HYDRAULIC ANALYSIS OF FLOODFLOWS IN BUTTE BASIN AT STATE HIGHWAY 162

GLENN AND BUTTE COUNTIES, CALIFORNIA

By J. C. Blodgett and P. L. Stiehr

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Inundation of State Highway 162 near Butte City during flood of January 24, 1970.

Photograph by California Department of Transportation Division of Highways

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CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) are given below to four significant figures. However, in the text, the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by:*	*Metric (SI)*
ft (feet)	0.3048	m (metres)
ft^3/s (cubic feet per second)	0.02832	m^3/s (cubic metres per second)
mi^2 (square miles)	2.59	km^2 (square kilometres)
mi (miles)	1.609	km (kilometres)

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ABSTRACT

Inundation of State Highway 162 across Butte Basin at the latitude of Butte City results from overland floodflow from the Sacramento River and flooding on Butte Creek. Flooding of Butte Basin from the Sacramento River will occur whenever flow in the main channel at Butte City exceeds 90,000 cubic feet per second (2550 cubic metres per second), a discharge with a recurrence interval of about 3 years. The distribution of floodflow across the basin is not uniform. During the flood of January 24, 1970, 84 percent of the total discharge resulted from overland flow from the Sacramento River and 16 percent from flooding on Butte Creek.

When flooding in Butte Basin is severe enough to affect State Highway 162, overflow across the road first occurs between bridges 11-21 and 11-22. The construction of bridges or culverts at two locations between bridges 11-21 and 11-22 would increase the period of time that the road is usable.

Analysis of the present roadway, bridge geometry, and ground elevations adjacent to the roadway indicates that backwater is less than 0.6 foot (0.2 metre) for flows of the magnitude experienced during the flood of January 24, 1970. The concurrent maximum velocity of flow at the bridges is 6.8 feet per second (2.1 metres per second). Part of the backwater is caused by ground elevations adjacent to the roadway that are, at many locations, higher than the road crown.

If the roadway embankment were raised to prevent overtopping by a flood equivalent to that of January 24, 1970, without increasing the capacity or number of the bridges, backwater greater than 0.5 foot (0.2 metre) would result upstream from 6 of the 15 bridges on State Highway 162, and velocities would be excessive. Additional bridge openings to discharge a total of 37,800 cubic feet per second (1070 cubic metres per second) would be required for at least six locations if backwater and velocity were to be kept to levels similar to those observed for present conditions.

During the flood of November 12, 1973, water-surface elevations recorded in several of the overflow channels of Butte Creek were higher than those observed during the January 1970 flood even though the discharge was less. The higher water-surface elevations in 1973 probably resulted from vegetal growth in the channels and consequent reduction in the capacity of the channel to carry floodflows.

INTRODUCTION

Purpose and Scope

The California Department of Transportation, Division of Highways, is planning to improve parts of State Highway 162 on the flood plain, and would like to reduce the frequency of flooding of the roadway. The proposed improvements include replacing certain bridges, widening other bridges, and possibly raising selected parts of the roadway between bridges. The purpose of the changes is to reduce the duration of road overflow and to allow some use of the highway even when overtopped by floodflow.

At the request of the California Department of Transportation, Division of Highways, the U.S. Geological Survey made a study in 1971-73 of the hydraulic characteristics of floodflow at State Highway 162 on the east-bank flood plain of the Sacramento River (pl. 1) near Butte City.

The purpose of the study is to evaluate the frequency of flooding, the effects of changes in the roadway design on flow patterns across the flood plain, potential backwater, and velocity of flow at bridge crossings. The study included surveys of cross sections across the flood plain at selected locations, determination of historic high-water levels in the study area, and identification of areas subject to inundation.

The east-bank flood plain of the Sacramento River extends east of the main channel at Butte City more than 7 mi (11 km) and includes 15 separate channels. State Highway 162 crosses the flood plain at the latitude of Butte City and is subject to inundation during floods. Overtopping of the road, presently built near natural grade level, results whenever flood discharge in the main channel of the Sacramento River exceeds about 90,000 ft^3/s (2550 m^3/s) at Butte City, or when local runoff is excessive. Since completion of Shasta Dam in 1944, overbank flooding on the east-bank flood plain, caused by high flows of the Sacramento River, has occurred at least 11 times.

Description of Study Area

Butte Basin is a part of the Sacramento River flood plain situated to the east of the main channel between Sutter Buttes on the south and Big Chico Creek on the north. The eastern boundary of the basin is an indefinite line marked by the limits of inundation caused by flooding from Butte Creek, several small streams, and overflow from the Sacramento River. The western part of Butte Basin is protected from inundation by a project levee (pl. 1), which extends about 5 mi (8 km) upstream from Butte City on the east (left) bank of the main channel. The levee was constructed during the years 1937 to 1941 as a part of the Sacramento River flood control project. The design flood capacity of the channel between the levees at Butte City is 150,000 ft^3/s (4250 m^3/s), (The Reclamation Board, State of California, 1964, p. 28).

A major roadway across Butte Basin at the latitude of Butte City was constructed about 1929. The roadway, designated as State Highway 162, has been improved over the years. The latest major improvements to the road and bridges were constructed in 1970. Highway 162 and secondary roads in the study area (pl. 1) have been built at about the natural grade level. Bridges that have been constructed across the channels have insufficient capacity for major floodflows, and as a result, the roadway is subject to inundation.

Historically, water from the Sacramento River enters Butte Basin upstream from the project levee when the flows in the river at Butte City reach about 90,000 ft^3/s (2550 m^3/s) (Blodgett, 1971, p. 5). Depending on the duration of flooding, natural channels in upper Butte Basin (upstream from Highway 162) can handle about 10,000 ft^3/s (283 m^3/s) of the initial overflow from the river. When flows in the Sacramento River main channel significantly exceed 90,000 ft^3/s (2550 m^3/s), general flooding in Butte Basin occurs. The east-bank overflow drains south into lower Butte Basin (downstream from Highway 162) by way of many interconnected sloughs and depressions in the wide flood plain. Angel and Campbell Sloughs and Butte Creek (pl. 1) are three of the many channels that carry natural drainage and overflow from the Sacramento River. Before reaching State Highway 162, east of Butte City, overflow from the Sacramento River is augmented by local runoff from several smaller streams (pl. 1).

Prior to 1964, private levees were built and modified along the east bank of the Sacramento River to reduce the frequency of flooding in Butte Basin (California Department Water Resources, 1969). In 1964, The Reclamation Board had the levees along the main channel degraded to a level so that flows greater than 150,000 ft^3/s (4250 m^3/s) would not enter the main channel between the project levees near Butte City. Actually, flows somewhat in excess of 150,000 ft^3/s (4250 m^3/s) can enter the leveed reach--a discharge of 152,000 ft^3/s (4300 m^3/s) was observed at the Butte City gage on January 25, 1970.

Land leveling (fig. 1) over the years has caused a redistribution of floodflow on the flood plain. The natural sloughs and depressions on the flood plain (pl. 1) have been altered by construction of low levees, or have been blocked off or leveled in such a way that flood waters reaching lower Butte Basin now occupy channels of insufficient capacity or flow over lands not previously inundated. The effect of land-leveling operations will be most noticeable for floods of lesser magnitude (90,000 to 110,000 ft^3/s or 2550 to 3120 m^3/s on the Sacramento River). Larger floods, those exceeding 110,000 ft^3/s (3120 m^3/s), may scour out many of the low levees and agricultural dikes, and inundate lands that historically have been flooded.

The changes in the land surface will affect the distribution of flows at State Highway 162. For example, a drainage ditch constructed in the spring of 1973 (fig. 1) and associated land leveling near Road Z, diverts all flow from a channel of Campbell Slough that formerly passed under bridge 11-24 to another channel that passes under bridge 11-31. Only during extreme floods will floodflows overtop the levees along the drainage ditch near Road Z and again pass through bridge 11-24. Because of the continual changes to the flood plain, which in turn affect distribution of floodflow, the relations established from data obtained during the period 1970-73 are primarily applicable to the conditions prevailing at the time data were collected.

Collection of Data

Field Surveys

The pertinent geometry of the channels and flood plain was determined by surveys from 1969 to 1973. All elevations given in this report are referenced to mean sea level datum (1929 datum, 1946-47 adjustments) unless otherwise identified. The datum of the gaging stations, Sacramento River at Butte City and Butte Creek near Durham, are referenced to the datum of the U.S. Corps of Engineers.

Channel and approach cross sections and intermediate points to aid in the analysis were surveyed at selected intervals throughout the study area (pl. 1). Flow patterns and boundaries were determined using topographic maps (7.5-minute series) and aerial photographs of the floods of February 1940 and January 1970.

FIGURE 1.--Land leveling upstream from State Highway 162, July 31, 1973.

Instrumentation

A continuous record of the river stage on the main channel is obtained by a water-stage recorder on the main channel of the Sacramento River at Butte City (pl. 1).

In the autumn of 1969, two additional water-stage recorders were installed just downstream from the bridges across Campbell Slough and Butte Creek on State Highway 162 (pl. 1). These gages provide a record of the water stage near the center and east side (pl. 1) of the flood plain that extends 7 mi (11 km) east from the main channel.

CHARACTERISTICS OF FLOODFLOW

Frequency of Flooding

Annual flood peaks in the Sacramento River at Butte City and Butte Creek near Durham have been compiled (tables 1 and 2) for the period of record through the 1973 water year. Using these data, flood frequency and duration relations have been prepared (fig. 2). The frequency analysis of flooding in Butte Basin at the latitude of Butte City required separation of floods caused by overland flow from the Sacramento River from those floods occurring on Butte Creek.

Because of changes over the years in the drainage patterns on the flood plain, floods caused by high runoff in Butte Creek are presently restricted to channels east of bridge 11-32 (pl. 1). There are occasions, however, when overland flow from the Sacramento River contributes to the flow of Butte Creek (Blodgett, 1971, p. 14). During the flood of January 1970, overland flow from the Sacramento River reached State Highway 162 about 21 hours after peak flows occurred on Butte Creek, thus tending to extend the duration of flooding on Butte Creek.

An analysis of flood frequency for the Sacramento River at Butte City has shortcomings in that flows are not strictly random; they have been and will be controlled by upstream reservoir operation, notably Shasta Dam. However, the drainage area between Shasta Dam and Butte City is 5,513 mi^2 (14,280 km^2), about 46 percent of the total drainage area above Butte City. Therefore, floodflows reaching Butte City are not completely regulated.

The probability of an annual flood of a selected magnitude can be determined by the use of the flood-frequency relations (fig. 2); likewise, the duration of flooding during any 1 year for various probabilities may be determined. The use of the flood-frequency curves is illustrated by an example:

Table 1.--*Annual peak elevation and discharge of the Sacramento River at Butte City*

[Entries for 1970 and earlier are derived from a report by Blodgett and Pearce, 1971, p. 22]

Water year	Date	Elevation (feet)[1]		Instantaneous peak discharge (ft^3/s)[2]	Maximum mean daily discharge (ft^3/s)
		Corps of Engineers datum	Mean sea level datum		
1915	2- 3-15	[3]95.8	92.9	—	—
1917	2-26-17	[3]93.8	90.9	—	—
1921	1-31-21	[3]92.8	89.9	—	—
1930	12-17-29	86.4	83.5	—	—
1931	1-24-31	[3]78.9	76.0	—	—
1932	12-28-31	89.3	86.4	—	—
1933	3-29-33	[3]80.3	77.4	—	—
1934	1- 2-34	87.6	84.7	—	—
1935	4- 9-35	90.44	87.52	—	—
1936	2-23-36	92.75	89.83	—	—
1937	3-14-37	89.40	86.48	—	—
1938	12-12-37	95.39	92.47	—	—
1939	3-14-39	81.40	78.48	[4]35,000	—
1940	2-28-40	96.21	93.29	[4]162,000	—
1941	2-12-41	95.17	92.25	151,000	—
1942	2- 7-42	96.87	93.95	170,000	—
1943	1-24-43	94.44	91.52	143,000	—
1944	2- 4-44	82.95	80.03	42,400	38,500
1945	2- 2-45	86.43	83.51	62,700	58,100
1946	12-29-45	91.69	88.77	114,000	112,000
1947	2-13-47	83.56	80.64	49,300	47,200
1948	3-24-48	86.44	83.52	58,000	57,500
1949	3-12-49	90.53	87.61	82,200	80,100
1950	2- 7-50	86.76	83.84	59,400	57,200
1951	1-23-51	89.25	86.33	74,300	70,800
1952	12-29-51	92.49	89.57	111,000	102,000
1953	1-14-53	91.96	89.04	106,000	104,000
1954	2-19-54	90.54	87.62	80,700	78,900
1955	12-10-54	80.49	77.57	33,500	32.100
1956	1-16-56	94.66	91.74	149,000	145,000
1957	3- 6-57	88.00	85.08	59,500	59.200
1958	2-20-58	96.70	93.78	160,000	158,000
1959	2-17-59	91.37	88.45	94,100	70,700
1960	2- 9-60	90.93	88.01	89,300	82,700
1961	12- 2-60	88.34	85.42	65,300	57,500
1962	2-16-62	90.90	87.98	87,800	81,500
1963	4-15-63	92.20	89.28	105,000	94,800
1964	1-21-64	84.80	81.88	50,800	39,100
1965	12-24-64	94.89	91.97	126,000	122,000
1966	1- 6-66	89.33	86.41	72,700	68,600
1967	2- 1-67	92.40	89.48	98.400	97,000
1968	2-26-68	89.38	86.46	69,500	68,500
1969	1-14-69	93.30	90.38	120,000	114,000
1970	1-25-70	95.92	93.00	152,000	146,000
1971	1-18-71	91.10	88.18	95,800	87,600
1972	3- 1-72	78.04	75.12	27,500	26,300
1973	1-19-73	91.41	88.49	98,500	94,200

[1]Datum of gage is 2.92 ft below mean sea level (U.S. Geological Survey, 1969, p. 832).
[2]Peak discharge on the Sacramento River does not include east-bank overflow that bypassed the Butte City gaging station.
[3]Maximum mean daily gage height.
[4]Maximum mean daily discharge.

Table 2.--*Annual peak elevation and discharge of Butte Creek near Durham*

Water year	Date	Elevation (feet)[1] Gage datum	Elevation (feet)[1] Corps of Engineers datum	Instantaneous peak discharge (ft^3/s)	Maximum mean daily discharge (ft^3/s)
Gage installed Dec. 11, 1958					
1959	2-16-59	8.72	189.73	5,100	3,260
1960	2- 8-60	8.65	189.66	5,100	4,290
1961	1-31-61	7.30	188.31	3,600	2,330
1962	12- 2-61	6.04	187.05	7,380	3,790
1963	1-31-63	11.29	192.30	9,810	6,260
1964	1-20-64	8.12	189.13	5,110	2,180
1965	12-22-64	14.55	195.56	21,300	16,900
1966	1- 4-66	6.99	188.00	3,410	2,640
1967	1-21-67	9.12	190.13	7,810	5,560
1968	2-21-68	6.83	187.84	3,850	3,210
1969	1-21-69	11.62	192.63	15,900	12,900
1970	1-24-70	12.42	193.43	18,300	10,700
1971	3-12-71	6.76	187.77	3,750	3,190
1972	1-23-72	5.30	186.31	2,050	1,290
1973	1-16-73	8.49	189.50	7,150	2,950

[1]Datum of gage is 181.01 ft above Corps of Engineers datum (California Department of Water Resources, 1973, p. 60).

To determine the probable number of days of flooding at State Highway 162 that may be expected to occur for an annual maximum daily mean discharge of 130,000 ft^3/s (3680 m^3/s) on the Sacramento River at Butte City, determine the probability of exceedence from figure 2 (graph A) for this flood. This is about 10 percent. The corresponding annual peak discharge is 134,000 ft^3/s (3790 m^3/s). In figure 2 (graph B), when the probability of exceedence is 10 percent, flows will exceed 90,000 ft^3/s (2550 m^3/s) for about 9 days on the Sacramento River at Butte City. Reference to table 3 indicates that major flows in the main channel of 9-days duration correspond to about 13-days overflow on the flood plain. Estimates of flow duration and flood frequency for Butte Creek may be determined in a similar way from figure 2 (graphs C and D).

The relations presented in figure 2 do not indicate the probability of flooding or duration for a combined flood resulting from overland flow from the Sacramento River and flooding on Butte Creek.

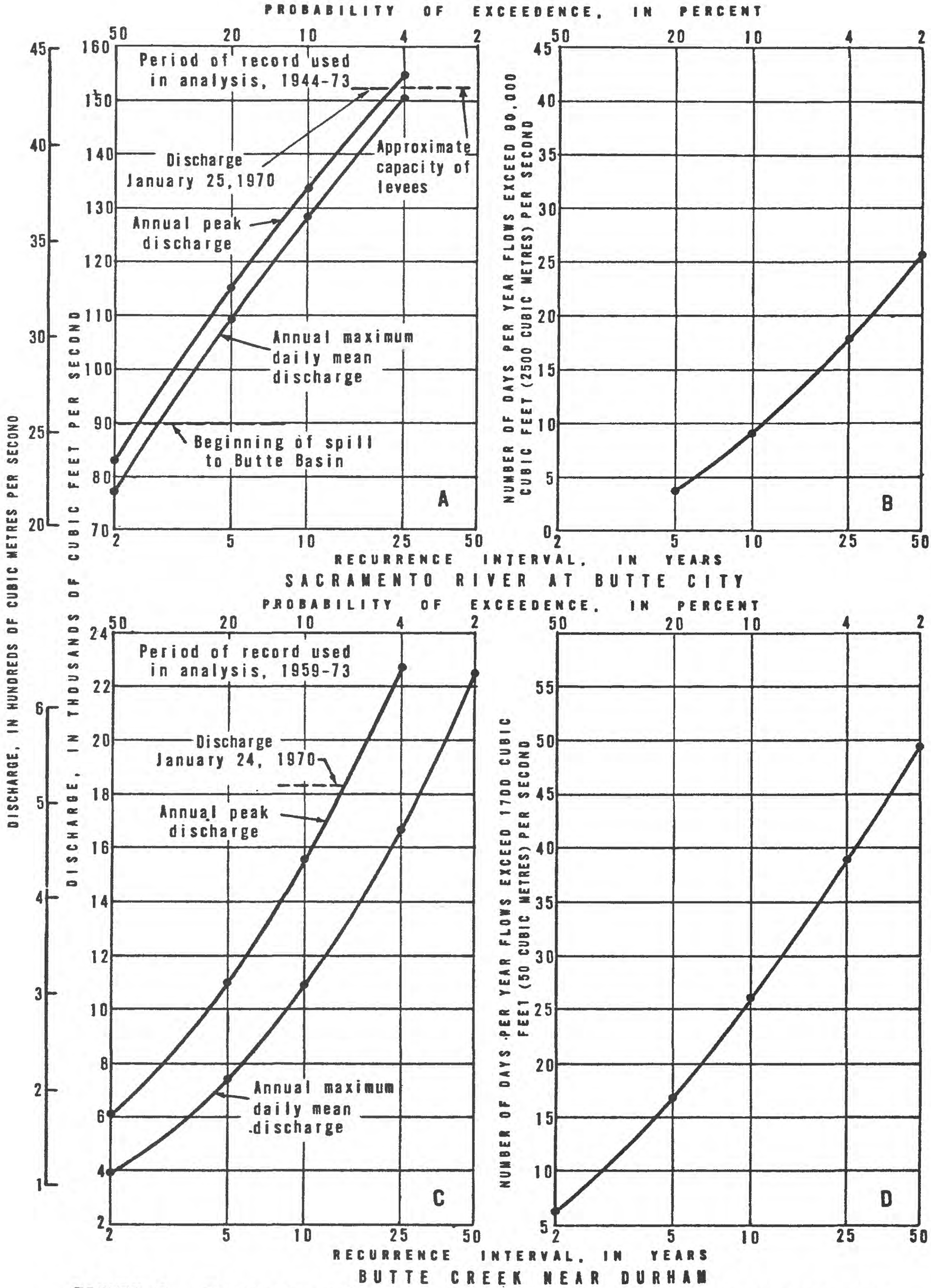


FIGURE 2.--Frequency relations of maximum discharge and duration for Sacramento River at Butte City and Butte Creek near Durham.

Table 3.--*Duration of flooding at the latitude of Butte City, January 9-31, 1970*

Sacramento River at Butte City		Campbell Slough at Highway 162		Butte Creek near Durham		Butte Creek at Highway 162	
Mean daily discharge (ft^3/s)	Duration (days)	Stage (ft)	Duration (days)	Mean daily discharge (ft^3/s)	Duration (days)	Stage (ft)	Duration (days)
80,000	16	78.5	18	1,700	19	79.5	14
[1]90,000	12	79	16	2,000	18	80	12
95,000	12	[2]79.5	13	2,500	15	80.5	9
100,000	11	80	13	3,000	11	[3]81	4
110,000	7	80.5	12	4,000	9	81.5	3
120,000	5	81	6	5,000	5	82	1/4
130,000	2	81.5	1				

[1]Flows begin to overtop private levees along Sacramento River upstream from State Highway 162.
[2]Flows begin to overtop State Highway 162 near Bridge 11-21.
[3]Flows begin to overtop State Highway 162 when stage in main channel exceeds about 18 ft (3,600 ft^3/s).

Flow data for the gaging station on Butte Creek near Durham were used in the frequency analysis because data are insufficient for frequency analysis at the latitude of Butte City. The Durham gage is 17 mi (27 km) upstream from State Highway 162. The average time of travel for flood events to traverse this reach is 10 hours. Because of the increase in drainage area between the two locations, floodflows increase in the downstream direction (fig. 3).

The curve (fig. 3) that defines the relation in discharge between the two gaging stations has been drawn to the left of the majority of the plotted points. Channel storage in the reach has a greater effect on floodflows during earlier or isolated floods, and such floods are represented by most of the plotted points in figure 3.

Areas Subject to Inundation

The parts of Butte Basin in the vicinity of State Highway 162 that are subject to inundation by floodwaters from Butte Creek or overland flow from the Sacramento River are shown in figures 4, 5, and 6. Areas that were inundated during the floods of February 1940 (fig. 4), January 1970 (fig. 5), and January 1973 (fig. 6) were determined from aerial photography to illustrate the variation in areas that may be flooded. The change in areas subject to inundation is due to:

(1) Variation in magnitude of flows on the Sacramento River,
(2) changes in location of overflow sites along the Sacramento River caused by alteration of the banks or levees,
(3) variation in magnitude of flows in Butte Creek and adjacent streams,
(4) alteration of the natural drainage patterns by land-leveling operations, and
(5) variation of flood duration.

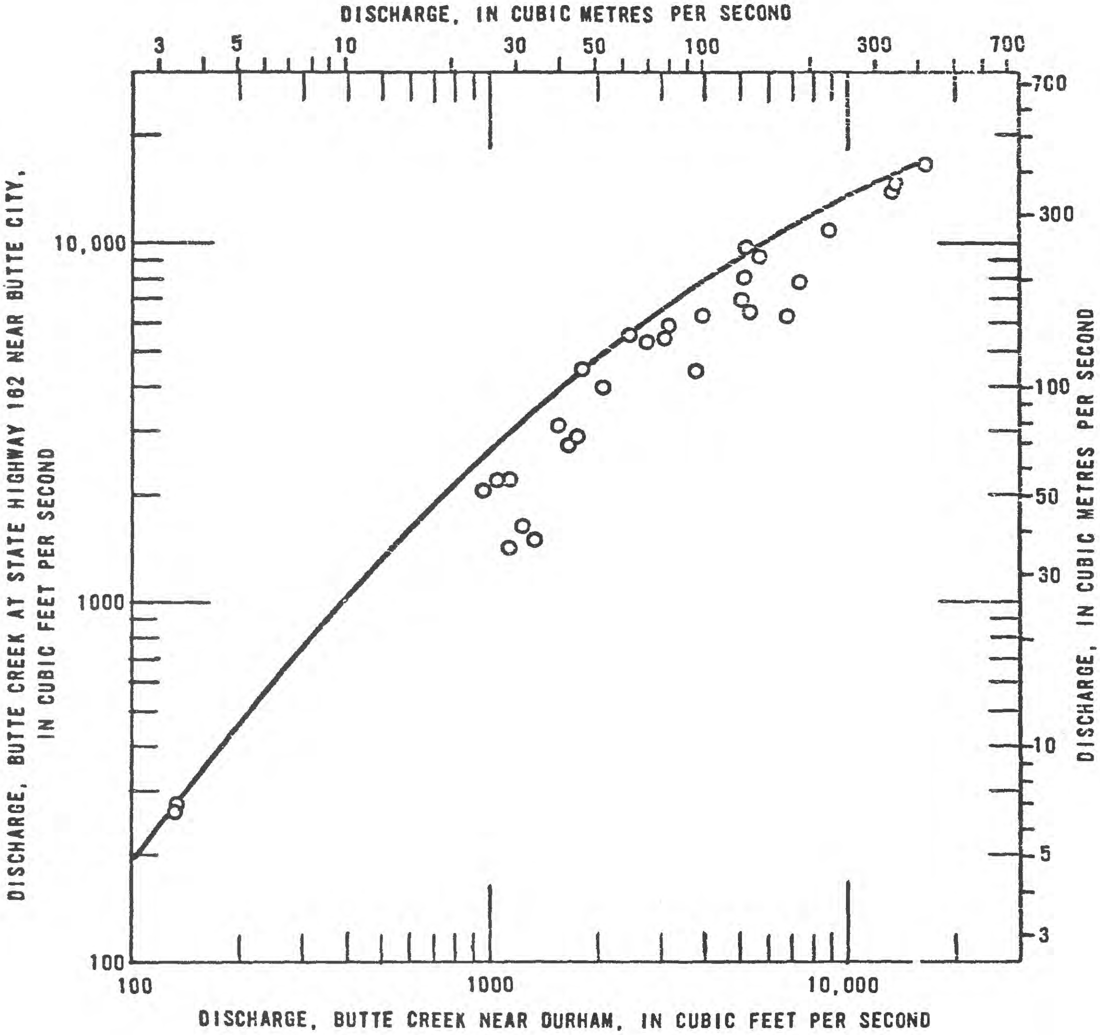
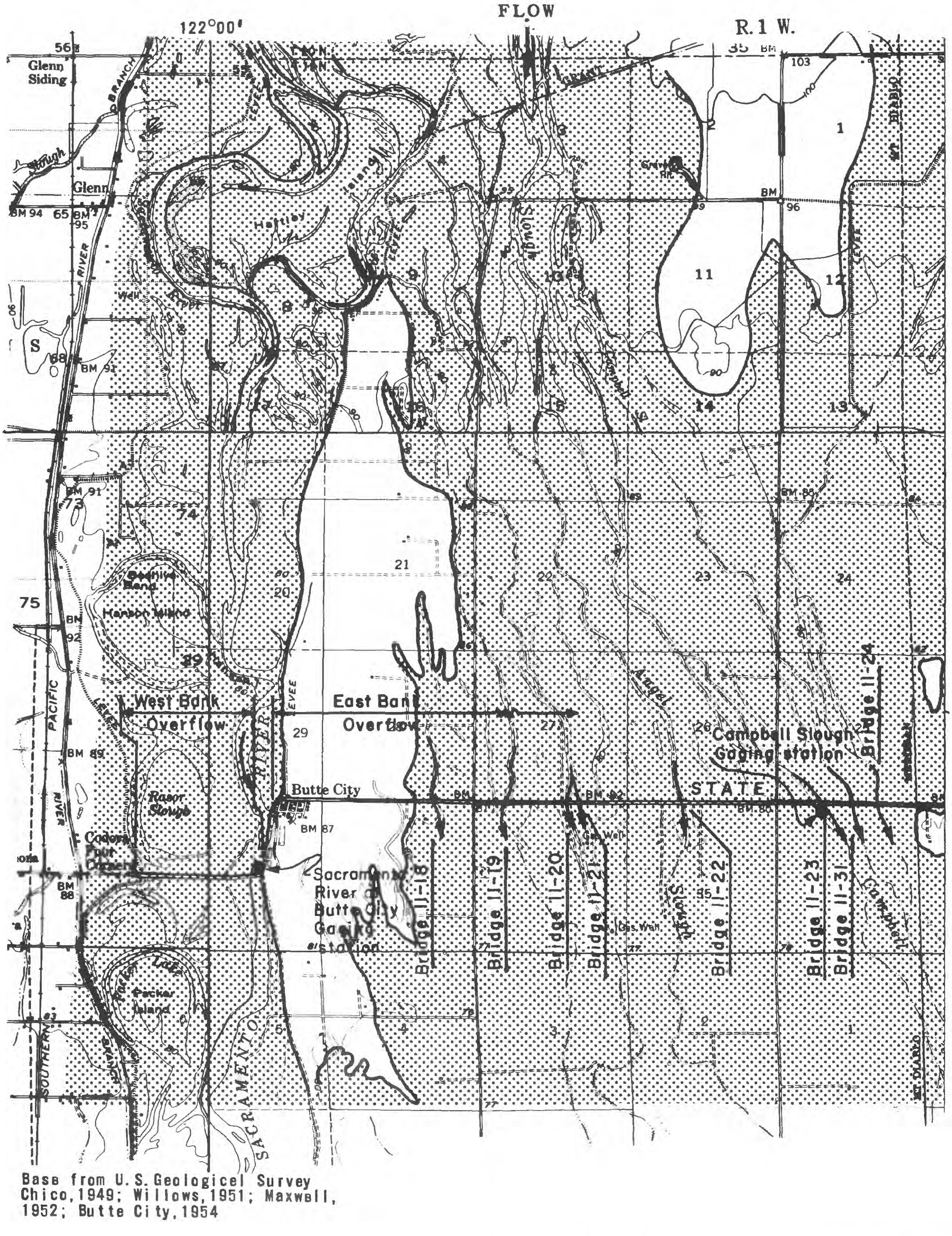


FIGURE 3.--Relation of discharge for Butte Creek near Durham and at State Highway 162.

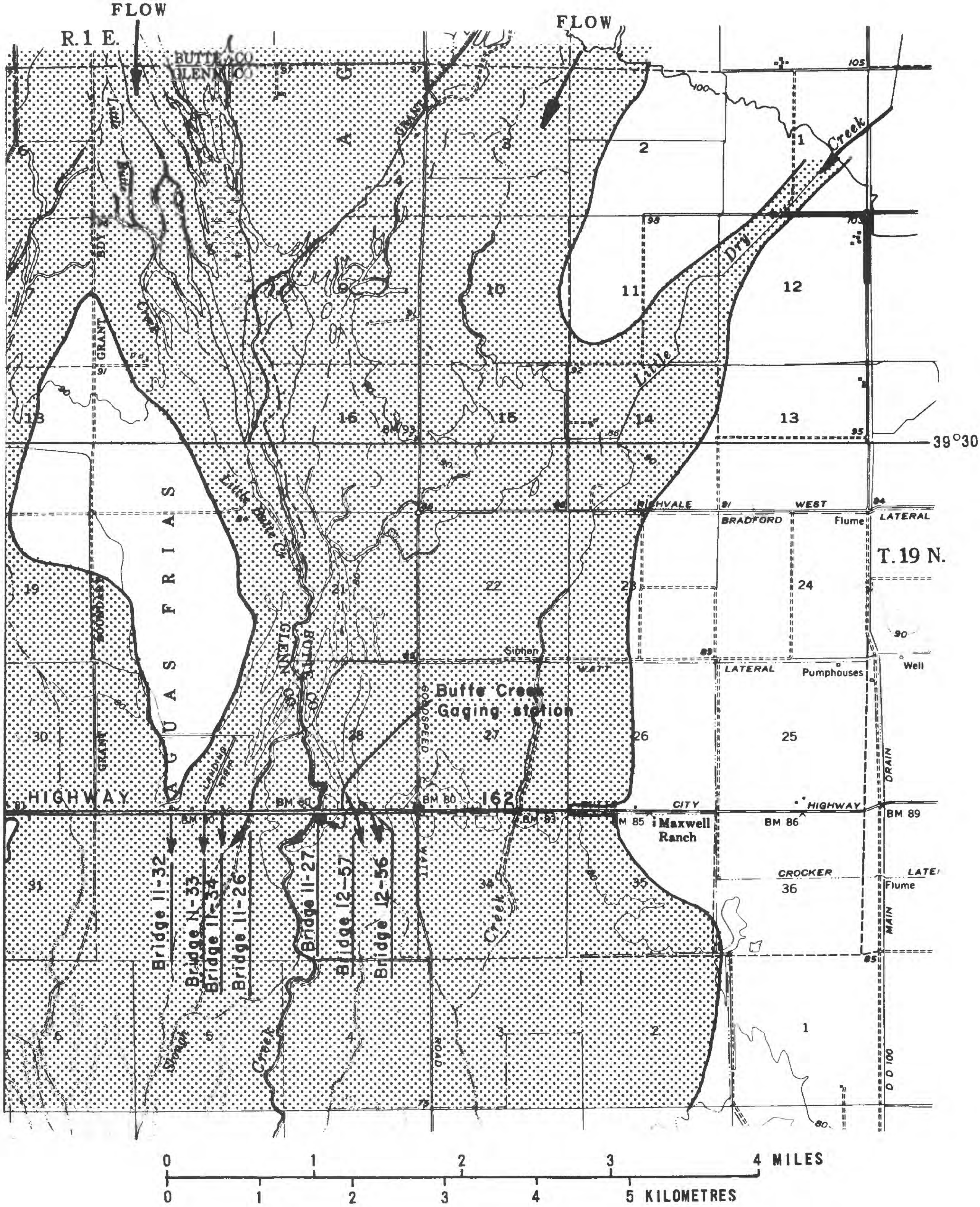
Figures 4 and 5 show areas inundated during the floods of 1940 and 1970 by overland flow from the Sacramento River and floodflow in Butte Creek. Figure 6 shows the areas inundated by flood runoff from Butte Creek and tributary drainage channels.

Peak water-surface elevations in the vicinity of State Highway 162 have been recorded by local residents and various State and Federal agencies for several historical floods. Flood elevations have been compiled in table 4 for sites whose locations are shown on plate 1. In general, the water surface for an individual flood slopes from the main channel toward the center of Butte Basin (fig. 7). This reflects the topography within the basin, and the higher water levels in the main channel compared to those in the basin.

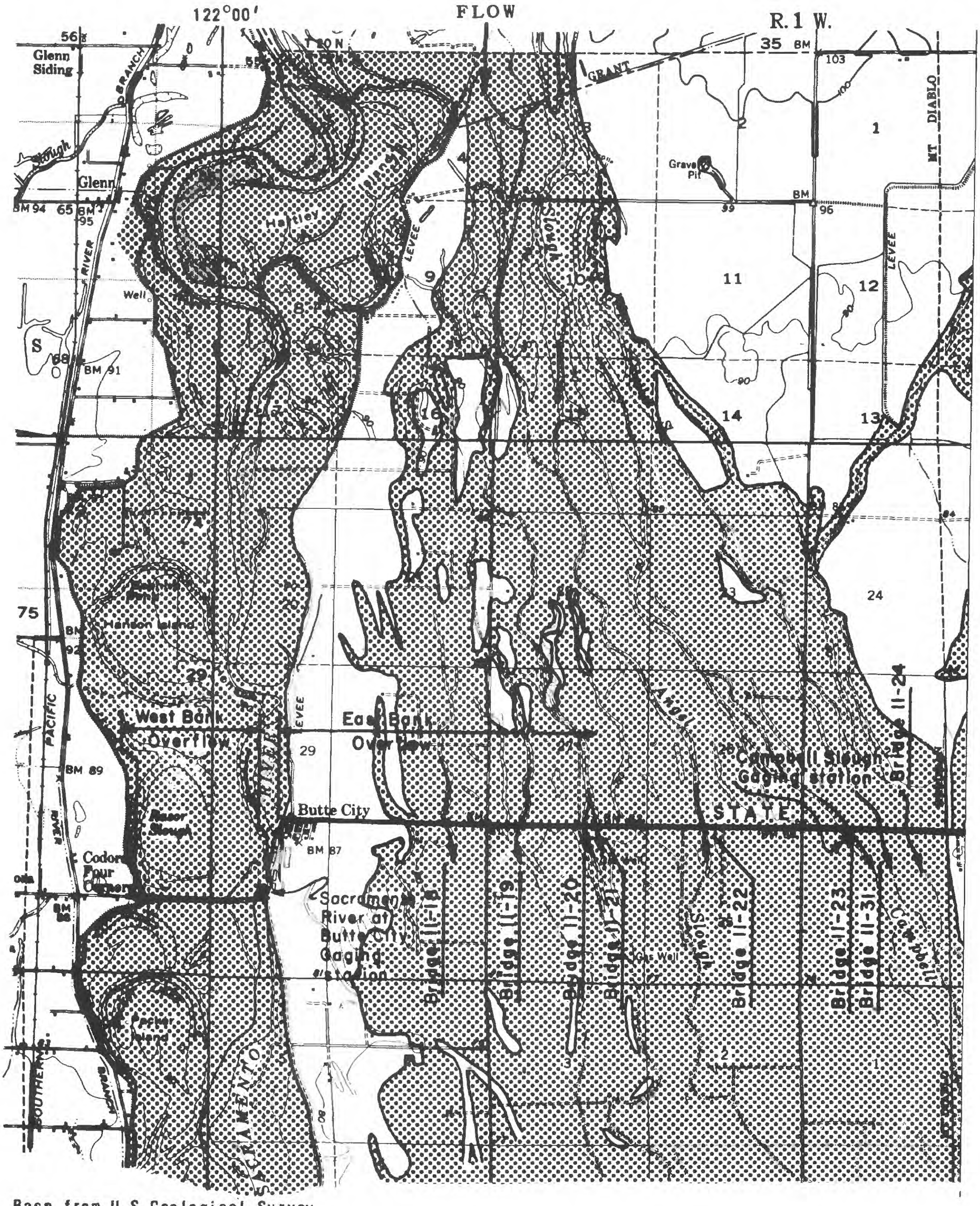


Base from U.S. Geological Survey Chico, 1949; Willows, 1951; Maxwell, 1952; Butte City, 1954

FIGURE 4.--Area inundated (shaded) on February 28, 1940,

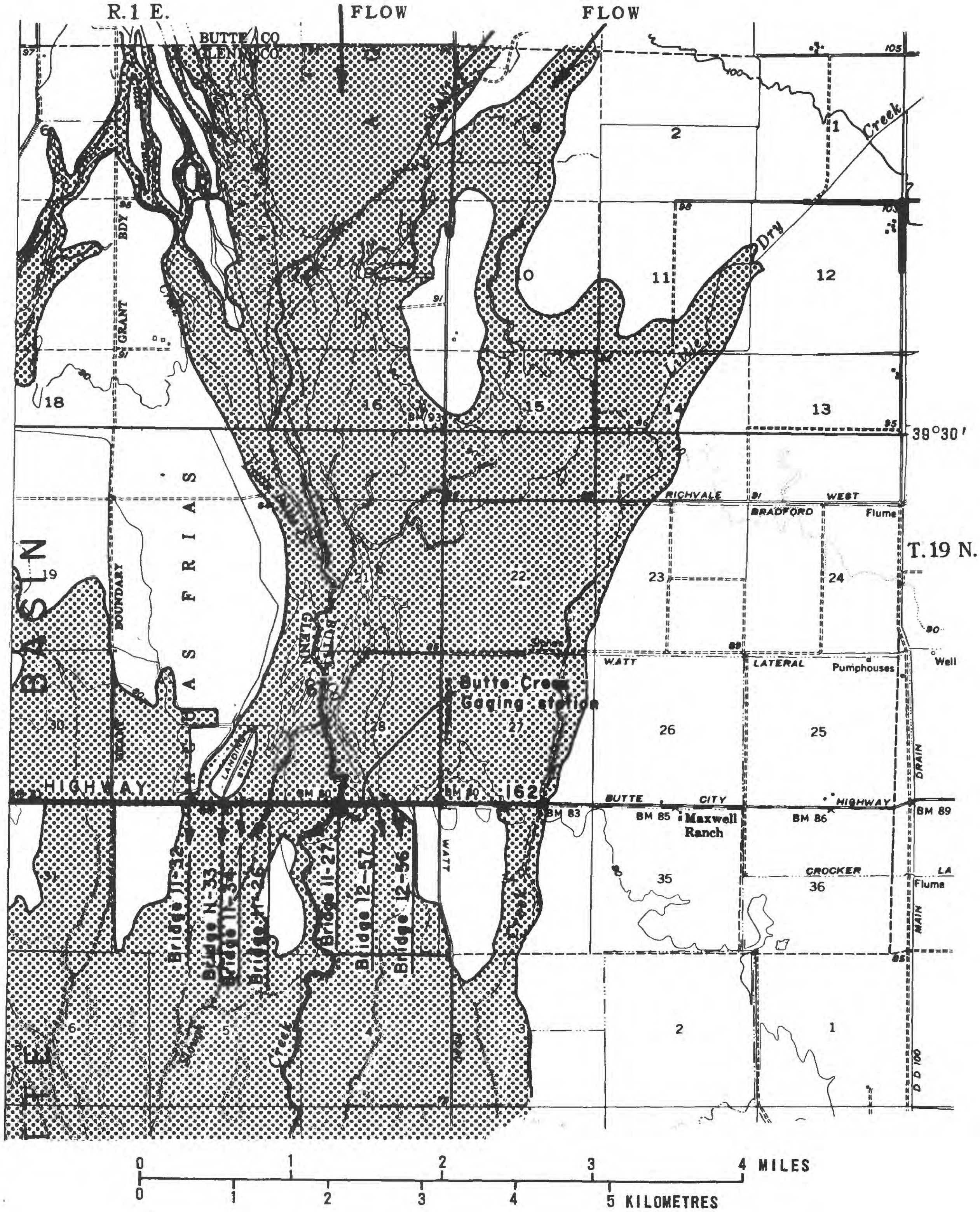


discharge 162,000 ft^3/s, in main channel.

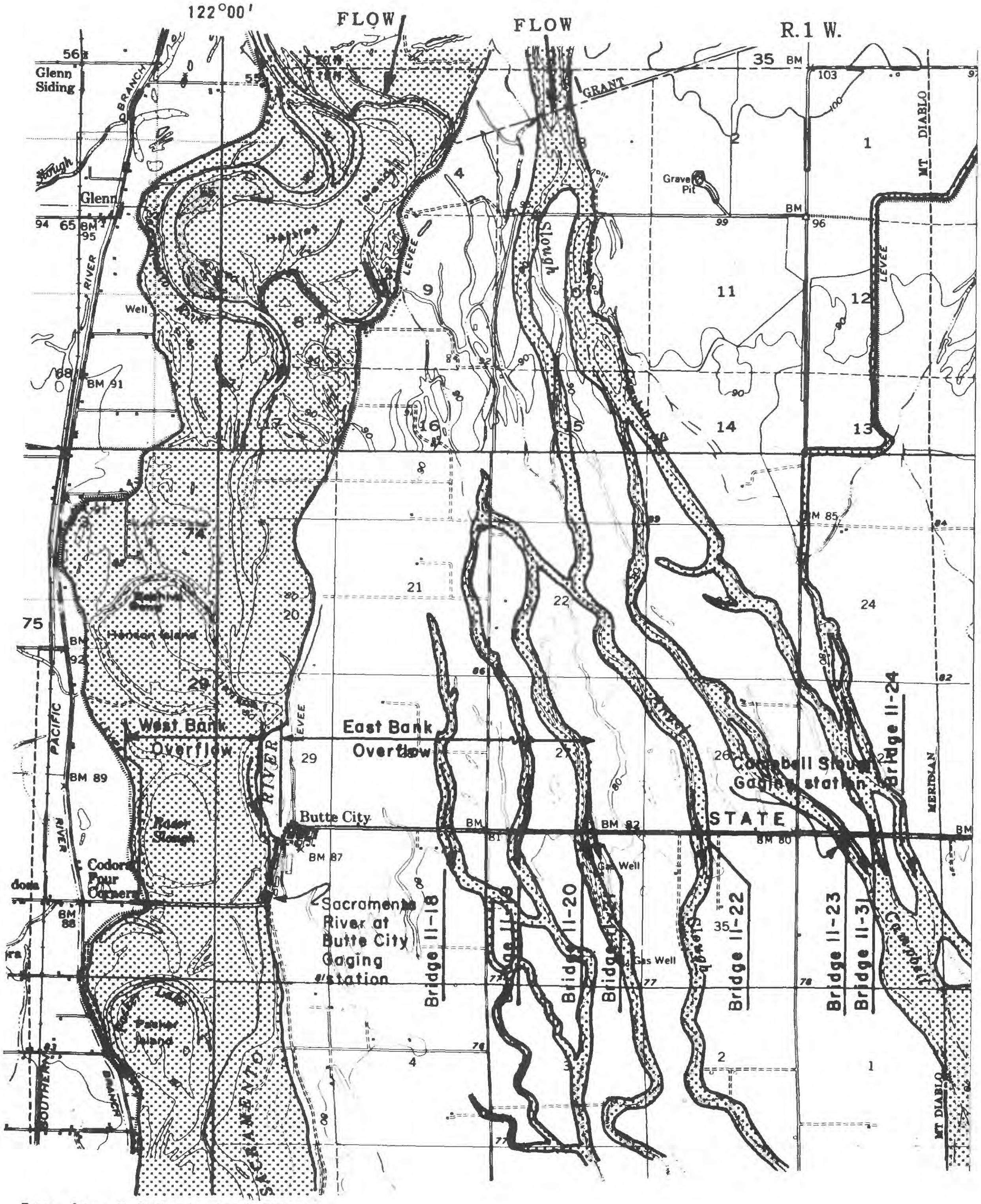


Base from U.S. Geological Survey Chico, 1949; Willows, 1951; Maxwell, 1952; Butte City, 1954

FIGURE 5.--Area inundated (shaded) on January 25, 1970,

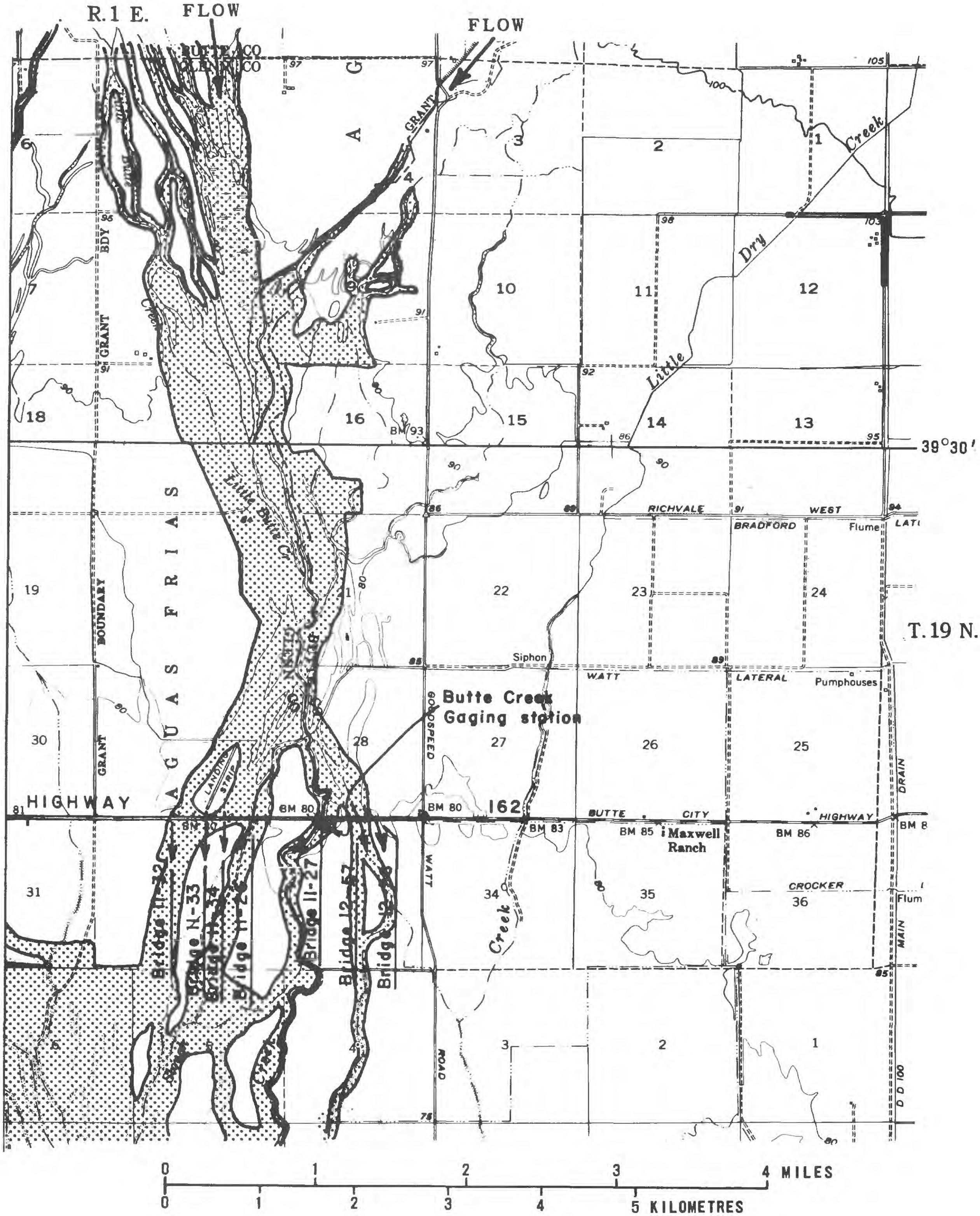


discharge 146,000 ft³/s, in main channel.



Base from U S Geological Survey Chico, 1949; Willows, 1951; Maxwell, 1952; Butte City, 1954

FIGURE 6.--Area inundated (shaded) on January 19, 1973,



discharge 98,500^3/s, in main channel.

Table 4.--*Historical water-surface elevations in Butte Basin near State Highway 162*

Location[1]	Year	Elevation (ft)
1	1940	101.8
2	1970	99.6
3	1940	101.5
4	1940	101.1
5	1940	99.3
6	1940	99.9
7	1940	97.5
8	1940	101.6
9	1970	97.1
10	1940	97.1
11	1915-16	94.6
12	1955	93.3
	1958	95.6
	1964	94.8
	1965	93.6
	1-14-69	92.7
	1-21-69	91.7
	1970	96.4
13	1940	97.3
14	1937	96.5
	1940	97.1
15	1970	89.3
16	1915-16	90.6
17	1970	86.5
18	1937	88.4
	1940	85.8
	1958	85.4
	1970	85.0
19	1937	87.4
	1942	87.9
	1958	87.4
	1964	87.4
	1970	87.8
20	1937	88.4
	1940	89.0
	1970	88.2
21	1970	84.1
22	1915-16	85.0
	1969	83.7
	1970	85.2
23	1940	84.5
24	1940	84.5
	1970	83.3
25	1970	82.9
26	1970	83.0
27	1970	83.2
28	1970	83.2
29	1970	82.7
30	1969	81.0
	1970	82.1
31	1969	80.6
	1970	81.2
32	1970	81.2
33	1970	80.7
34	1969	81.8
	1970	81.3
35	1970	81.2
36	1970	81.3
37	1970	81.3
38	1970	80.8
39	1969	81.8
	1970	82.0
40	1970	82.5
41	1970	82.4
42	1940	83.1
43	1970	82.0
44	1964	79.5
	1969	81.8
	1970	81.8
45	1915-16	79.8
46	1915-16	77.1
47	1958	78.6
	1964	78.0
	1970	78.0
48	1915-16	75.9
49	1937	76.9
	1958	75.6
	1964	75.0
	1969	74.2
	1970	76.2
50	1940	76.8
51	1970	76.8
52	1940	76.0
53	1940	76.8
	1958	74.6
	1964	75.3
	1970	75.9
54	1940	74.8
55	1915-16	73.1
	1940	74.5
	1969	71.7
	1970	74.3
56	1970	73.1
57	1970	73.1
58	1940	74.7
59	1940	73.9
60	1940	73.6

[1] Location of high-water marks shown on plate 1.

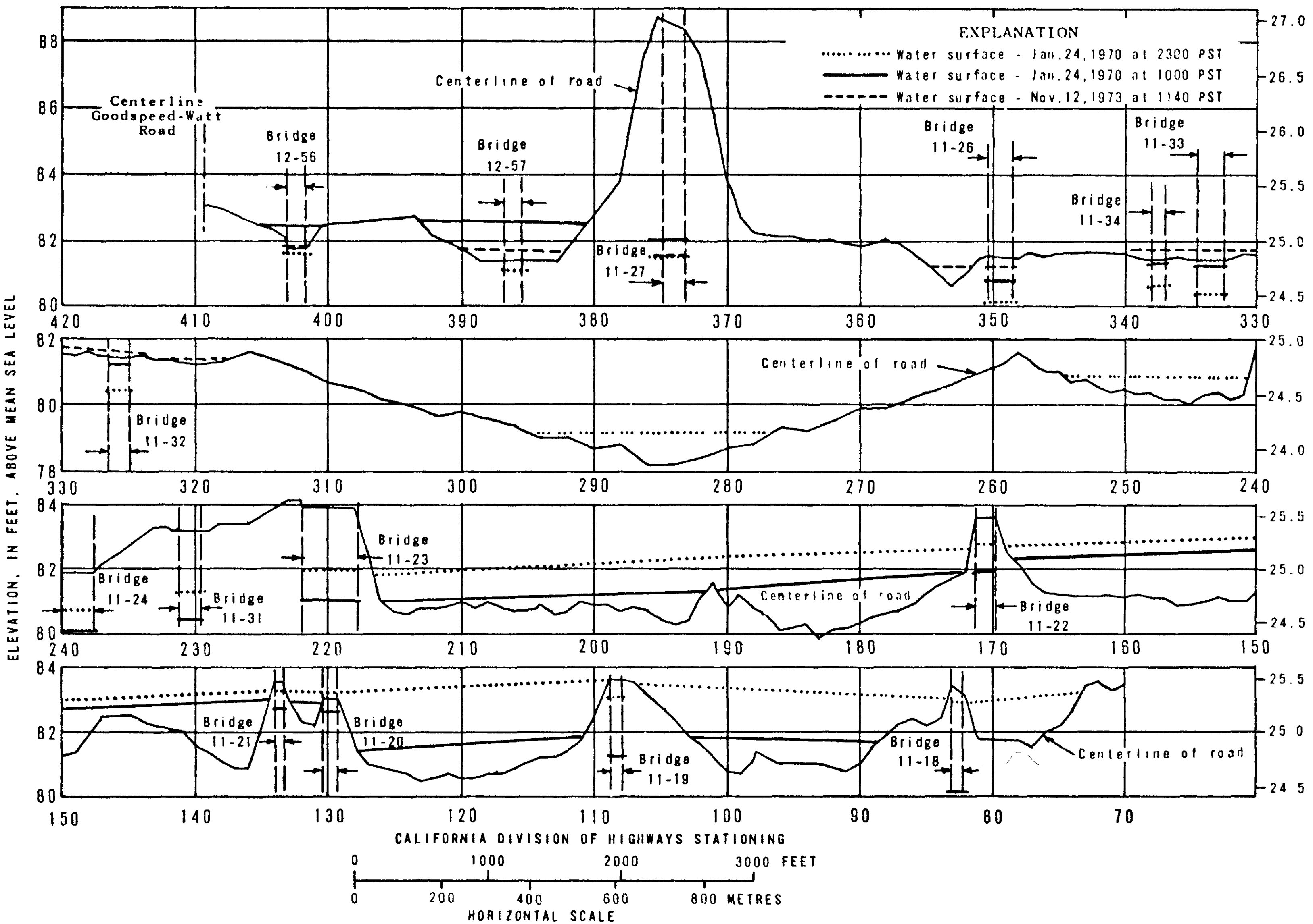


FIGURE 7.--Water-surface elevations along centerline of State Highway 162 for selected floods.

When flooding occurs in the vicinity of State Highway 162, maximum water-surface elevations occur near highway station 110+00[1] (fig. 7). Flows first cross the highway near highway station 137+00. Both of these locations are at points where the ground elevation is about 3 ft (0.9 m) higher than the lowest point on the flood plain.

Flood Profiles

Water-surface profiles for several historical floods have been determined utilizing the flood peak data (high-water marks) at locations shown on plate 1 and compiled in table 4. In order to develop flood profiles, base lines (A through G) were designated (pl. 1) for five major channels on the flood plain. At each base line, profiles of peak water-surface elevations were prepared for the floods of November 1973, January 1970, and February 1940 (fig. 8). Water-surface elevations and slopes of the profiles in the vicinity of State Highway 162 are shown in table 5.

Water-surface elevations at locations 6,000 ft (1830 m) downstream and upstream from State Highway 162 were interpolated from the profile plots. Slopes in water surface upstream from the highway for the various floods varied by a maximum of 17 percent for a given base line. Land-leveling and channelization works probably have not greatly altered the natural slope in water surface for large floods in this part of Butte Basin. The slopes in water surface recorded upstream from the highway during the flood of January 1970 were generally steeper than the present streambed slope.

---

[1] Highway stationing is the measured distance along the centerline of the road, in feet, from a starting reference. The customary usage is to give a station number in hundreds of feet. A station 27,000 ft (8230 m) from the start is shown as station 270+00.

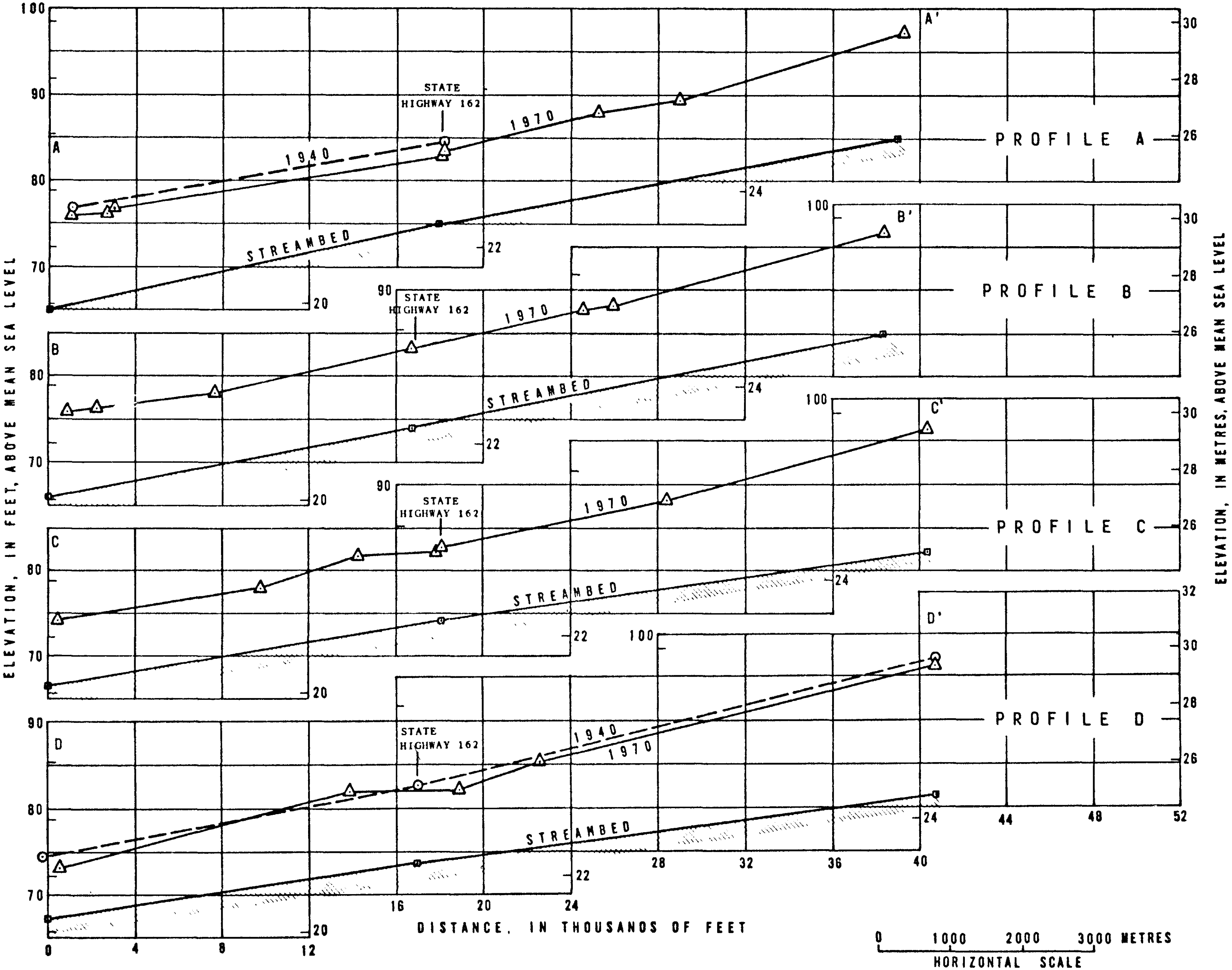


FIGURE 8.--Water-surface profiles A through G for selected floods.

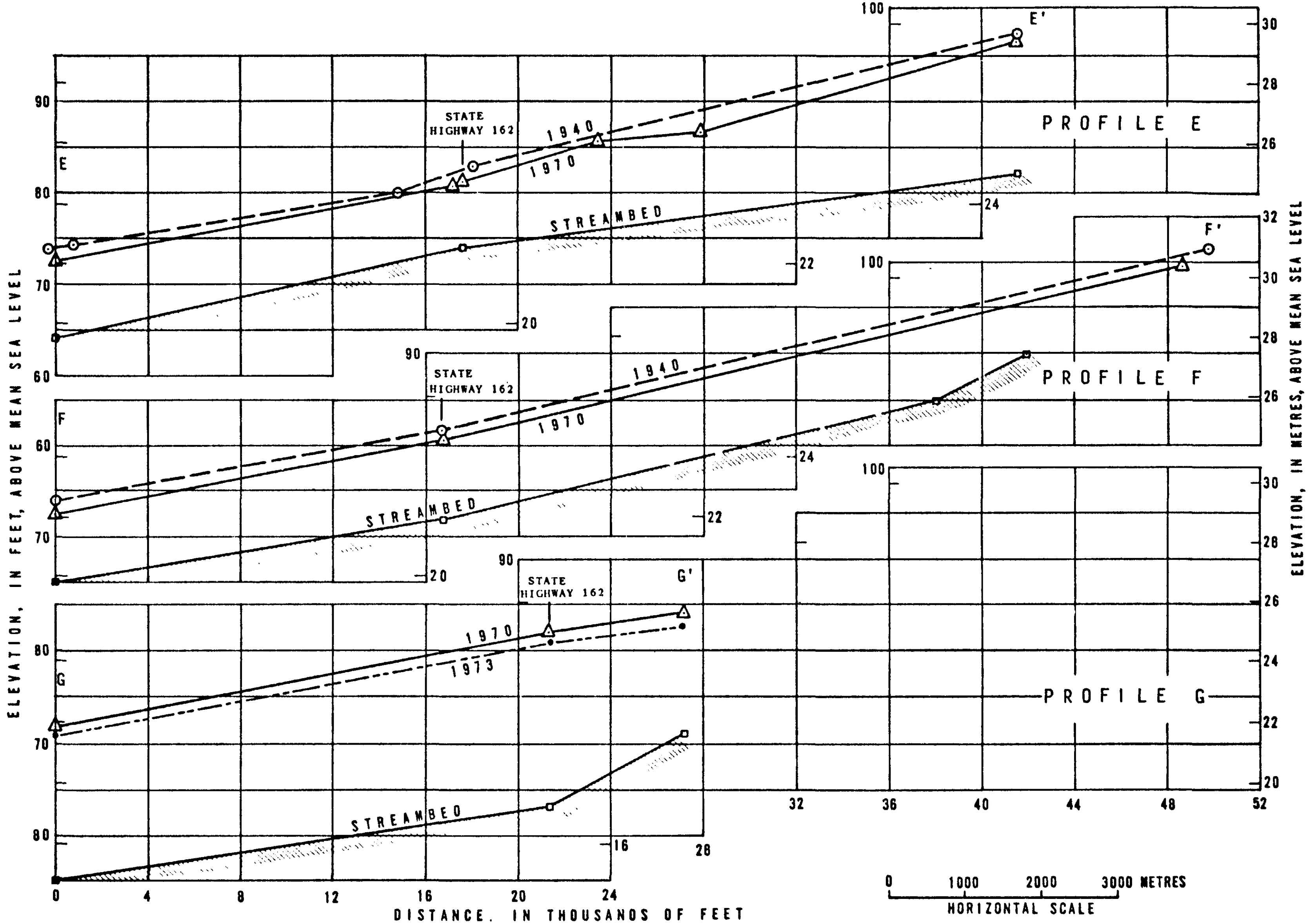


FIGURE 8.--Continued.

Table 5.--*Water-surface elevations and slopes for selected floods*

Date of flood	Base line (plate 1)	Water-surface elevation (ft): Downstream 6,000 ft	Water-surface elevation (ft): At Highway 162 (downstream side of bridge)	Water-surface elevation (ft): Upstream 6,000 ft	Slope, ft/ft: Water surface: Overall length (12,000 ft)	Slope, ft/ft: Water surface: Upstream from highway	Slope, ft/ft: Streambed upstream from highway
Feb. 1940	A	81.8	84.5	--	--	--	0.00050
	B	--	--	--	--	--	.00050
	C	--	--	--	--	--	.00037
	D	79.6	82.5	86.1	0.00054	0.00060	.00042
	E	78.8	82.5	86.1	.00061	.00060	.00032
	F	79.0	81.8	85.3	.00052	.00058	.00062
	G	--	--	--	--	--	--
Jan. 1970	A	80.5	82.9	87.1	.00055	.00070	.00050
	B	79.8	83.2	86.7	.00058	.00058	.00050
	C	80.0	82.7	85.7	.00048	.00050	.00037
	D	80.0	82.1	85.4	.00045	.00055	.00033
	E	78.0	81.2	85.5	.00062	.00072	.00032
	F	77.8	81.3	84.2	.00053	.00048	.00062
	G	79.1	82.0	84.2	.00043	.00037	--
Nov. 12, 1973	G	78.6	81.5	83.5	.00041	.00033	[1].00058

[1]Average slope of reach with length equal to 27,100 ft.

Distribution of Flow Across Flood Plain

During the flood of January 1970, flow data and corresponding water-surface elevations were obtained across Butte Basin along State Highway 162. This information indicated:

1. Peak water-surface elevations generally were lower eastward from the Sacramento River. An exception is in the vicinity of Butte Creek where elevations were higher due to flows in Butte Creek.
2. Channels in the lowest part of Butte Basin contained only 1 percent of the total flow on the flood plain.

A complete discussion of floodflow phenomena on the east-bank flood plain and main channel in the vicinity of Butte City observed during the flood of January 1970 is given by Blodgett and Pearce (1971).

Water-surface elevations and the distribution of flow between bridges on the east-bank flood plain at State Highway 162, for peak flow conditions during the January 1970 flood, are given in table 6. Data on the magnitude of floodflows across the flood plain at Butte City are not available for floods occurring prior to 1970.

During the flood of November 12, 1973, additional data were obtained on Butte Creek at the crossing of State Highway 162. Water-surface elevations and the distribution of flow between the main channel and six overflow bridges on Butte Creek for the flood of November 12, 1973 (peak discharge of 11,000 ft^3/s or 312 m^3/s) are shown in table 7.

Table 6.--*Distribution of discharge during peak of January 24, 1970*

Overflow area[1]	Bridge Number	Bridge Peak stage[2] (ft)	Bridge Discharge (ft³/s)	Road overflow Peak stage[3] (ft)	Road overflow Discharge (ft³/s)	Total discharge (ft³/s)	Percentage of total discharge
			Overland flow from Sacramento River @ 2300 P.s.t.				
10	11-18	82.9	1,900	83.2	700	2,600	4
9	11-19	83.0	3,400	83.4	8,860	12,260	19
8	11-20	83.2	3,000	83.6	7,460	10,460	17
7	11-21	83.2	1,100	83.1	2,400	3,500	6
6	11-22	82.7	2,800	82.8	5,800	8,600	14
5	--	--	--	82.4	5,500	5,500	9
4	11-23	81.9	4,200	82.0	5,600	9,800	16
	11-31	81.2	2,000	--	--	2,000	3
3	11-24	80.7	6,500	80.8	680	7,180	11
2	--	--	--	79.1	750	750	1
	Total		24,900		37,750	62,650	100
			Floodflow from Butte Creek @ 0930 P.s.t.[4]				
1	11-32	81.2	3,200	--	--	3,200	19
	11-33	81.3	2,000	--	--	2,000	12
	11-34	81.3	1,000	--	--	1,000	6
	11-26	80.8	2,100	80.8	20	2,120	12
	11-27	82.0	4,200	--	--	4,200	24
1A	12-57	82.5	3,000	82.5	1,000	4,000	23
	12-56	82.4	650	82.4	50	700	4
	Total		16,150		1,070	17,220	100

[1]Divisions of flow (see fig. 16).
[2]Water-surface elevation at downstream side of bridge.
[3]Water-surface elevation on roadway embankment.
[4]Total floodflow from Butte Creek @ 2300 P.s.t. on Jan. 24, 1970 (concurrent with the peak flow of the Sacramento River at Butte City) was 11,600 ft³/s.

Water-surface elevations for the flood of November 1973 in several of the overflow channels of Butte Creek were higher than those recorded during the flood of January 1970, even though the 1970 peak discharge was the greater of the two. This increase in water-surface elevation is probably due to increased vegetal growth in the various channels subsequent to the flood of January 24-25, 1970.

A comparison of peak stage for the February 1940 flood (table 4, pl. 1, and fig. 7) indicates a slope in water surface across the flood plain away from the main channel similar to that observed during the January 1970 flood. It is therefore probable that other large floods occurring between 1940 and 1970 exhibited a similar water-surface slope across the flood plain.

Table 7.--*Distribution of discharge during peak of November 12, 1973*

Sites[1]		Water-surface elevation[2] (ft)	Discharge (ft³/s)			Percentage of total discharge
Overflow area	Bridge number		Bridge	Road overflow	Total	
1	11-32	81.5	1060	130	1,190	11
1	11-33	81.7	1220	82	1,300	12
1	11-34	81.7	770	108	880	8
1	11-26	81.2	1850	24	1,870	17
1	11-27	81.5	4240	--	4,240	38
1A	12-57	81.7	1290	130	1,420	13
1A	12-56	81.8	90	--	90	1
					10,990	100

1 Bridge and overflow areas are shown in figure 16.
2 Water-surface elevation at downstream side of bridge.

HYDRAULIC CONSIDERATIONS IN THE DESIGN OF ROAD IMPROVEMENTS

Computation of Water-Surface Profiles

The contraction of a stream channel at a roadway crossing creates a change in water-surface elevation between the approach section and the downstream side of the bridge. Discharge equation 1 for flow through a bridge opening is based on the continuity and energy equations between the approach cross section (upstream from the roadway) and the contracted section under the bridge. Contractions have been classified according to type, and extensive laboratory investigations have been conducted (Matthai, 1968) to define discharge coefficients for various abutment geometries and channel-bridge alinement conditions.

When the drop in water surface is computed between an upstream section and the contracted section (equation 1), the corresponding change in velocity is related to the discharge. The discharge equation for width contractions results from writing the energy and continuity equations for a reach between these two sections, designated sections 1 and 3 in figure 9:

$$Q=CA_3\sqrt{2g\left(\Delta h+\alpha_1\frac{V_1^2}{2g}-h_f\right)} \quad (1)$$

in which

Q=discharge,
C=coefficient of discharge,
A_3=gross area of section 3; this is the minimum section parallel to the constriction between the abutments and is not necessarily at the downstream side of the bridge,
Δh=difference in elevation of the water surface between sections 1 and 3,
$\alpha_1\frac{V_1^2}{2g}$=weighted average velocity head at section 1, where V_1 is the average velocity, Q/A_1, and α_1 is a coefficient which takes into account variation in velocity in that section, and
h_f=the head loss due to friction between sections 1 and 3.

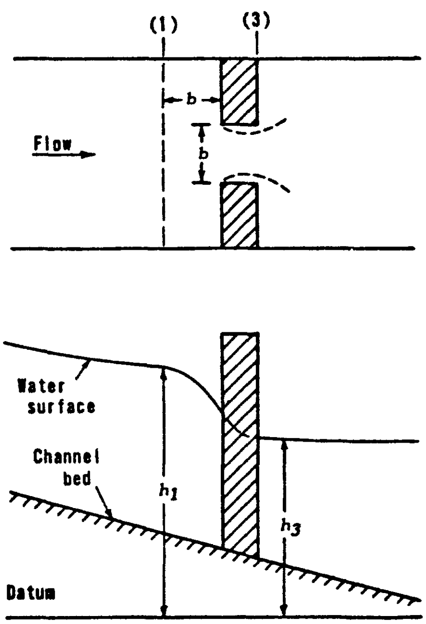


FIGURE 9.--Definition sketch of an open-channel contraction.

In the event that road overflow occurs, the road crown is considered to be a broad-crested weir. Under free flow conditions, critical depth occurs near the crown line (high point on the road surface). The water-surface head is referenced to the roadway crown, and the coefficent of discharge is related to the bridge and embankment geometry (Hulsing, 1968). The height of the embankment has no influence on the coefficient. The geometry of the roadway and location of the approach section (designated section 1) are given in figure 10.

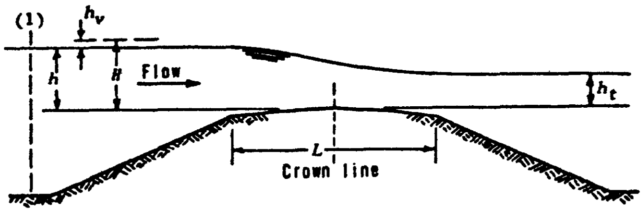


FIGURE 10.--Definition sketch of flow over a highway embankment.

The discharge equation for flow over roadways is referred to the total head, *H*, and is

$$Q=CbH^{3/2} \tag{2}$$

where

Q=discharge,
C=coefficient of discharge,
b=length of the flow section along the road normal to the direction of flow, and

$$H=\text{total head}=h+h_V=h+\frac{\alpha_1 V_1^2}{2g}.$$

The analysis for backwater conditions consists of solving equations 1 and 2 for width contraction and road overflow by trial-and-error computations within specified tolerances. All flows through bridge contractions in this study were considered to be subcritical. The following flow conditions for contracted sections were assumed to be in effect:

1. Flow is steady between cross sections.
2. Slope is small so that depths perpendicular to the water surface can be considered equal to vertical depths.
3. Water-surface elevation is level across a cross section.
4. Effects of sediment and air entrainment are negligible.
5. All energy losses are included in the h_f term.

Water-surface elevations at the approach section computed by use of equations 1 and 2 reflect stages resulting from impediment to flow caused by the roadway embankment and bridge structures. In some cases, high downstream stages (h_t in fig. 10) that result from the ponding of flood water downstream from the highway required the adjustment of the computed flow over the road by assuming partial submergence of the highway embankment (Hulsing, 1968). Water-surface elevations at the approach section higher than those that would result from normal (unobstructed) channel and flood-plain conditions (fig. 11) are referred to as backwater. Backwater is defined as the increase in water-surface elevation produced by an obstruction such as a bridge contraction, roadway embankment, or levee over that which would result under natural channel and flood-plain conditions. Elements considered in the computation of backwater are the roughness coefficients and angularity of flow, and the geometry of the bridge opening (fig. 12) and approach section. For the purpose of this study, the slope of the streambed (table 5) is assumed to represent the natural flood profile (fig. 8).

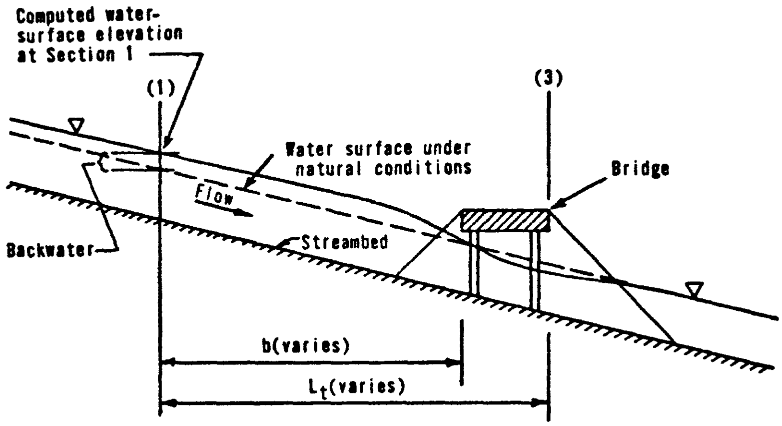


FIGURE 11.--Definition sketch of backwater effect.

The effects of backwater decrease with distance upstream from the approach section, and eventually the difference between the backwater profile and the normal water-surface profile disappears. A backwater analysis of flow in the channel upstream from bridge 11-22 using a backwater of 0.7 ft (0.2 m) for a discharge of 2,600 ft^3/s (74 m^3/s) indicates the backwater profile approaches the normal water-surface profile (fig. 8) within 0.1 ft (0.03 m) about 1.4 mi (2.3 km) upstream from the bridge contraction.

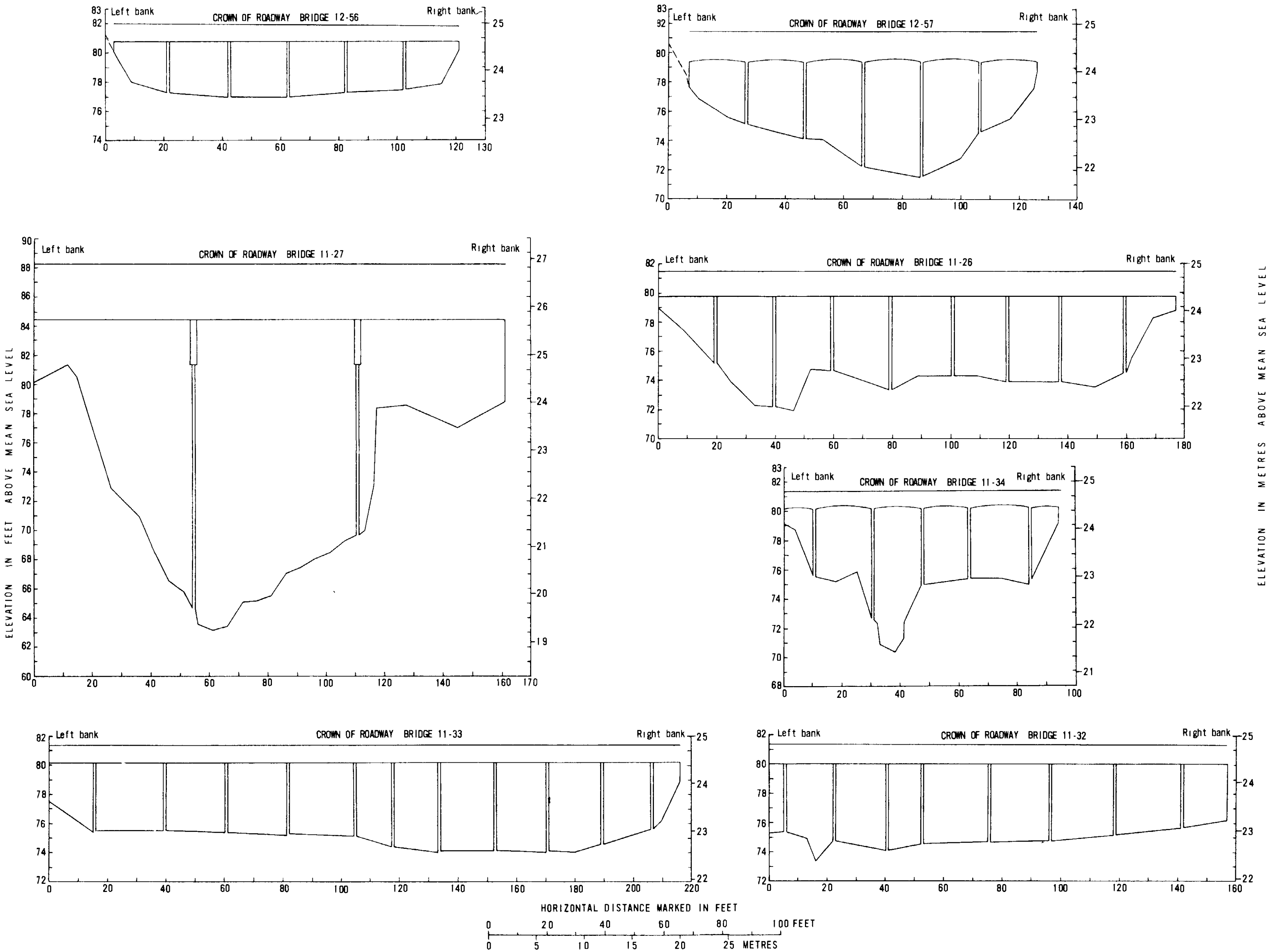


FIGURE 12.--Cross sections of channels at State Highway 162 bridges.

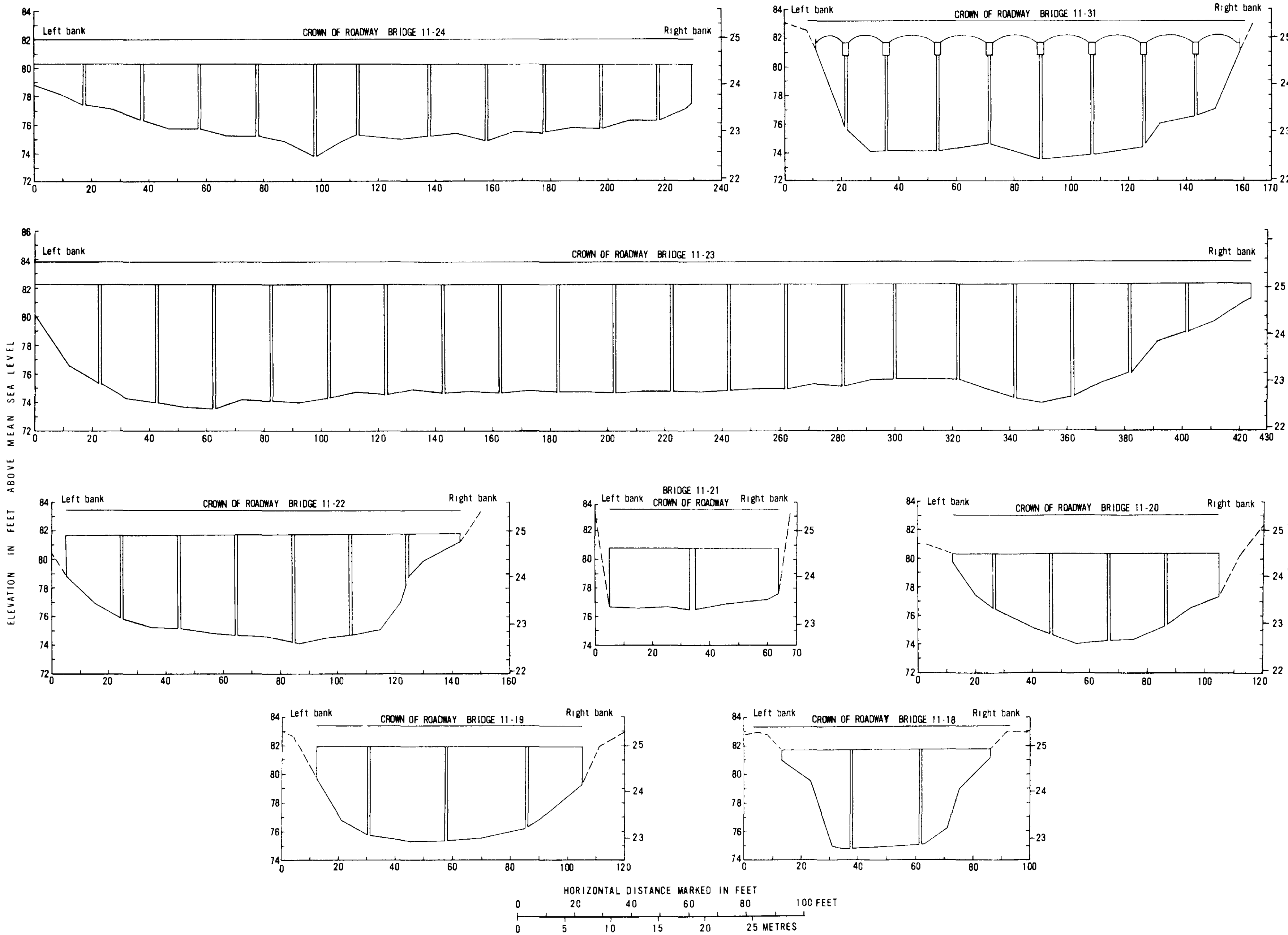


FIGURE 12.--Continued.

Factors Affecting Flood Profile

The slope of a water-surface profile on a flood plain is affected by the slope of the land surface, backwater from downstream flooding, magnitude of flow, and availability of channels. It also is affected by the presence of obstructions to flow such as levees, irrigation dikes, bridges, and embankments. The natural slope of the water-surface profile during major floods in Butte Basin is slightly steeper than the slope of the land surface (table 5). This hydraulic condition prevails until downstream flooding causes backwater--a condition that occurred at some locations on the downstream side of the State Highway 162 embankment during the January 1970 flood.

The magnitude of flow passing through the individual openings of a series of bridges across a flood plain is affected by the availability of channels, the distribution of flow in the channels and on the flood plain, and the size of the bridge openings. The distribution of flow across the flood plain may vary from flood to flood. Flow is affected by engineering or agricultural works upstream or downstream from State Highway 162; an example is the levee and dike system upstream from bridges 11-26, 11-32, 11-33, and 11-34 (figs. 13, 14, and 15) that effectively alters the distribution of flow, and consequently, the upstream stage at those bridges.

The dimensions of a bridge opening are the primary factor that governs the magnitude of discharge that can pass through an individual opening. If the bridge opening is too small, a large change in water-surface elevation (head) will result between the upstream and downstream cross sections (fig. 9). In addition, if the channel downstream from a bridge is inefficient, an inordinately high water-surface elevation will occur at the approach section upstream from the roadway. Examples of inefficient downstream channels are those at bridges 12-56 and 11-21 (figs. 14 and 15).

The efficiency of a channel is subject to change. It is often affected by scour or fill of the bed or banks, vegetal growth in the channel, or debris obstructing a bridge opening. Such conditions have occurred in the vicinity of State Highway 162. For example, the stage of Butte Creek at State Highway 162 was higher at bridges 11-32, 11-33, 11-34, and 11-26 during the flood of November 12, 1973 (table 7) than it was during the flood of January 24, 1970. This occurred even though the discharge was greater in 1970 and no changes had been made to the highway between floods.

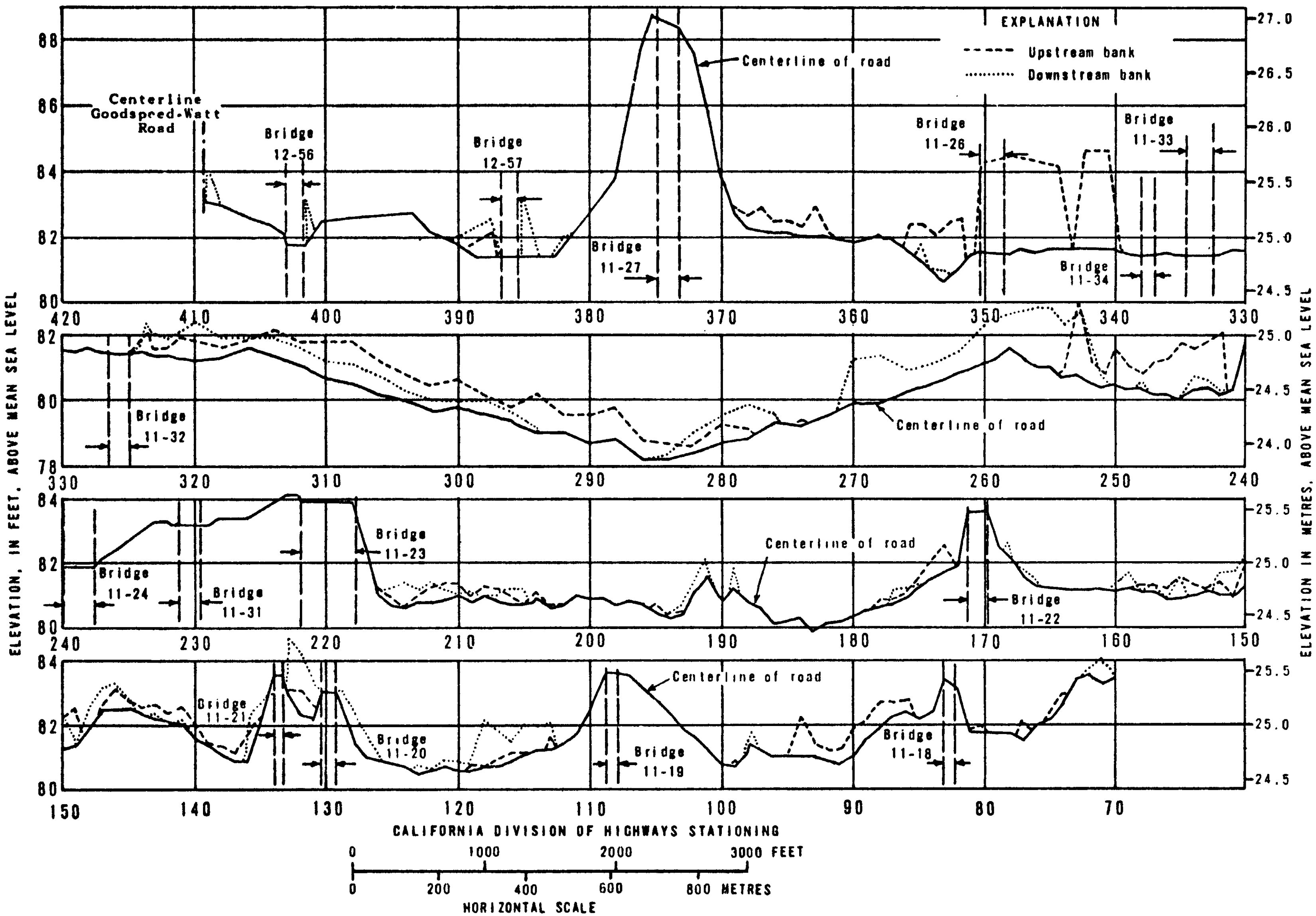


FIGURE 13.--Cross section along centerline of State Highway 162 showing adjacent natural ground elevations.

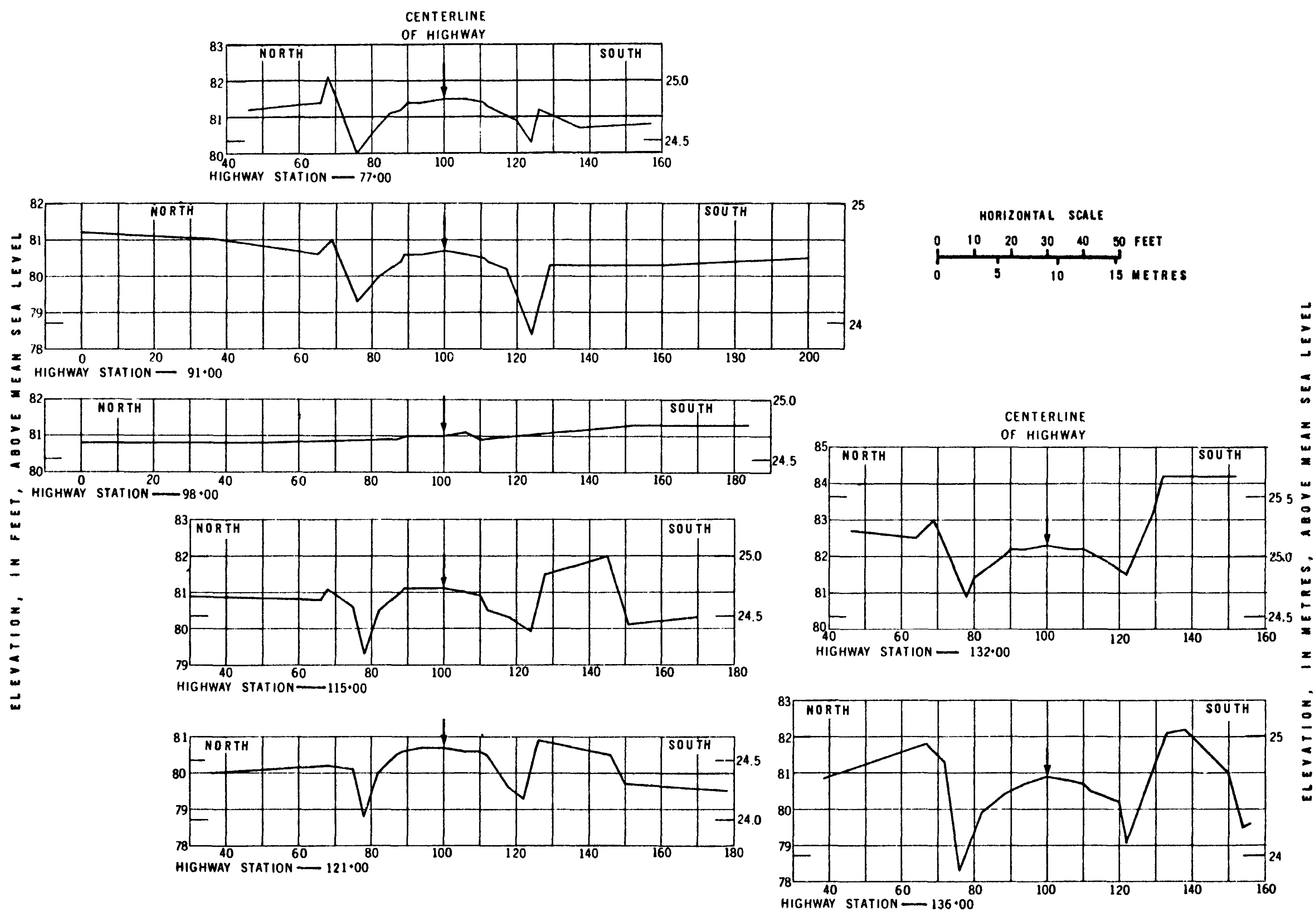


FIGURE 14.--Cross sections of State Highway 162 roadway embankment.

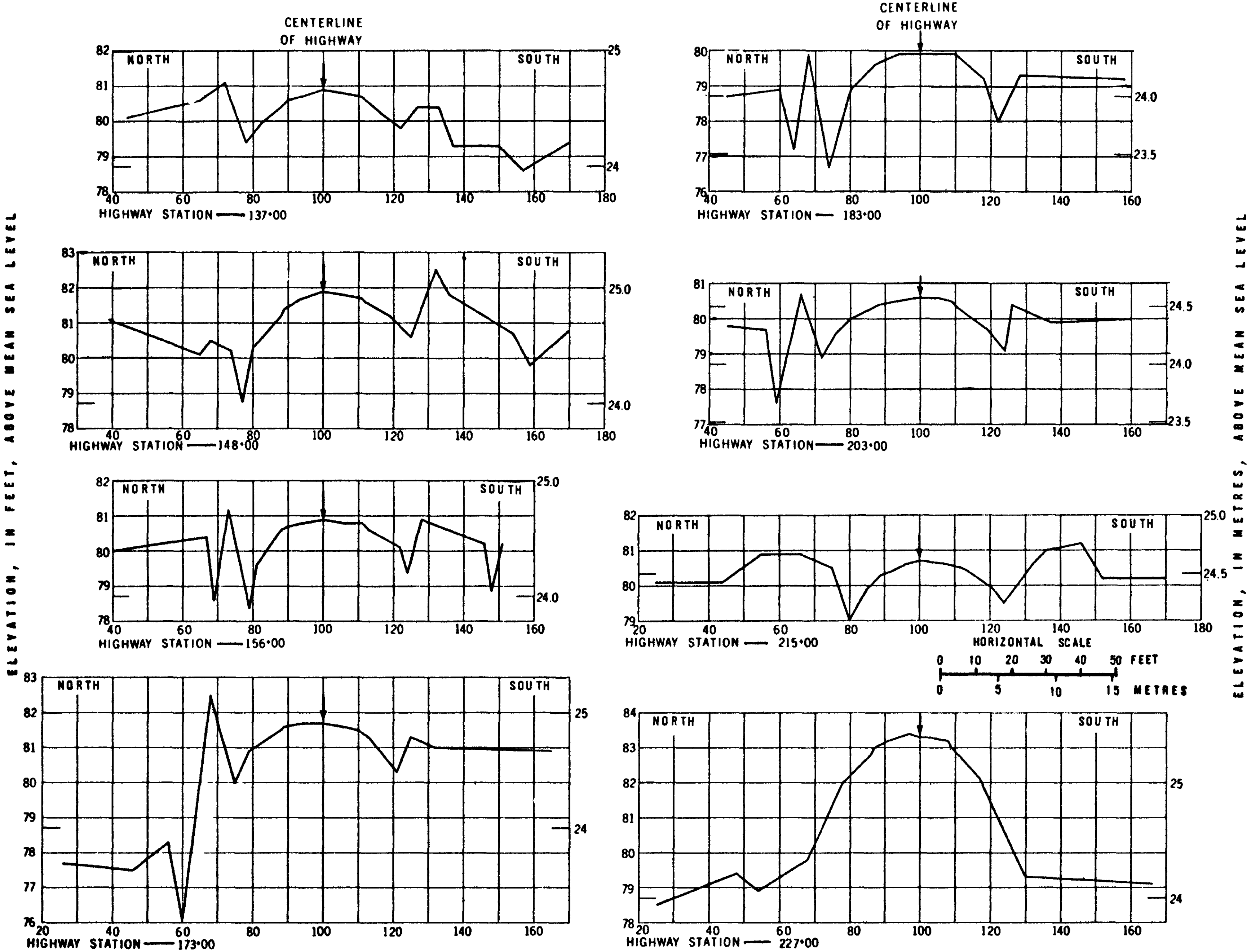


FIGURE 14.--Continued.

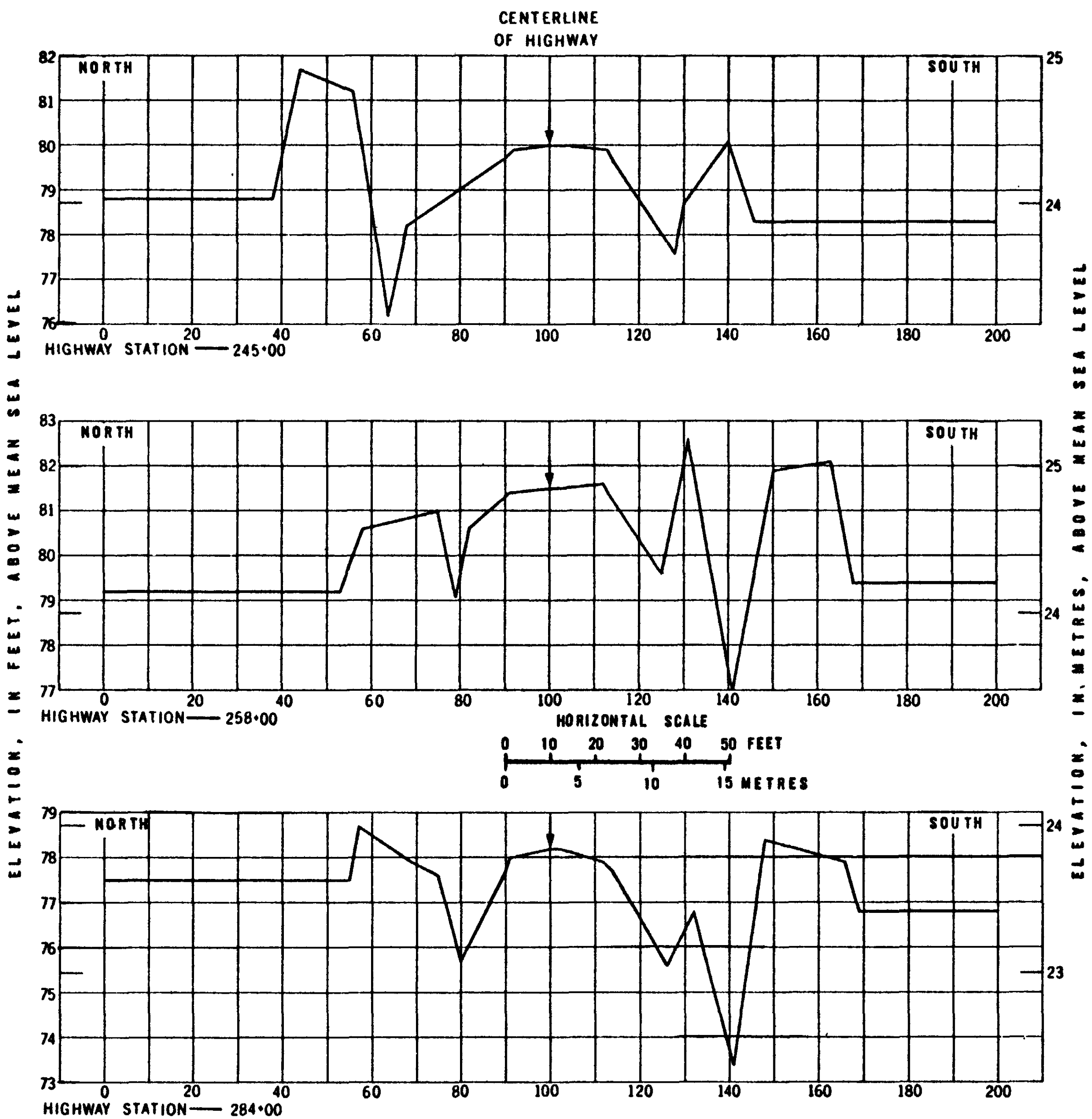


FIGURE 14.--Continued.

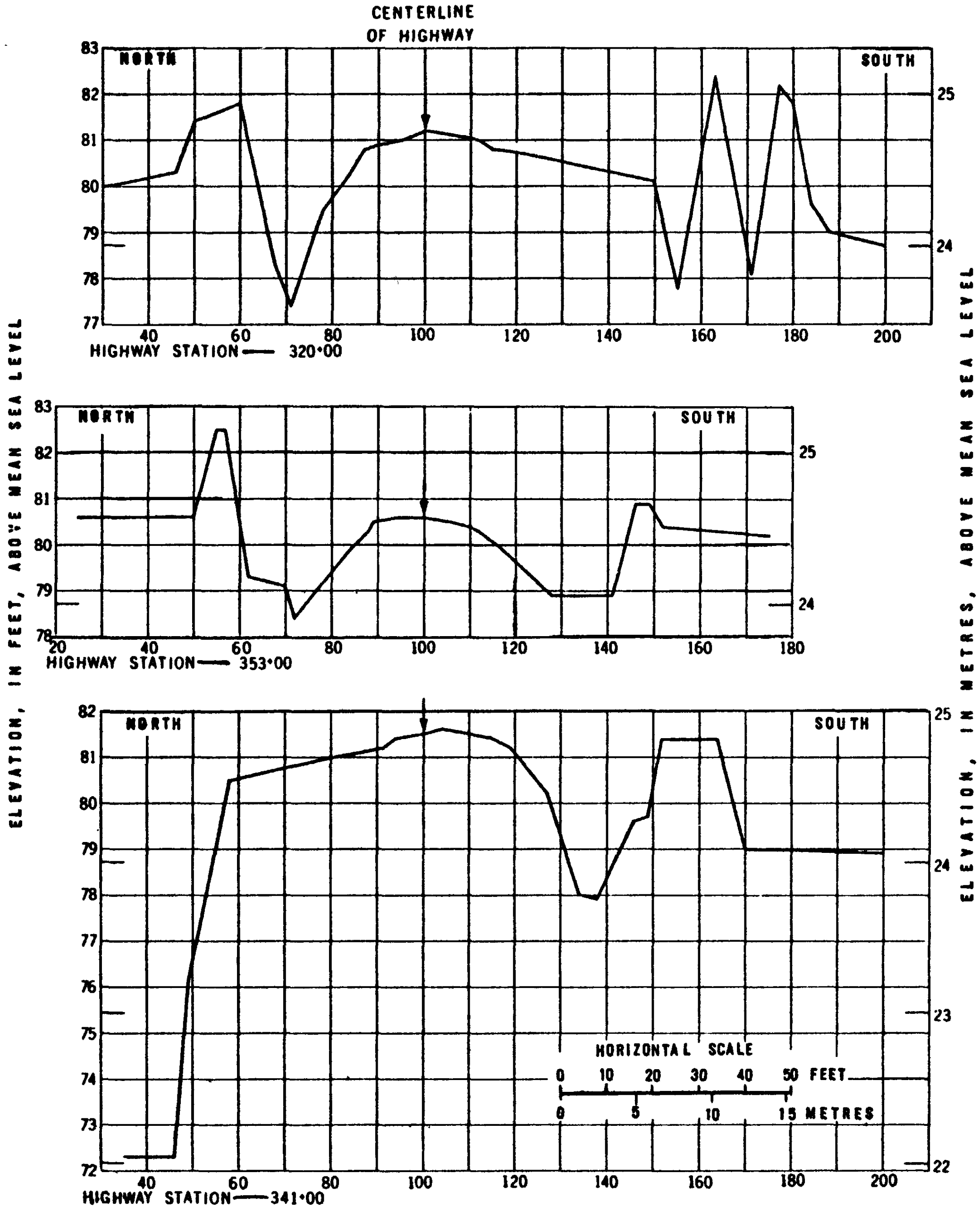


FIGURE 14.--Continued.

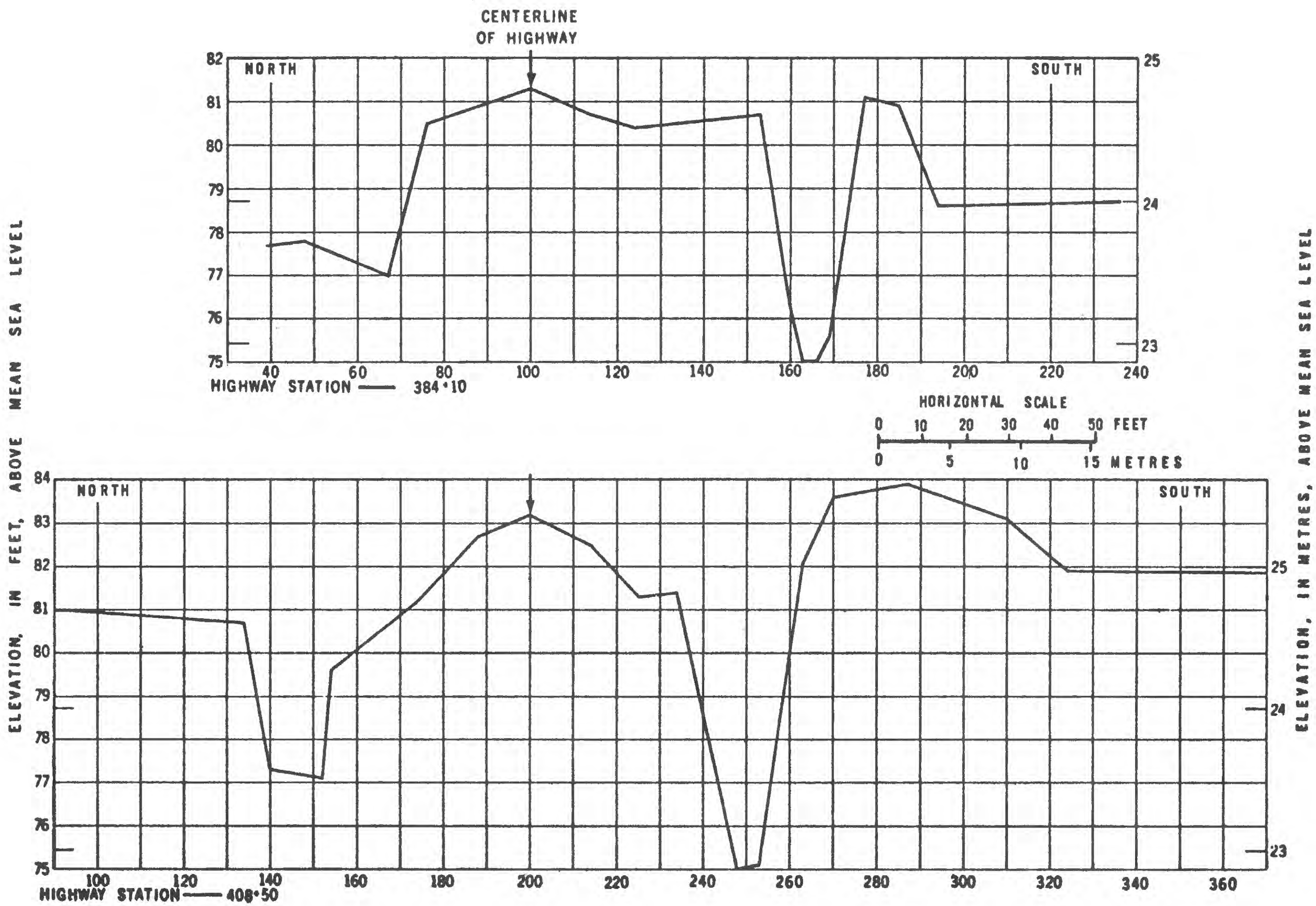
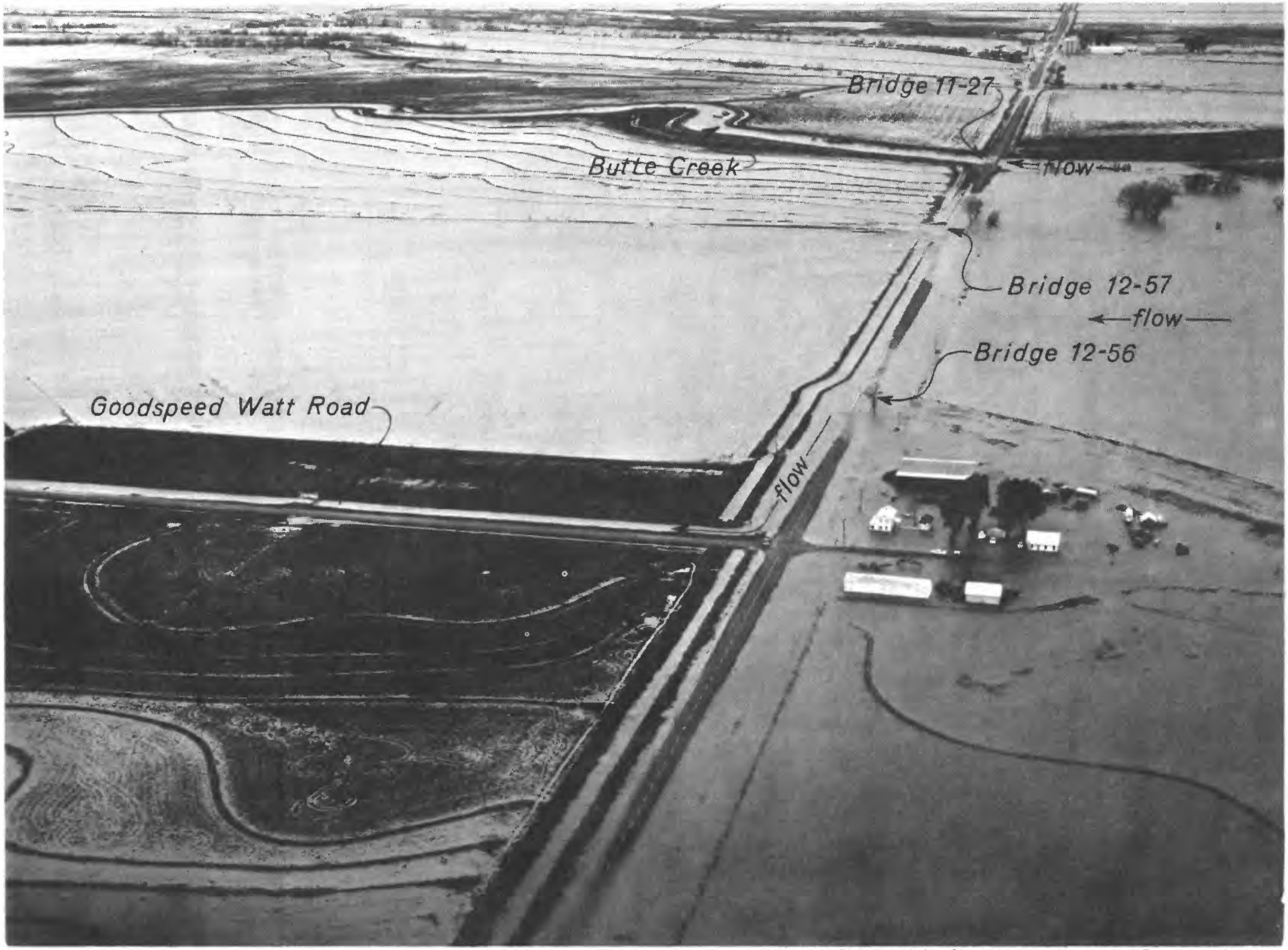


FIGURE 14.--Continued.



Photograph by California Department of Transportation
Division of Highways

FIGURE 15.--Inundation of State Highway 162 in the vicinity of Butte Creek during the flood of January 24, 1970.

For the type of debris that usually occurs during flooding in Butte Basin, a clearance of 1 ft (0.3 m) above the design high-water surface is generally necessary. During the flood of January 24, 1970, only bridges 11-27, 11-31, and 11-23 had any clearance above the water surface. Maximum water-surface elevations recorded during the flood at the downstream side of the bridges and the elevation of the lowest point on the bridge stringers are summarized in table 8. Water-surface elevations at the upstream side of the bridges were generally higher than those shown in table 8. Thus, an adequate clearance on both the upstream and downstream sides of the bridge should be available to convey floodflows. Brush and debris, if not kept clear of each bridge opening, will reduce the bridge's design capacity.

Table 8.--*Comparison of bridge member and water-surface elevations for flood of January 24, 1970*

Bridge number	Elevation, in feet, above mean sea level	
	Water surface	Low point on bridge stringers
12-56	82.4	80.8
12-57	82.5	79.4
11-27	82.0	84.6
11-26	80.8	79.8
11-34	81.3	80.2
11-33	81.3	80.2
11-32	81.2	80.1
11-24	80.7	80.3
11-31	81.2	81.8
11-23	81.9	82.3
11-22	82.7	81.8
11-21	83.2	80.8
11-20	83.2	80.4
11-19	83.0	82.0
11-18	82.9	81.8

Computations of backwater from flooding in the vicinity of State Highway 162 were made for two conditions--first, the highway in its present state, and second, for various possible modifications of the highway structures. Modifications that were considered include raising the roadway elevations to prevent road overflow, and increasing the span and number of bridges and culverts.

Effect of Present Flood-Plain and Roadway Conditions on Flood Profiles

The effect of present flood-plain and roadway conditions on flood profiles near State Highway 162 was determined using flood data collected between 1970 and 1973. In the analysis, overflow areas across the flood plain were designated (fig. 16) on the basis of the distribution of flow observed during the January 1970 flood. Within each overflow area, flows were then allocated to each bridge opening and road overflow area on a similar basis.

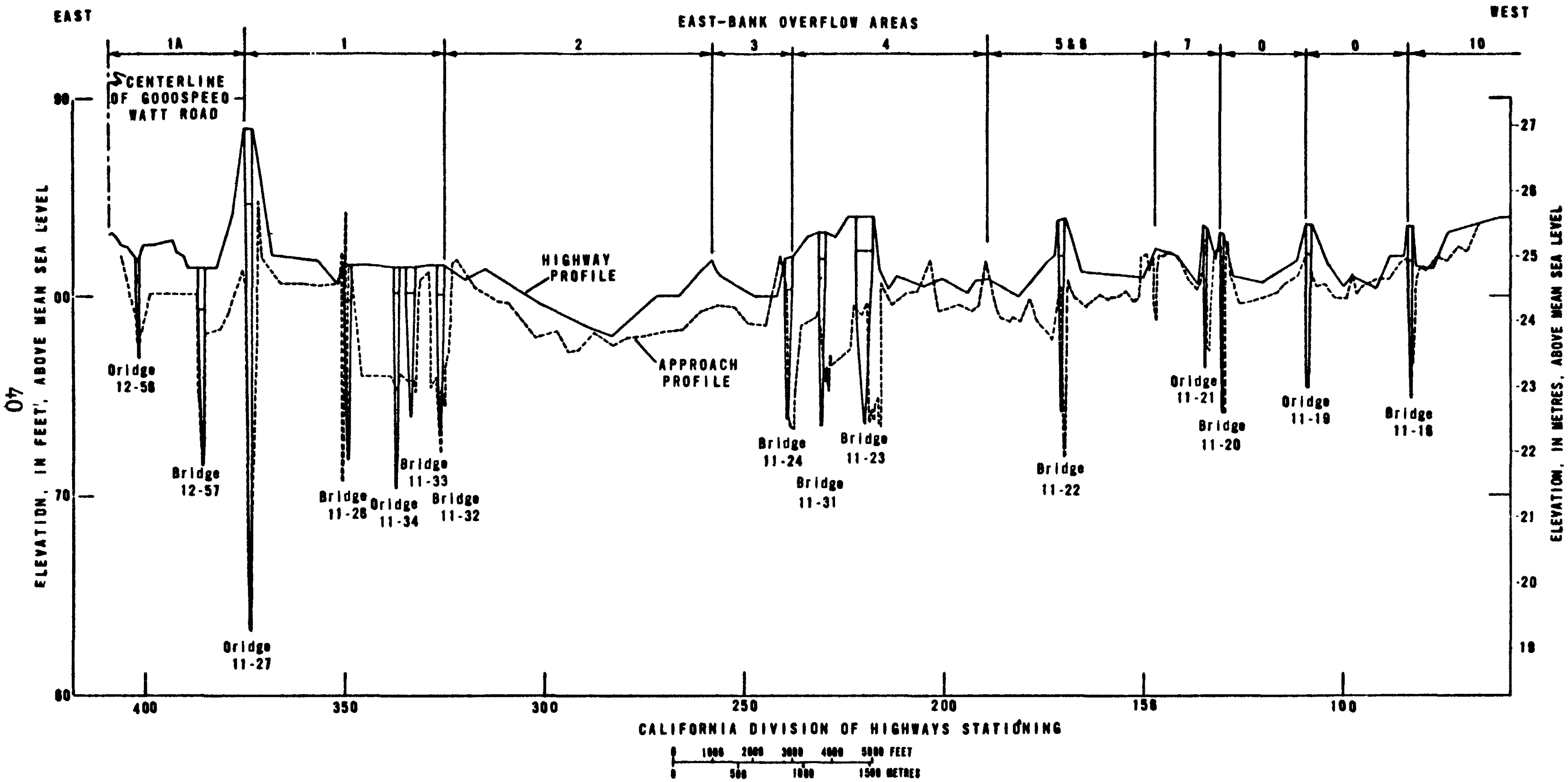


FIGURE 16.--Profile of State Highway 162 near Butte City showing overflow areas and approach section.

Additional data required for the analysis included surveys of the bridge openings, ground elevations upstream and downstream from the highway (fig. 13), and the approach section of the channel and flood plain upstream from the various bridges (fig. 16). On the average, the approach sections are about 180 ft (55 m) upstream from the road. Water-surface elevations at the approach section to each bridge and adjacent road overflow area were then computed for flow conditions observed during the flood of January 1970. Results of the analysis are shown in table 9.

The maximum amount of backwater caused by roadway embankment and bridge openings for present conditions (fig. 12) is 0.6 ft (0.2 m) at the approach to bridges 12-57 and 11-24 (table 9). The backwater calculations are based on conditions that occurred on January 24, 1970. The natural high ground or levees and inefficient channels adjacent to the highway (figs. 13 and 14) are responsible for some of the backwater presently experienced during floods.

Values of fall in water surface, less than 0.3 ft (0.09 m), across the highway between cross sections 1 and 3, and associated minor backwater upstream from 11 of the 15 bridges result from the large proportion of the total floodflow that overtops the road and bypasses the bridge openings. The amount of road overflow near bridges 12-56, 12-57, 11-26, 11-34, 11-33, 11-32, 11-22, 11-21, and 11-20 (fig. 7) is increased partly because of floating debris (brush, cattails, and so forth) that lodges against low members of the bridge (fig. 12), thus reducing the efficiency of the bridge opening.

Table 9.--*Hydraulics of bridge openings and road overflows for present roadway embankment and flood-plain conditions*

Sites[1]		Discharge (ft^3/s)			Velocity (ft/s)		Water-surface elevation, in feet, above mean sea level		Fall between cross sections 1 to 3 (ft)	Normal stage at cross section 1 (ft)	Backwater (ft)
Overflow area	Bridge number	Under bridge	Across road	Total	Cross section 3	Cross section 1	Cross section 3	Cross section 1			
Jan. 24, 1970 - about 1000 hours P.s.t.											
1A	12-56	650	50	700	1.7	0.4	82.4	82.5	0.1	82.5	0
1A	12-57	3,000	1,000	4,000	4.3	.6	82.5	83.2	.7	82.6	.6
1	11-27	4,200	--	4,200	2.8	2.4	82.0	82.1	.1	82.1	0
1	11-26	2,100	20	2,120	2.3	3.6	80.8	80.9	.1	80.9	0
1	11-34	1,000	--	1,000	2.9	.7	81.3	81.5	.2	81.4	.1
1	11-33	2,000	--	2,000	2.5	.8	81.3	81.4	.1	81.4	0
1	11-32	3,200	--	3,200	4.1	1.2	81.2	81.6	.4	81.3	.3
2	--	--	--	--	--	--	--	--	--	--	--
3	11-24	3,500	0	3,500	3.6	1.4	80.1	80.4	.3	80.2	.2
4	11-31	1,500	0	1,500	1.8	.5	80.6	80.7	.1	80.7	0
4	11-23	2,150	450	2,600	.9	.4	81.0	81.1	.1	81.1	0
5 & 6	11-22	2,700	7,000	9,700	3.3	1.0	82.0	82.4	.4	82.1	.3
7	11-21	900	1,800	2,700	3.8	1.1	82.7	82.8	.1	82.7	.1
8	11-20	2,150	1,150	3,300	4.9	.6	82.6	82.7	.1	82.7	0
9	11-19	1,730	1,200	2,930	3.9	.9	81.2	81.7	.5	81.3	.4
10	11-18	360	0	360	1.5	1.1	80.1	80.2	.1	80.2	0
Jan. 24, 1970 - about 2300 P.s.t.											
1A	12-56	300	0	300	0.8	0.2	81.6	81.7	0.1	81.7	0
1A	12-57	1,700	0	1,700	2.7	.4	81.1	81.3	.2	81.2	.1
1	11-27	3,840	0	3,840	2.6	2.3	81.4	81.5	.1	81.5	0
1	11-26	1,330	0	1,330	1.4	2.6	80.1	80.2	.1	80.2	0
1	11-34	630	0	630	1.3	.5	80.6	80.7	.1	80.7	0
1	11-33	1,500	0	1,500	1.3	.8	80.4	80.5	.1	80.6	0
1	11-32	2,300	0	2,300	2.8	1.0	80.4	80.7	.3	80.5	.2
2	--	--	750	750	(2)	(2)	(2)	79.1	--	--	--
3	11-24	6,500	680	7,180	6.3	2.2	80.7	81.4	.7	80.8	.6
4	11-31	2,000	--	2,000	2.2	.5	81.2	81.4	.2	81.3	.1
4	11-23	4,200	5,600	9,800	1.5	1.1	81.9	82.1	.2	82.0	.1
5 & 6	11-22	2,800	11,300	14,100	3.5	1.1	82.7	82.9	.2	82.8	.1
7	11-21	1,100	2,400	3,500	4.6	.9	83.2	83.3	.1	83.2	.1
8	11-20	3,000	7,460	10,460	6.8	1.4	83.2	83.7	.5	83.3	.4
9	11-19	3,400	8,860	12,260	6.5	1.7	83.0	83.5	.5	83.1	.4
10	11-18	1,900	700	2,600	5.4	.9	82.9	83.3	.4	83.0	.3

[1]See figure 16 for location of sites.
[2]Not determined.

Effect of Raising the Existing Roadway to Eliminate Road Overflow Under Flood Conditions of January 24, 1970

If flood stages upstream from a series of bridges on a highway are such as to inundate the roadway, and if no remedial changes are to be made to the channels or flood plain, the depth of inundation over the roadway may be reduced or eliminated by one of the following highway modifications: (1) Raising the roadway, (2) increasing the span of existing bridges, (3) providing additional bridges or culverts, or (4) a combination of two or more of these measures. Constraints on the design of modifications are the allowable backwater and velocity of flow through a bridge. For this study, backwater greater than 0.5 ft (0.15 m) and velocity of flow greater than 5 ft/s (2 m/s) were considered excessive.

The first modification investigated was that of eliminating inundation by raising the roadway without increasing the span or number of bridge openings and culverts. The effects of this modification are indicated by the data in table 10. The figures in table 10 are estimates of stages that would have occurred during a flood similar to the flood of January 24, 1970. Actually, raising the roadway to prevent any overflow (assuming bridge openings as presently built) would cause an excessive increase in water-surface elevation on the flood plain upstream from the highway. Data in table 10 show that the criteria for allowable backwater and allowable velocity would be exceeded at many sites. It is therefore impractical to modify only the roadway elevation to completely eliminate inundation during a flood such as that of January 24, 1970, without also increasing the span or number of waterway openings.

Modification of Both Existing Roadway and Bridges to Eliminate Road Overflow Under Flood Conditions of January 24, 1970

Another course of action would be to modify both the roadway and bridge openings to some degree. The modifications could be carried out to the extent that no overtopping would occur during a flood of the magnitude of that of January 24, 1970. This approach to the problem is therefore concerned with modification of the existing roadway elevation and the span or number of bridge openings for the purpose of eliminating inundation by a flood as great as that of January 24, 1970, without exceeding criterion values of backwater and velocity at a bridge location.

Table 10.--*Hydraulics of bridge openings assuming no road overflow*

Sites[1]		Discharge (ft^3/s)			Velocity (ft/s)		Water-surface elevation, in feet, above mean sea level		Fall between cross sections 1 to 3 (ft)	Normal stage at cross section 1	Backwater (ft)
Overflow area	Bridge number	Under bridge	Across road	Total	Cross section 3	Cross section 1	Cross section 3	Cross section 1			
					Jan. 24, 1970 - about 1000 hours P.s.t.						
1A	12-56	700	0	700	1.8	0.4	82.6	82.7	0.1	82.6	0
1A	12-57	4,000	0	4,000	>5	.3	84.2	>85.0	>.8	84.3	>.5
1	11-27	4,200	0	4,200	2.8	2.4	82.0	82.1	.1	82.1	0
1	11-26	2,120	0	2,120	2.3	3.6	80.8	80.9	.1	80.9	0
1	11-34	1,000	0	1,000	2.9	.7	81.3	81.5	.2	81.4	.1
1	11-33	2,000	0	2,000	2.5	.8	81.3	81.4	.1	81.4	0
1	11-32	3,200	0	3,200	4.1	1.2	81.2	81.6	.4	81.3	.3
2	--	--	0	--	--	--	--	--	--	--	--
3	11-24	3,500	0	3,500	3.6	1.4	80.1	80.4	.3	80.2	.2
4	11-31	1,500	0	1,500	1.8	.5	80.6	80.7	.1	80.7	0
4	11-23	2,600	0	2,600	1.0	.4	81.2	81.3	.1	81.3	0
5 & 6	11-22	9,700	0	9,700	>5	<.7	>85.0	--	--	>85.0	>.5
7	11-21	2,700	0	2,700	>5	<.4	84.0	>85.0	>1.0	84.0	>.5
8	11-20	3,300	0	3,300	>5	<.3	83.2	>85.0	>1.8	83.3	>.5
9	11-19	2,930	0	2,930	>5	.4	82.5	83.5	1.0	82.6	>.5
10	11-18	360	0	360	1.5	1.1	80.1	80.2	.1	80.2	0
					Jan. 24, 1970 - about 2300 hours P.s.t.						
1A	12-56	300	0	300	.8	.2	81.6	81.7	.1	81.7	0
1A	12-57	1,700	0	1,700	2.7	.4	81.1	81.3	.2	81.2	.1
1	11-27	3,840	0	3,840	2.6	2.3	81.4	81.5	.1	81.5	0
1	11-26	1,330	0	1,330	1.4	2.6	80.1	80.2	.1	80.2	0
1	11-34	630	0	630	1.3	.5	80.6	80.7	.1	80.7	0
1	11-33	1,500	0	1,500	1.3	.8	80.4	80.5	.1	80.6	0
1	11-32	2,300	0	2,300	2.8	1.0	80.4	80.7	.3	80.5	.2
2	([2])	750	0	750	([3])	([3])	([3])	79.1	([3])	([3])	([3])
3	11-24	7,180	0	7,180	>5	2.2	80.8	81.8	1.0	80.9	>.5
4	11-31	2,000	0	2,000	2.2	.5	81.2	81.4	.2	81.3	.1
4	11-23	9,800	0	9,800	3.6	.7	83.2	83.6	.4	83.3	.3
5 & 6	11-22	14,100	0	14,100	>5	<1.1	>85.0	--	--	>85.0	>.5
7	11-21	3,500	0	3,500	>5	<.5	84.3	>85.0	>.7	84.3	>.5
8	11-20	10,460	0	10,460	>5	<1.0	>85.0	--	--	>85.0	>.5
9	11-19	12,260	0	12,260	>5	<1.1	>85.0	--	--	>85.0	>.5
10	11-18	2,600	0	2,600	>5	<.5	83.8	>85.0	>1.2	83.9	>.5

[1]See figure 16 for location of sites. [2]New drainage structure. [3]Not determined.

Under present conditions, bridges 12-56, 11-27, 11-26, 11-34, 11-33, 11-32, 11-31, and 11-23 can carry additional flow, without exceeding the allowable backwater or velocity criteria, for the distribution of flow across the flood plain observed during the flood of January 24, 1970 (table 6). Inundation could be prevented in the stretch of highway between stations 380+00 and 390+00 by enlarging the opening of bridge 12-57 and at the same time, raising the roadway. To prevent highway flooding in the area further west (bridges 11-18 to 11-23), additional bridges would be required, together with raising of the highway. The need for additional bridges between highway stations 50+00 and 220+00 (fig. 7) is illustrated in figure 17 by a comparison of the bridge area available for conveying floodwaters and the total discharge observed on the flood plain at State Highway 162 during the flood of January 1970. It is evident that the greatest percentage of flow on the flood plain occurs where the number and size of available drainage channels and associated bridge openings is inadequate to convey floodflows.

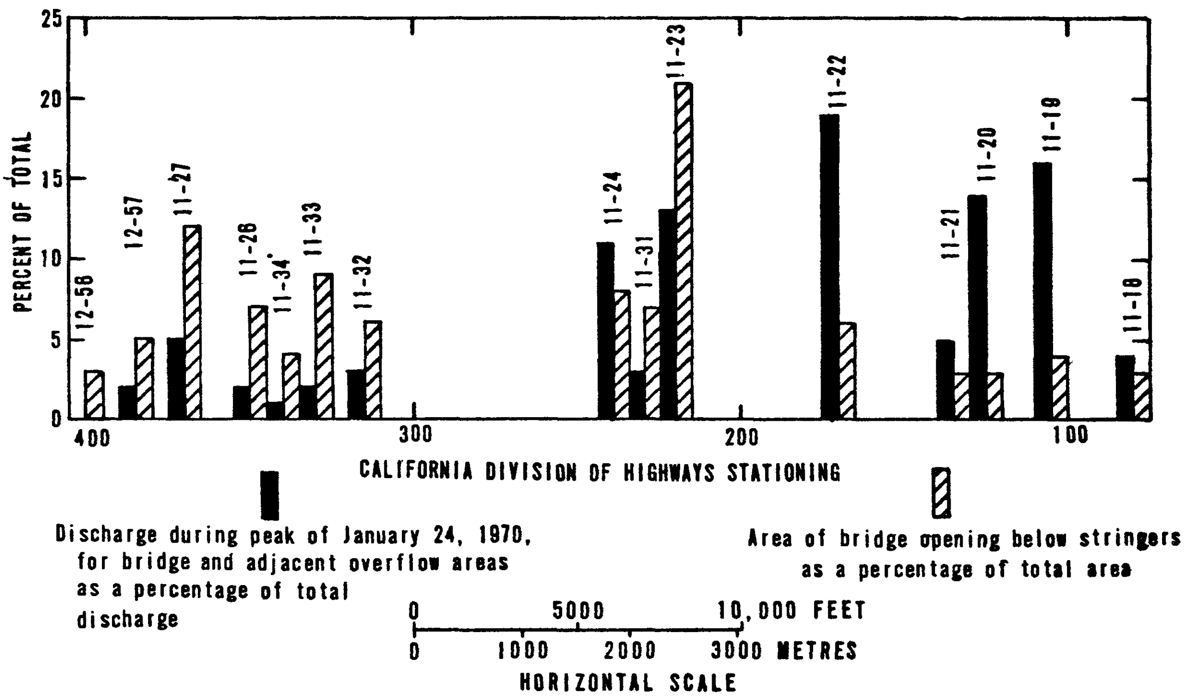


FIGURE 17.--Comparison of bridge-opening size and distribution of floodflow across the flood plain at State Highway 162.

If the roadway is to remain above the stage of a flood equivalent to that of January 24, 1970 (table 9), it will be necessary to provide adequate bridge openings to convey a total discharge of 74,300 ft^3/s (2100 m^3/s). Of the 74,300 ft^3/s (2100 m^3/s), 36,500 ft^3/s (1034 m^3/s) passed through existing bridges during the January 1970 flood, and the remainder, 37,800 ft^3/s (1070 m^3/s), flowed over the roadway embankment. Most of the flow over the road occurred in overflow areas 4 through 9, and of the total road overflow, 45 percent occurred in areas 8 and 9 (fig. 16). A review of flood data in the vicinity of State Highway 162 (figs. 7, 13, and 16) indicates additional bridge openings near highway stations 100+00, 120+00, 137+00, 156+00, 184+00, and 203+00 would be needed. Raising the roadway between station 203+00 and Goodspeed-Watt Road (station 409+00) will not cause significant amounts of backwater except at highway station 285+00, if facilities for the drainage of impounded water upstream from the highway, especially near stations 285+00, are provided. Facilities for drainage also would be needed near highway stations 77+00 and 246+00. The existing bridge 12-57 (highway station 387+00) would have to be lengthened to reduce the amount of backwater (table 10) and eliminate road overflow.

The length of the bridge openings required to handle a total discharge of about 37,800 ft^3/s (1070 m^3/s) which presently flows over the road, is governed by the ground elevations in the vicinity of the proposed openings, the allowable velocity of flow, and the need to limit the effects of backwater. The location and design of waterway structures to accommodate that flow is beyond the scope of this report.

Modification of Existing Roadway to Reduce Road Overflow

A third course of action would be to increase the span or number of bridge openings at selected sites and raise the elevation of the roadway in certain places to accommodate floods of limited magnitude. This course of action would permit roadway inundation to occur during extreme floods.

During the flood of January 18, 1970, a peak discharge of 115,600 ft^3/s (3270 m^3/s) was recorded on the Sacramento River at Butte City. This flood was followed by an even greater flood on January 24, 1970, which eventually reached a peak discharge of 152,000 ft^3/s (4305 m^3/s) at Butte City. Use of State Highway 162 during the flood of January 18, 1970, was restricted, however, by road overflow that occurred in overflow areas 5, 6, and 7 (fig. 16). A tabulation of peak stages and discharges for the flood of January 18 is given in table 11.

Table 11.--*Distribution of discharge during peak of January 18, 1970*

Sites[1]		Bridge		Road overflow		Total discharge (ft^3/s)
Overflow area	Bridge number	Peak stage (ft)	Discharge (ft^3/s)	Peak stage (ft)	Discharge (ft^3/s)	
		Floodflow from Butte Creek at 0400 P.s.t.				
1A	12-56	80.1	80	--	--	80
1A	12-57	79.6	710	--	--	710
1	11-27	80.5	3,360	--	--	3,360
1	11-26	78.8	670	--	--	670
1	11-34	79.0	180	--	--	180
1	11-33	79.0	570	--	--	570
1	11-32	78.9	650	--	--	650
		Overland flow from Sacramento River at 0200				
2	--	--	--	78.1	7	7
3	11-24	79.6	1,900	--	--	1,900
4	11-31	80.1	950	--	--	950
4	11-23	80.6	1,600	81.0	300	1,900
5	--	--	--	81.1	(2)	--
6	11-22	81.3	2,400	81.6	700	3,100
7	11-21	81.6	1,800	82.2	300	2,100
8	11-20	81.3	1,000	--	--	1,000
9	11-19	--	--	--	--	--
10	11-18	77.4	(2)	--	--	--

[1]See figures 14 and 16 for location of sites.
[2]Negligible flow.

Most of the road overflow occurred near highway stations 137+00 and 156+00. It is at these locations that flooding of State Highway 162 first occurs. To reduce the effects of inundation and high velocity of flow at those stations, additional bridges or culverts, complemented by road overflow areas at the ends of the new bridge approaches, would be required. The size of the openings would need to be sufficient to discharge as much as 1,000 ft^3/s (28 m^3/s) each at velocities as much as 2 or 3 ft/s (0.6 or 0.9 m/s). Invert elevations of the bridge or culvert openings could be placed at present ground levels. Installations of these additional bridges or culverts at highway stations 137+00 and 156+00 would allow uninterrupted use of the highway for floods up to a magnitude of about 129,000 ft^3/s (3650 m^3/s) on the Sacramento River at Butte City. The road would be subject to overflow, however, by a flood whose magnitude was equivalent to that of the flood of January 24, 1970.

REFERENCES

Blodgett, J. C., and Pearce, V. F., 1971, Determination of floodflow of the Sacramento River at Butte City, California, January 1970: U.S. Geol. Survey open-file rept., 29 p.

California Department of Water Resources, 1969, Upper Sacramento River Basin investigation: California Dept. Water Resources Bull. 150-1, 30 p.

______1973, Hydrologic data, 1972, Volume II. Northeastern California: Bull. 130-72, 383 p.

Hulsing, Harry, 1968, Measurement of peak discharge at dams by indirect methods: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A5, 29 p.

Matthai, H. F., 1968, Measurement of peak discharge at width contractions by indirect methods: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A4, 44 p.

The Reclamation Board, 1964, Master plan for flood control in Butte Basin: State of California, The Resources Agency, 32 p.

U.S. Geological Survey, 1969, Water Resources data for California--Part 1. Surface water records, volume 2: Northern Great Basin and Central Valley: Menlo Park, Calif., U.S. Geol. Survey ann. rept., p. 501-1031.

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