These possible channel changes that would result from the proposed removal of the diversion dam would require additional protection of the State Highway 140 embankment.

INTRODUCTION

The National Park Service has discontinued hydroelectric power generation on the Merced River at Yosemite National Park and plans to remove the Cascade Diversion Dam, water intake structure, and associated facilities. The diversion dam was constructed to impound water for the intake structure that diverts flows to a powerhouse. The dam is located near the western boundary of the park (fig. 1). There is concern that removal of the dam will cause a general degradation of the Merced River channel in the vicinity of the dam and also cause erosion of the State Highway 140 embankment on the north side of the river (fig. 1).

Flows of the Merced River at the damsite are unregulated; the drainage basin area is about 325 mi². The U.S. Geological Survey gaging station at Merced River at Pohono Bridge, near Yosemite Village (11266500), is located about 1 mi upstream from the dam. Flows at the dam are considered equivalent to those at the gage. The average annual mean daily flow at the gage is 624 ft³/s, and the peak of record, 23,400 ft³/s, occurred on December 23, 1955. The frequency of this flood is estimated to be about 40 years, on the basis of 70 years of record at the Pohono gage.

Previous studies of the hydraulic changes that would result from removal of the Cascade Dam were done by Kennedy, Jenks, and Chilton, Consulting Engineers (1986). The results of their study are included in a report to the National Park Service dated September 1986. Their report includes results of geophysical soundings done in April 1986 by Harding, Lawson, and Associates, of the sediment trapped upstream from the dam.

The purpose of this study, done in cooperation with the National Park Service, was to evaluate the possible changes in hydraulic characteristics of the Merced River caused by removal of the dam. As part of this study, data included in the report by Kennedy, Jenks, and Chilton, Consulting Engineers (1986) were used where possible.

DESCRIPTION OF SITE

Cascade Dam is a timber crib diversion dam constructed in 1917 on the Merced River about 6 mi downstream from Yosemite Village (not shown in fig. 1) and 1 mi downstream from the Pohono Bridge gage (11266500) (fig. 1). Flows at the dam were diverted through an intake structure on the right bank, and then through a 54-inch-diameter low-pressure wood pipeline to a steel penstock and powerhouse located about 1 mi downstream. The dam is about 170 ft long, 10 ft high at the upstream face, and 22 ft wide (fig. 2). The timber crib part of the dam extends down from the crest about 13 ft to the bottom of the stream channel at an elevation of 3,795 ft above sea level (from drawings by Kennedy, Jenks, and Chilton, Consulting Engineers, December 1987). Since construction, sand and gravel have accumulated in the pool upstream from the dam. The intake structure and toe of the dam were modified and reinforced with concrete and large boulders about 1970. Operation of the powerhouse was discontinued in 1985, and the wood pipeline was subsequently destroyed and removed.

A Geological Survey topographic map of Yosemite Valley (dated 1958, with a contour interval of 40 ft) indicates that the diversion dam is located at a natural breakpoint in the channel gradient. Downstream from the dam, the channel gradient is about 0.06 ft/ft. Upstream from the dam, the gradient is 0.01 ft/ft. Accordingly, there is potential for bed scour at the site of the diversion dam unless the channel bed is armored.

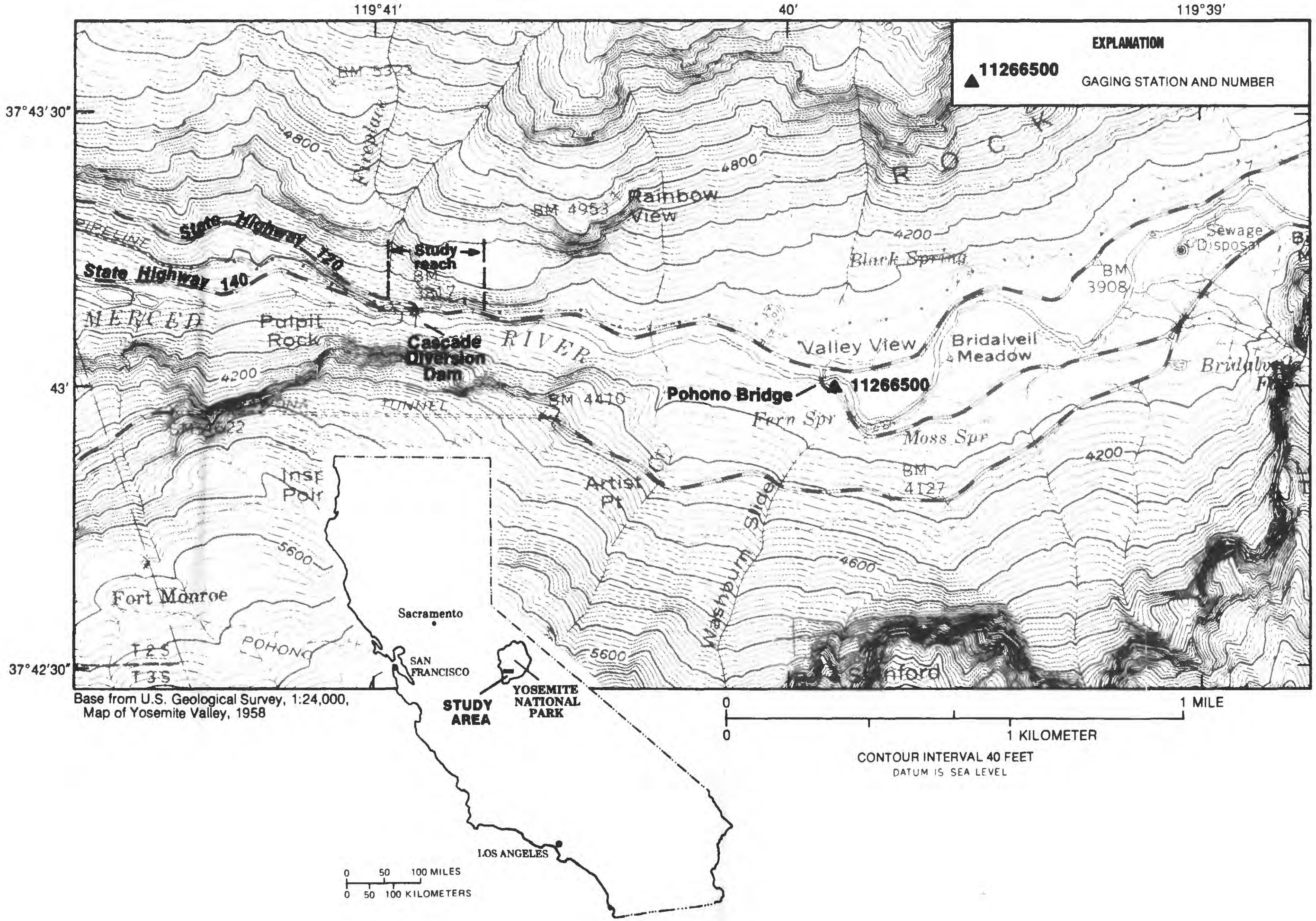

FIGURE 1. Stndy reach on Merced River at Cascade Diversion Dam.

Cascade Diversion Dam structure, looking from right (north) bank. Intake structure in foreground.

View upstream of large boulders in channel downstream from dam. Note dam crest in center of photograph.

FIGURE 2. Merced River downstream from Cascade Diversion Dam. Photographed April 12, 1988.

The diversion dam creates a pool that extends about 550 ft upstream from the dam (fig. 3). The pool width ranges from about 80 to 240 ft (fig. 3). Flow at the upstream end of the pool is directed toward the right bank (channel banks are described as right or left when looking downstream) and the State Highway 140 embankment. Flows on the left bank near the upstream end of the pool tend to form a large eddy, consequently depositing sand on a point bar near point A (fig. 4). Large boulders in the channel from a rockfall on the left bank downstream from the dam (fig. 4) tend to stabilize the channel and prevent erosion in the downstream part of the study reach.

HISTORIC FLOODS

Flooding is an annual occurrence on the Merced River, with most floods occurring during the spring snowmelt season (table 1). The mean annual discharge of the Merced River at Pohono Bridge gage (11266500) is about 5,000 ft^3/s. During some years, floods occur during the winter as a result of heavy rain from tropical storms and melting of the existing snowpack. Floods of this type usually are larger than the floods caused by spring snowmelt. Large floods caused by winter storms occurred in December 1937, November 1950, and December 1955, with peak discharges of about 23,000 ft^3/s (table 1). The frequency of these floods was determined using flood-frequency-analysis techniques described by the Hydrology Subcommittee in Bulletin 17B (U.S. Geological Survey, 1982). On the basis of records for the Pohono Bridge gage for 1917-86, the average frequency of these floods is about 40 years.

Water-surface profiles in the vicinity of the diversion dam for floods occurring in 1937, 1950, and 1982 are shown in figure 5. The high-water marks for the 1982 flood were found during site surveys in April 1988; the floods of December 1937 and December 1950 were documented by the Geological Survey in order to calculate flows over the dam. The location and elevation of high-water marks for the floods of December 1937 and November 1950 (fig. 5) indicate that State Highway 140 was inundated at least 2 ft deep north of the right bank abutment of the dam (fig. 4).

The first report of sediment deposition in the pool upstream from the diversion dam was described in drawings by the U.S. Bureau of Public Roads dated July 1931. A cross section plot of the deposited material as surveyed in 1931 (fig. 6) was determined from a detailed topographic survey of the sediment deposits by the Bureau of Public Roads. Field notes by the Geological Survey after the 1937 flood report indicate that an island upstream from the dam, composed of sediment deposits in the pool, was removed prior to the 1938-39 flood season by the Bureau of Public Roads. According to reports by the resident engineer, the deposits were excavated to about 2.5 ft below the dam crest.

Evidently, sediment deposition upstream from the dam was a recurring problem before 1938 and may have been a problem following the floods in November 1950 and December 1955 (table 1). As such, geophysical surveys of the bed deposits done by Harding, Lawson, and Associates in 1986 (Kennedy, Jenks, and Chilton, Consulting Engineers, 1986) define present sediment deposition conditions in the pool, and not layers of deposition prior to 1938, and possibly prior to 1950 or 1955.

View of river upstream from diversion dam pool. Note State Highway 140 on left side of photograph.

View of diversion dam pool. Pool extends 550 feet upstream from dam.

FIGURE 3. Merced River upstream from Cascade Diversion Dam. Photographed April 12, 1988.

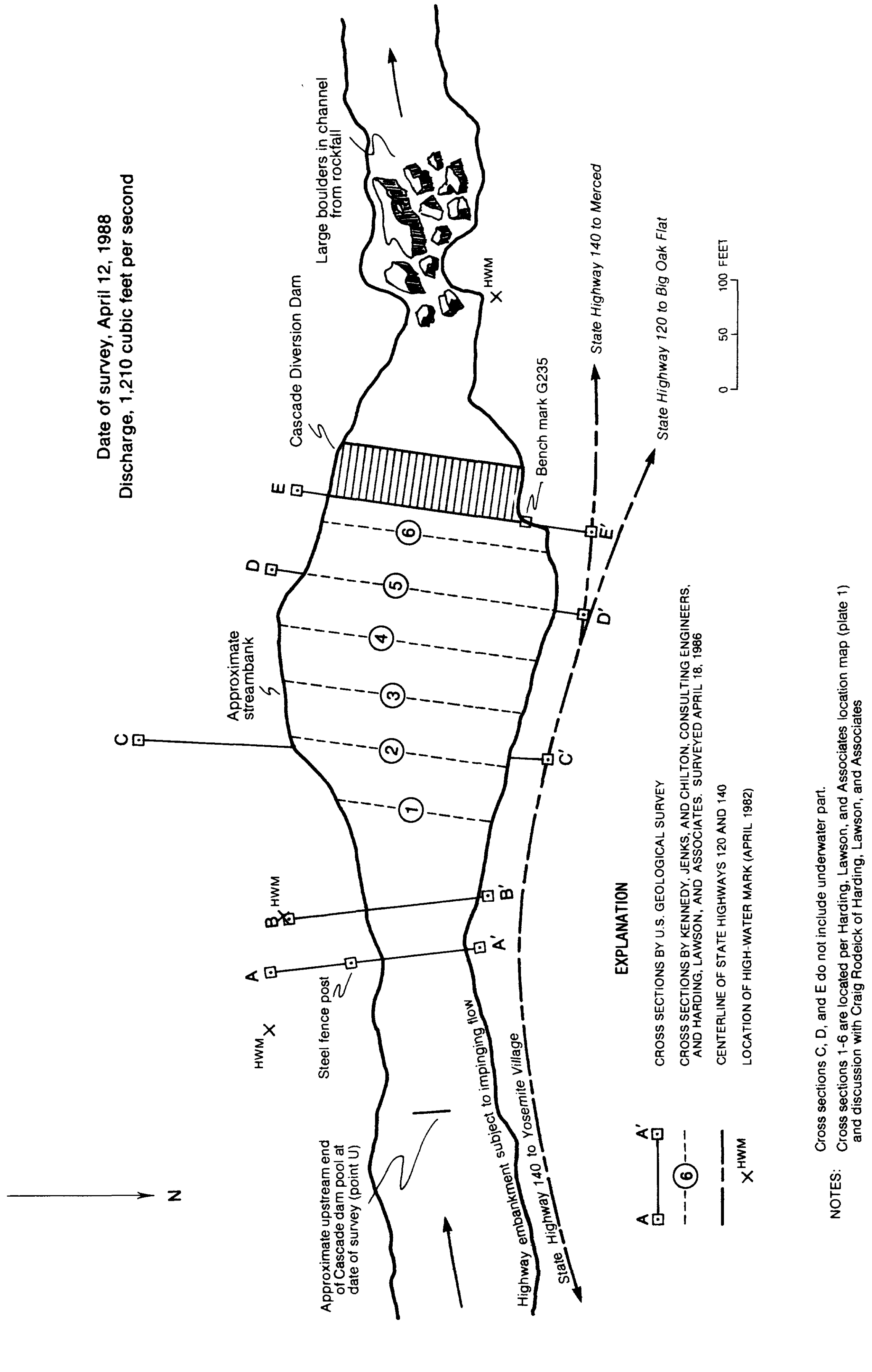

FIGURE 4. Diagram of Cascade Diversion Dam and study reach.

TABLE 1.--*Annual peak stage and discharge of Merced River at Pohono Bridge, near Yosemite Village, California*

[ft, feet; ft³/s, cubic feet per second]

Water year	Date	Gage height (ft)	Peak discharge (ft^3/s)	Water year	Date	Gage height (ft)	Peak discharge (ft^3/s)
1917	06-10-17	8.75	5,880	1953	04-27-53	7.11	3,480
1918	06-12-18	7.05	4,000	1954	05-20-54	7.57	3,990
1919	05-29-19	9.80	6,150	1955	05-22-55	7.46	3,870
1920	05-20-20	8.80	5,050	1956	12-23-55	21.52	23,400
1921	06-11-21	8.40	4,610	1957	05-18-57	9.24	4,880
1922	06-05-22	10.00	6,370	1958	05-19-58	10.43	6,630
1923	05-16-23	8.30	4,500	1959	05-13-59	6.80	2,340
1924	05-02-24	5.95	2,120	1960	05-12-60	7.54	3,010
1925	05-06-25	8.30	4,500	1961	04-05-61	5.84	1,550
1926	05-05-26	7.77	3,950	1962	05-06-62	8.59	4,300
1927	05-17-27	9.48	5,700	1963	02-01-63	14.25	13,200
1928	03-25-28	8.58	4,680	1964	05-26-64	6.91	2,710
1929	06-16-29	9.25	4,890	1965	12-23-64	16.96	18,000
1930	05-28-30	7.23	2,780	1966	05-08-66	6.97	2,670
1931	05-07-31	6.10	1,840	1967	05-23-67	10.53	6,950
1932	05-18-32	9.12	4,780	1968	04-30-68	6.13	2,020
1933	05-31-33	8.60	4,230	1969	06-02-69	11.34	3,190
1934	06-14-34	5.43	1,470	1970	05-18-70	8.31	4,150
1935	06-05-35	9.44	5,110	1971	05-16-71	7.63	3,420
1936	05-05-36	8.84	4,450	1972	06-08-72	7.48	3,270
1937	05-15-37	10.25	6,010	1973	05-31-73	10.32	6,620
1938	12-11-37	19.10	22,000	1974	05-28-74	9.31	5,320
1939	04-22-39	5.95	2,200	1975	06-02-75	10.80	7,280
1940	05-13-40	8.45	4,750	1976	10-26-75	6.18	2,060
1941	05-24-41	9.55	6,410	1977	06-09-77	6.58	2,390
1942	05-25-42	9.21	5,860	1978	06-09-78	10.19	6,440
1943	04-28-43	9.53	6,370	1979	05-22-79	9.71	6,010
1944	05-09-44	7.36	3,470	1980	01-13-80	13.01	11,000
1945	05-05-45	9.18	5,810	1981	05-01-81	7.64	3,560
1946	05-07-46	8.15	4,680	1982	04-11-82	13.11	11,200
1947	05-03-47	7.52	3,930	1983	05-30-83	12.11	9,520
1948	05-27-48	8.50	5,100	1984	05-14-84	8.94	5,030
1949	05-14-49	7.96	4,450	1985	04-14-85	7.14	3,060
1950	05-28-50	7.99	4,490	1986	03-08-86	10.39	6,930
1951	11-19-50	19.98	23,000	1987	05-16-87	6.49	2,410
1952	05-23-52	9.63	6,790	1988	05-16-88	6.11	2,090

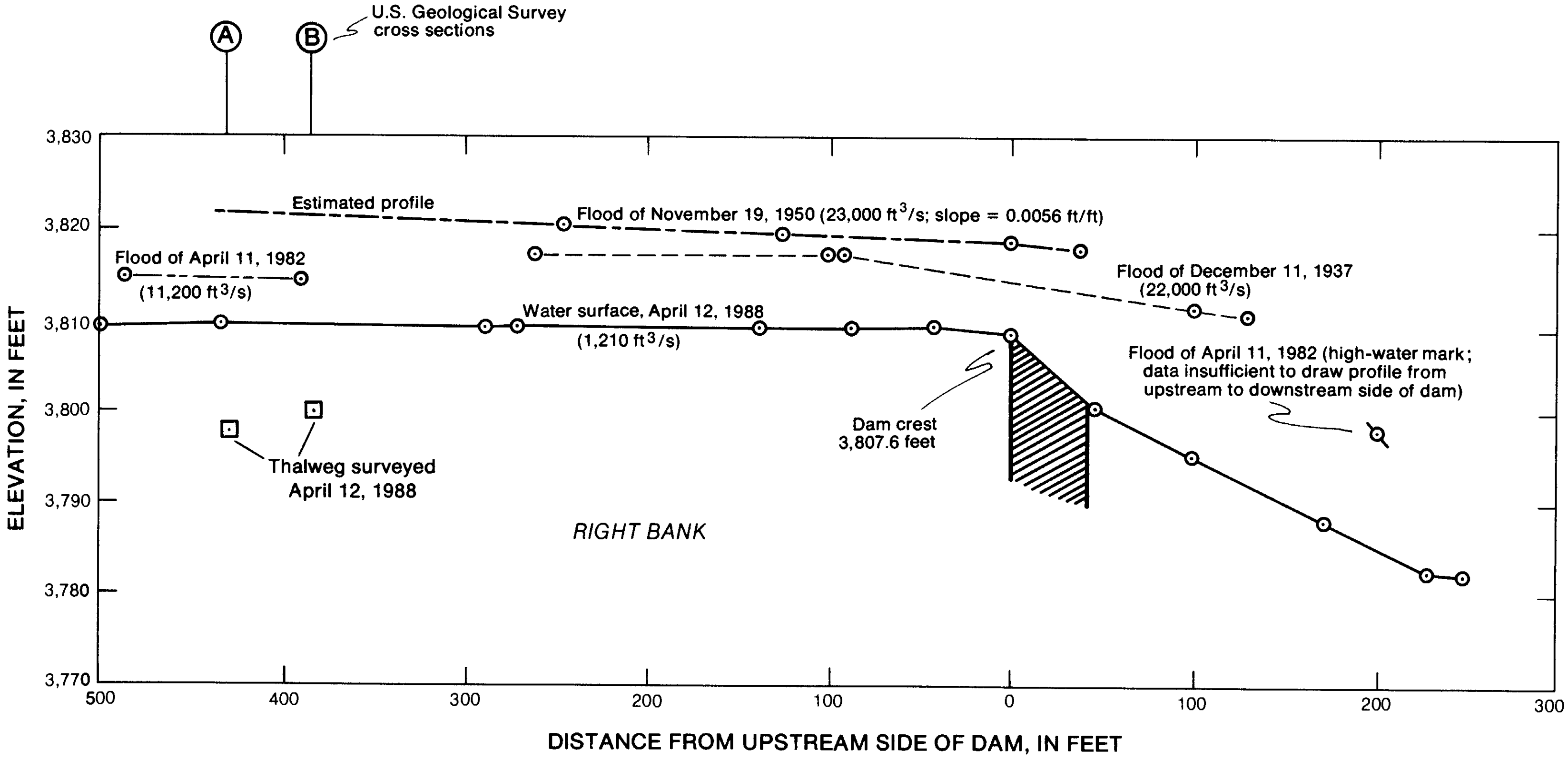

FIGURE 5. Profiles of selected historic floods at Cascade Diversion Dam.

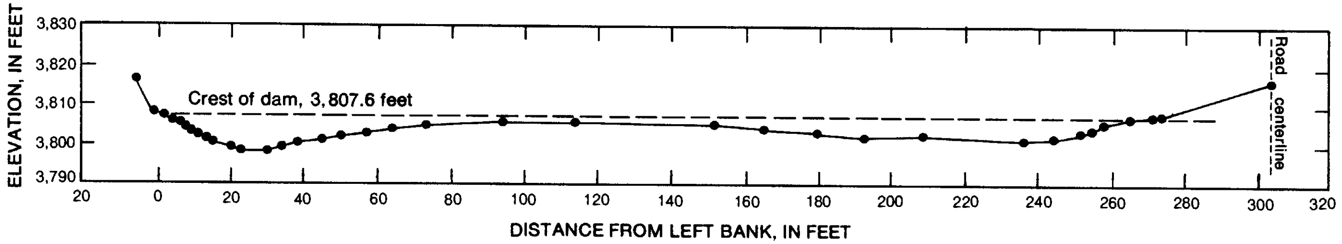

FIGURE 6. Cross section of streambed 25 feet upstream from Cascade Diversion Dam in 1931. (From topographic map by U.S. Bureau of Public Roads, dated July 1931).

DESCRIPTION OF APRIL 1988 FIELD SURVEYS

A map of the study reach (fig. 4) and water-surface profile for a reach about 1,200 ft long in the vicinity of the dam was surveyed (fig. 7). On the basis of flow records collected at the Merced River at Pohono Bridge gage (11266500), the stages of the river at the dam during the 1986 Harding, Lawson, and Associates survey and 1988 Geological Survey survey are within 0.1 ft of each other. All Survey elevations are referenced to bench mark G235 (elevation 3,816.41 ft) located on the right bank (north) dam abutment.

Cross sections at A and B were surveyed (fig. 8). Parts of cross sections C, D, and E (figs. 4 and 7) were surveyed on the land only. A steel fence post on the left bank (south side) of the river at cross section A and several high-water marks, believed to be from the April 1982 flood (table 1), were found. A discharge measurement of 1,210 ft^3/s was made April 13, 1988, at cross section B. At this location, all flow was in a downstream direction and no flow eddy or turbulence was evident at cross section A.

A large (old) rockfall from the left bank cliff located downstream from the dam has deposited large boulders in the channel (fig. 2). This deposit is about 200 ft downstream from the dam (fig. 4) and likely acts as a channel control and probably limits scour or channel degradation downstream from the dam.

A location map of geophysical surveys by Harding, Lawson, and Associates in 1986 (their stations 3+50 to 6+00) indicates they surveyed a reach starting 230 ft upstream from the dam and extending 250 ft upstream from their initial point (Kennedy, Jenks, and Chilton, Consulting Engineers, 1986). However, survey data obtained by Harding, Lawson, and Associates were not used because the channel width and depth did not agree with comparative data obtained during surveys by the Geological Survey during April 1988.

The water-surface profile on April 12, 1988, is shown in figure 7. Backwater at this discharge extends about 550 ft upstream from the dam.

A tabulation of elevation data for the toe of the bank (base of State Highway 140 rock riprap and embankment), State Highway 140 pavement centerline, and channel thalweg at selected cross sections is given in table 2. The elevation data indicate the toe of the bank or that part of the highway embankment protected with rock riprap is about 10 ft higher than the channel thalweg at cross section B and about the level of the water surface when surveyed in April 1988.

TABLE 2.--*Tabulation of profile data surveyed April 1988*

Cross section[1]	Distance upstream from dam (feet)	Elevation (feet above sea level)		
		Toe bank and riprap	State Highway 140 centerline	Thalweg
A	430	3,815.0	--	3,797.8
B	385	3,809.9	--	3,799.9
C	234	3,811.5	3,820.9	--
D	75	3,811.3	3,816.6	--
E[2]	0	3,807.6	3,816.7	3,807.6
E[3]	0	--	--	3,776.6

[1]Location of cross sections in figure 4.
[2]Top dam crest.
[3]Base cutoff wall.

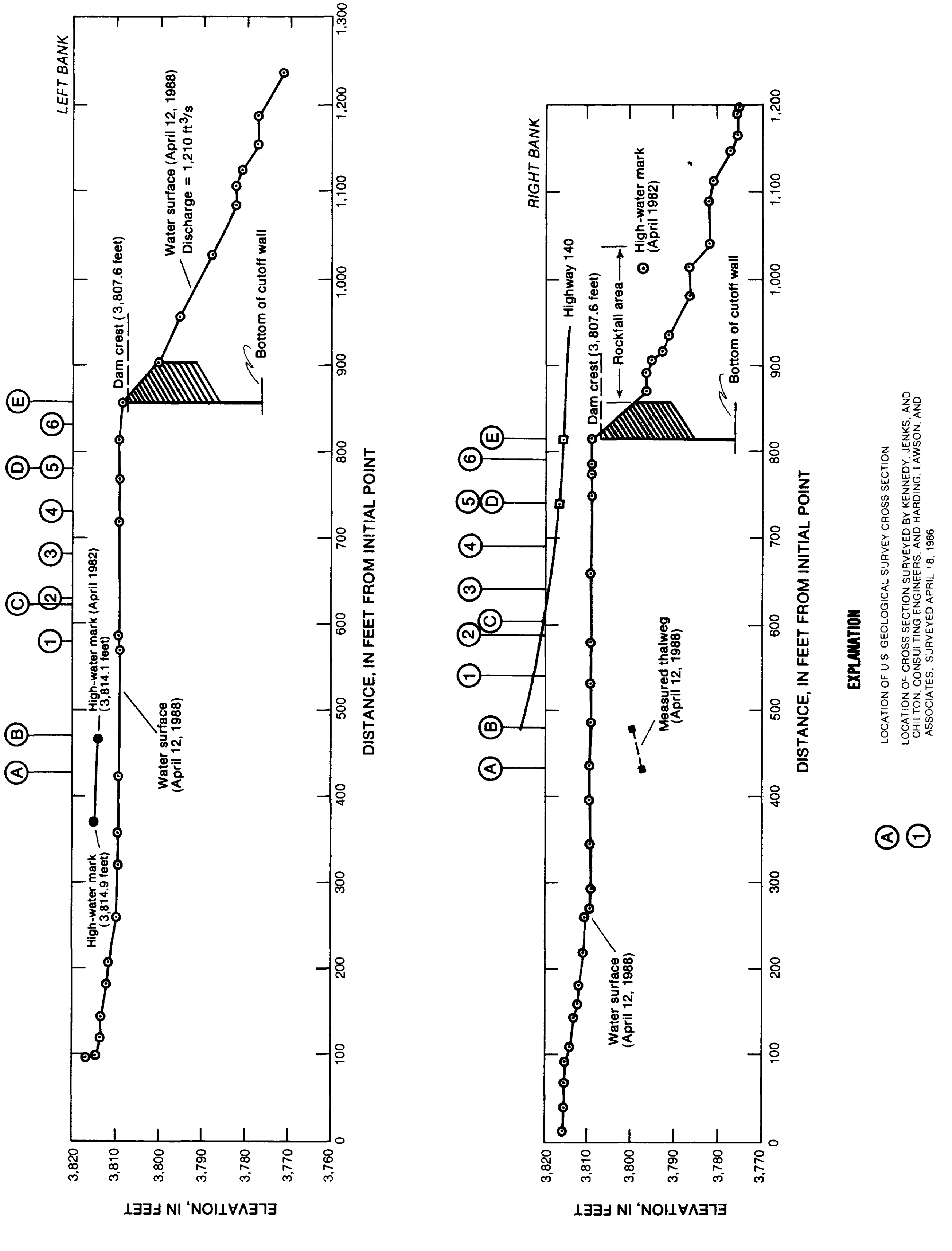

FIGURE 7. Water-surface profile of study reach on April 12, 1988.

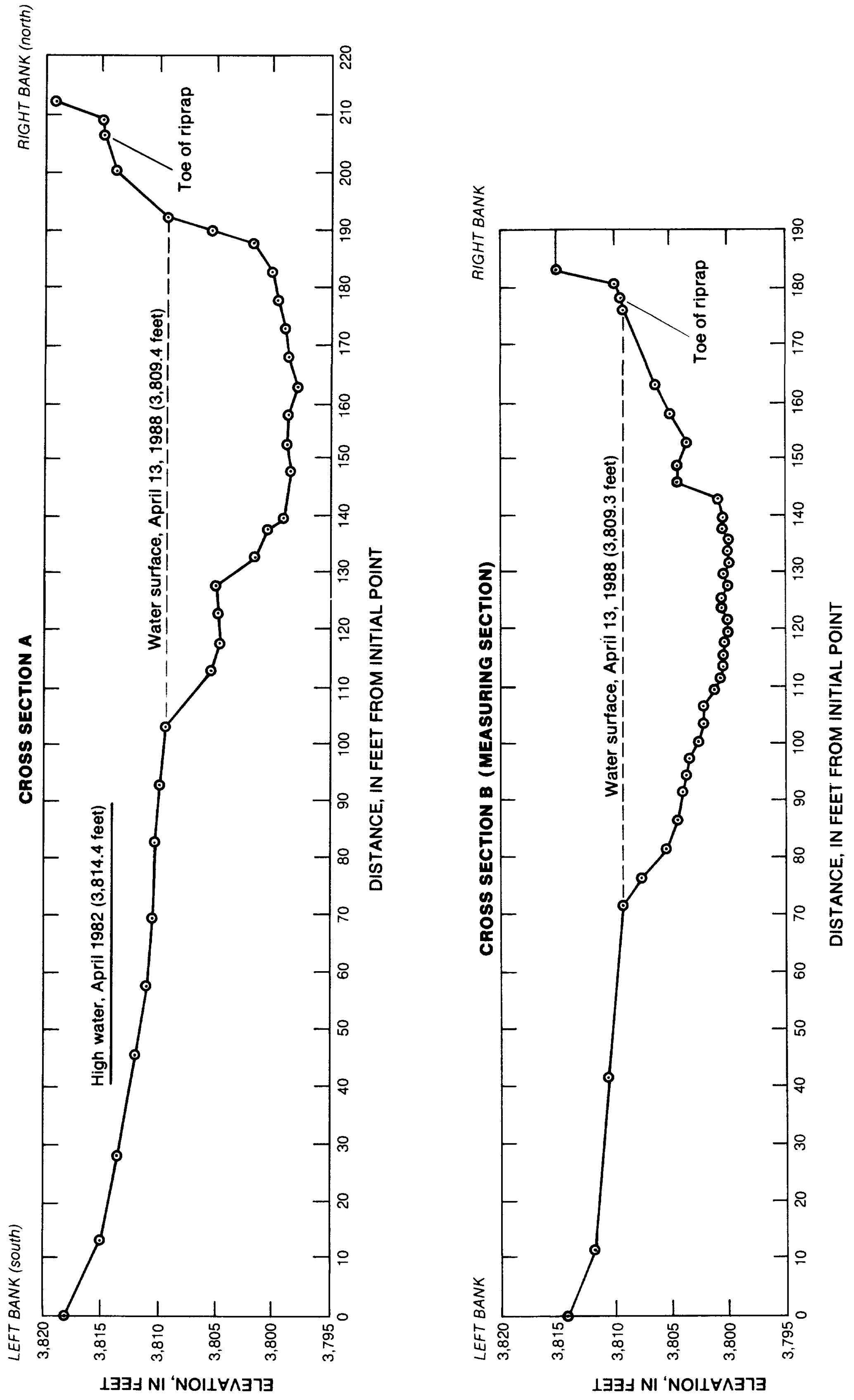

FIGURE 8. Cross sections A and B for April 1988 surveys.

POTENTIAL CHANGES IN WATER-SURFACE PROFILE AND CHANNEL THALWEG

The proposed removal of Cascade Diversion Dam will affect the Merced River channel for a distance both upstream and downstream from the dam. As shown in figure 9, the water-surface profile for flow conditions such as on April 12, 1988, will probably change for a reach length greater than 600 ft upstream and 300 ft downstream from the dam. In addition, the water-surface profile at the site of the dam would be about 18 ft lower than the April 12, 1988, elevation. These estimates are based on the points of tangency with the existing water-surface profile (fig. 9), as determined during the April 1988 surveys. The upstream point of tangency is the farthest upstream location in the reach at which changes in the existing channel may occur, regardless of future modifications to the diversion dam. The point of tangency at the downstream end of the reach is considered to be a stable location because of the large boulders in the channel that were deposited from a rockfall on the left bank (fig. 4). Even though erosive forces downstream from the dam are high because of the steep channel gradient in this reach (fig. 9), the channel has reached a state of equilibrium for present flow conditions. It is probable that these large boulders (fig. 2) will continue to stabilize the channel geometry in this part of the reach even if the dam is removed.

Associated with the lowering of the water surface will be a tendency for the active stream channel to incise within the former pool area and establish a new alignment. The thalweg elevation of the newly incised channel cannot be estimated with accuracy, but likely will approximate the existing thalweg elevation at points A and B (fig. 9), which are near the upstream end of the reach affected by the diversion dam. At the diversion dam, the future thalweg elevation could be as much as 21 ft lower than the present dam crest. With the dam removed, the future thalweg profile (fig. 9) would be about 5 ft lower than the estimated water-surface profile, based on flows surveyed on April 12, 1988.

EROSION POTENTIAL ADJACENT TO STATE HIGHWAY 140

During large floods, as in December 1937, erosion of the State Highway 140 embankment upstream from the diversion dam between point U and cross section C may occur (fig. 4). In addition, inundation of the junction of State Highways 140 and 120 at the right bank abutment of the diversion dam (fig. 4), as noted during the floods of December 1937 and November 1950, may reoccur. At cross section B (table 2), the elevation of the toe of the rock riprap is about 3,810 ft, with the thalweg at this cross section at an elevation of 3,800 ft. As such, there is about 10 ft of channel bank below the toe of the riprap that is unprotected. However, present channel and pool conditions provide some protection of the State Highway 140 embankment because the pool tends to dissipate the kinetic energy (shear stress) associated with inflow from the upstream reach. Removal of the diversion dam will eliminate the storage pool, and the resultant energy dissipation. In addition, the channel alignment then may tend to migrate towards the right bank because of curvature of the channel, thereby increasing the possibility of erosion of the highway embankment.

The changes in hydraulic forces in the study reach that would be caused by removal of the dam were estimated on the basis of flood data obtained after the November 1950 flood and from the April 1988 surveys. The maximum depth of flow during the November 1950 flood at cross section A, and with the dam in place, is about 24 ft (fig. 5). The hydraulic forces acting in the channel bed (which are indicative of forces acting on the channel bank) were estimated on the basis

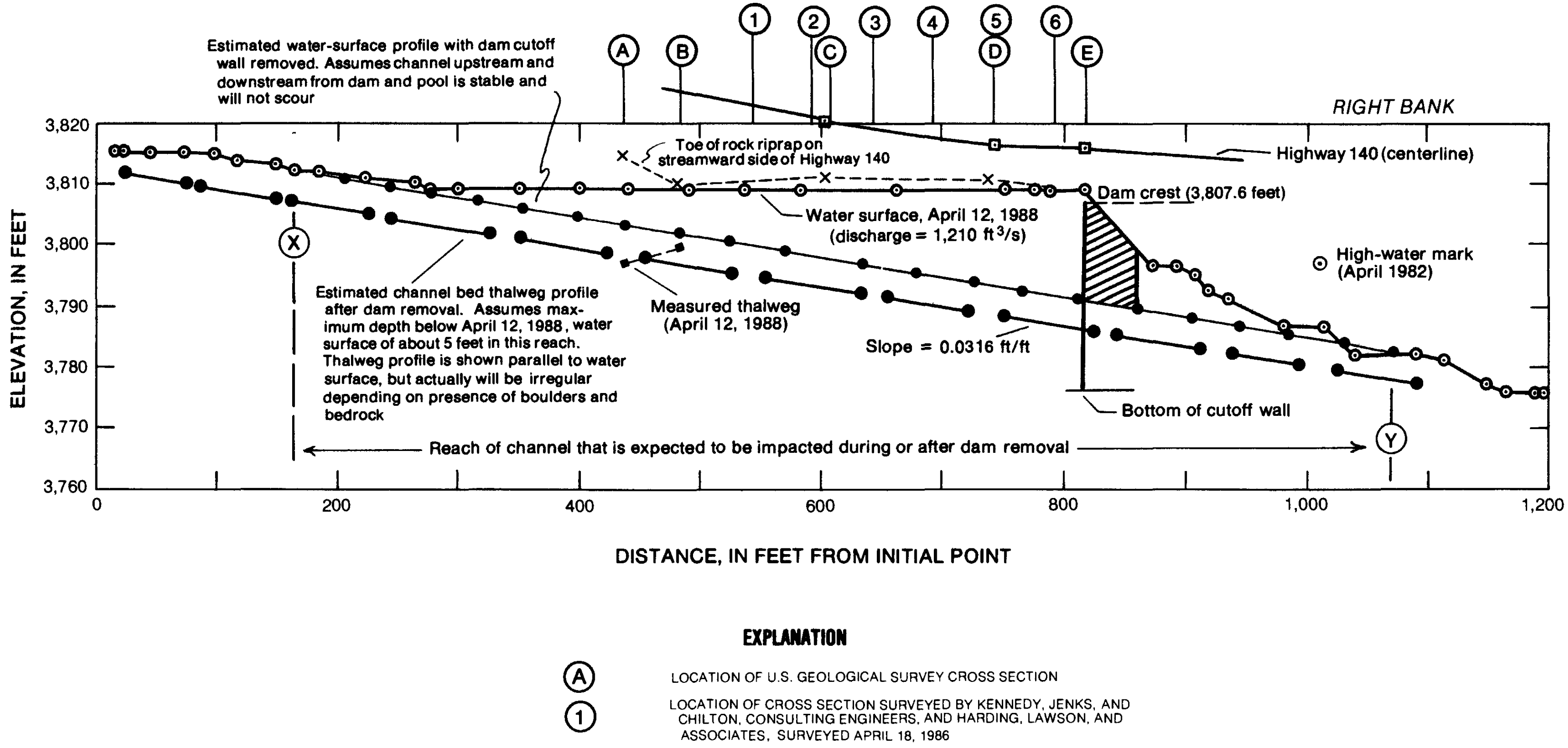

FIGURE 9. Profiles of water surface and thalweg for pre- and post-Cascade Dam conditions.

of shear stress. The shear stress at this cross section was calculated using the equation (Blodgett and McConaughy, 1986)

$$\tau = \gamma d S \qquad (1)$$

where

τ is shear stress, in pounds per square foot,

γ is unit weight of water, in pounds per cubic foot,

d is maximum depth of flow, in feet, and

S is water surface or bed slope, in feet per foot.

For the November 1950 flood, the water-surface slope in the vicinity of the dam was 0.0056 ft/ft (fig. 5), and the corresponding bed-shear stress was calculated to be 8.4 lb/ft^2. If the dam is removed, a maximum depth of flow of 24 ft at cross section A for flooding similar to that of November 1950 is expected to remain about the same (fig. 5). The channel-bed slope would increase to 0.0316 ft/ft (fig. 9), a value between the gradients of 0.06 and 0.01 ft/ft derived from the Geological Survey topographic map dated 1958. The corresponding bed-shear stress would be 47.3 lb/ft^2, nearly six times greater than the shear stress with the diversion dam in place.

If the dam is removed, the combination of inflow associated with high shear stress plus possible channel migration toward the State Highway 140 embankment suggests that bank protection will be needed at the site. Bank protection such as riprap would need to be installed at the toe of the embankment and to a point that is as high as the toe of the present riprap protection. The toe of the new bank protection should extend down to the elevation of 3,787 ft, which is the estimated thalweg profile (fig. 9), and extend upstream and downstream between point U and cross section C (fig. 4).

SUMMARY

The Cascade Diversion Dam pool extends about 550 ft upstream from the dam, depending on the magnitude of flow. Historic large magnitude floods in December 1937, November 1950, and December 1955 caused deposition of sediment in the pool upstream from the dam. Sediment deposits were removed in 1938 to a depth about 2.5 ft below the dam crest after the December 1937 flood. These same floods were large enough to cause inundation of the right bank dam abutment and road surface at the junction of State Highways 140 and 120. Removal of the dam could cause scour and a decrease in the elevation of the channel bed at the site of the dam to an elevation of about 3,787 ft (about 21 ft lower than the present dam crest). Dam removal also could cause a six-fold increase in bed-shear stress, which may then result in erosion of the State Highway 140 embankment upstream from the dam site. Therefore, protection of the State Highway 140 embankment would be needed.

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