ANALYSIS OF OCTOBER 1986 FLOOD IN CANEY RIVER AT U. S. 75

BARTLESVILLE, OKLAHOMA

VOLUME I

by

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PRINCIPAL INVESTIGATOR

Report No. 88-2

Water Resources Engineering
School of Civil Engineering

Oklahoma State University
Stillwater, Oklahoma 74078

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Volume I

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16. ABSTRACT

Hurricane Paine, extending across the Central Plains of the United States, caused flooding of unprecedented proportions in the Caney River. This storm produced a rainfall varying from 20 to 30 inches in Oklahoma during September 29 through October 4, 1986.

Because of the severity of this extreme event, local residents questioned the adequacy of the bridges on the Caney River at U.S. 75. As a result, the Oklahoma Department of Transportation (ODOT) initiated this research investigation as an objective study of the hydraulic capacity of the bridges to convey floodwaters and the policies and procedures used in the design. This report presents hydrologic data, flood analysis, water surface profiles for 50-, 100-year, and the 1986 Flood due to the old bridge and new bridge, and hydraulic damage analysis.

Computer analysis indicates that the construction of the new bridge causes backwater effect in the range of 1 to 2 feet and maximum velocity between 6 to 8 feet per second for 50- and 100- year floods. The computer analysis further indicates that construction of the new bridge has resulted in lowering the water surface elevation by 2 to 3 feet when compared to the old bridge without Hulah and Copan Lakes, a condition that existed in 1930 at the time of construction of the old bridge. In addition, a review of policies and procedures of ODOT and the new bridge design on U.S. 75 on the Caney River shows that the design is within the guidelines. A second report, Volume II, containing hydrologic and computer analyses accompanies this report.

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EXECUTIVE SUMMARY

A large storm system, known as Hurricane Paine, extending across the central plains of the United States caused flooding of unprecedented proportions in the Arkansas, Cimarron, and Caney Rivers. This storm produced a rainfall varying from 20 to 30 inches in Oklahoma during September 29 through October 4, 1986.

Because of the severity of this extreme event, local residents questioned the adequacy of the bridges that were built in 1984. As a result, the Oklahoma Department of Transportation (ODOT) initiated this research study as an objective study of the hydraulic capacity of the bridges to convey floodwaters and the policies and procedures used in the design. This report presents hydrologic data, flood analysis, water surface profiles for 50-year, 100-year, and the 1986 Flood due to the old bridge and new bridge, and hydraulic damage analysis.

Four hydraulic conditions are analyzed to predict water surface profiles using the WSPRO computer model. The WSPRO model has been developed by the Federal Highway Administration. The four cases include Case I - Profiles for new bridge (50-year, 100-year and 1986 Flood), Case II - Profiles for old bridge (50-year, 100-year and 1986 Flood), Case III - Profiles without embankment (50-year, 100-year, and 1986 Flood), and Case IV - Profiles for old bridge without Hulah and Copan Lakes.

To determine the backwater effects due to the new bridge and the old bridge, water surface elevations between Case I and III and Case II and III are subtracted one bridge length upstream. In addition, water surface elevations between Case I and Case IV are subtracted to determine how the old bridge, built in 1930 without Hulah and Copan Lakes, compares with the new bridge in terms of hydraulic efficiency.

Procedures and policies on bridge design for interstate highways (such as U.S.75) are developed by FHWA and adopted by the ODOT as presented in Appendix J (separate volume). Computer analysis indicates that the construction of the new bridge causes backwater effect on the range of 1 to 2 feet and maximum velocity between 6 to 8 feet per second for 50-year and 100-year floods. Tables 3 through 8 summarize these results. The computer analysis further indicates that construction of the new bridge has resulted in lowering the water surface elevation by 2 to 3 feet when compared to the old bridge without Hulah and Copan Lakes, a condition that existed in the 1930's at the time of construction of the old bridge. In addition, a review of policies and procedures of ODOT and the new bridge design on U.S 75 of the Caney River shows that the design is within the guidelines.

The FHWA and ODOT policies indicate that an interstate bridge (U.S.75) should be designed for a 50-year flood and be checked for a 100-year flood. It is not cost-effective to design the bridge for higher frequency floods because of the life of a reinforced concrete bridge (30 to 50 years). To overdesign the bridge is a waste of state funds and taxpayers money. The new bridge was designed for 50-year and checked for 100-year floods.

The siltation in the 1986 Flood occurred on the upstream side of the new bridge in the floodplain. However, limited loss of soil would occur within 150 to 180 feet upstream of the overflow structures. Depending on the right-of-way within U.S. 75 slight damage due to soil loss would be experienced upstream of the two overflow structures. As seen in Appendix K, a jet is issued out of the overflow structure along the county road. Thus, scour damage is mostly limited to the road in the immediate vicinity of the highway and two county roads.

The backwater effect upstream of the exit section of the bridges is computed for 500-year flood or a discharge of 108,000 cfs. Using the WSPRO model, this effect due to new and old bridge options is determined extending to 5.55 and 3.66 miles upstream from U.S. 75.

The residents have built dikes along the Caney River in the floodplains. Once the flood water passes over dikes from the main river, dikes obstruct drainage from floodplain to the main river. Water ponds in the flood plain until it is drained by overflow structures.

The concept of floodplain utilization is that it can be used for agriculture but it is expected that a high flood of 50 to 100 to 500 year frequency will cause flooding in the floodplain. The 1986 flood is analyzed by the Corps of Engineers (1987) as a 500-year flood. Obviously, crop damages are expected to occur, but these are not caused by the construction of the new bridge and U.S. 75.

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I. INTRODUCTION

A large storm known as Hurricane Paine produced a rainfall of 20 to 30 inches over the Arkansas River Basin. This large rainfall over a six-day period (September 29 through October 4, 1986) resulted in extensive flooding in the Cimarron, Arkansas, and Caney Rivers. Due to the effect of this extreme event of rainfall exceeding 20 inches, the question was raised by the local residents about the adequacy of the bridges that were built in 1984. The Oklahoma Department of Transportation (ODOT) initiated this research investigation as an objective study of the hydrologic and hydraulic design of the bridges and the policies and procedures used in the design. This study analyzes various hydraulic conditions for the old bridge and new bridge and determines the impact of Hulah and Copan Lakes on the water surface profile at U.S. 75 bridge near Bartlesville.

II. HYDROLOGIC DATA AND ANALYSIS

This section presents historical data on the drainage area of the Caney River at U.S. 75, occurrence of major floods including the 1986 flood, peak flows for 50-and 100 year frequencies and for a condition before the construction of Hulah and Copan Lakes.

a) Drainage Area

The Caney River flows from north to south bisecting Bartlesville. The river begins in southern Kansas and flows generally south approximately 162 miles to its confluence with the Verdigris River. The average slope of the Caney River for the project area is 4.53 feet per mile.

A gaging station installed by the U.S. Geological Survey exists on the Caney River near Ramona. The drainage area for this location is 1955 square miles as presented in Appendix A (1977).

Hulah Lake was constructed in 1951 on the Caney River about 27 miles upstream of Bartlesville. Copan Lake was completed in 1983 on the Little Caney River at 7.4 miles upstream from the Caney River. The drainage areas of Hulah and Copan Lakes are 732 and 505 square miles (see Appendix B).

b) Historical Floods

Floods regularly occurred in the Caney River prior to 1951. Large floods were experienced in the drainage basin with one occurring in 1885, three in 1908, one each in 1909 and 1912, and two in 1926. Major floods also took place in 1928, three in 1929, two in 1930, 1933, 1935, three in 1941, 1942, 1943, and two in 1944.

Reviewing the flooding situation in the basin, the Corps of Engineers completed Hulah Lake in 1951. Although this lake helped contain the large floods of 1951 , 1957, and 1974, some flooding still occurred. Copan Lake was constructed in 1983 by the Corps of Engineers to further reduce flood damages in the basin. Appendix C presents peak flows in the Caney River from 1935 through 1986. The peak flow in October, 1986 was recorded at the gaging stations near Bartlesville and Ramona. These values include 108,000 and 92,000 cfs. Figures 1 and 2 show hydrographs. The Corps of Engineers (1987a, 1987b) analyzed the 1986 flood. Frequency of this flood is determined to be about 500 years.

c) Frequency Analysis of Peak Flows

Peak flow data for the Ramona gaging station is summarized in Appendix C. A plot of discharge, Q, with return period, T, for the Ramona station is presented in this appendix. Peak flows for the 50-year and 100-year frequency are computed as 39,600 and 45,600 cubic feet per second (cfs).

Review of the Federal Insurance Study (1980) indicates peak flows of 42,800 and 51,400 cfs for 50- and 100-year frequency as shown in Appendix D. Values of the OSU study and the FIS study are compared in Table 1. Peak flow values between the OSU study and the FIS study for 50 and 100 years are comparable. To be on the conservative side, larger values of peak flows for 50 and 100 years are selected and used in water surface analysis in Section III.

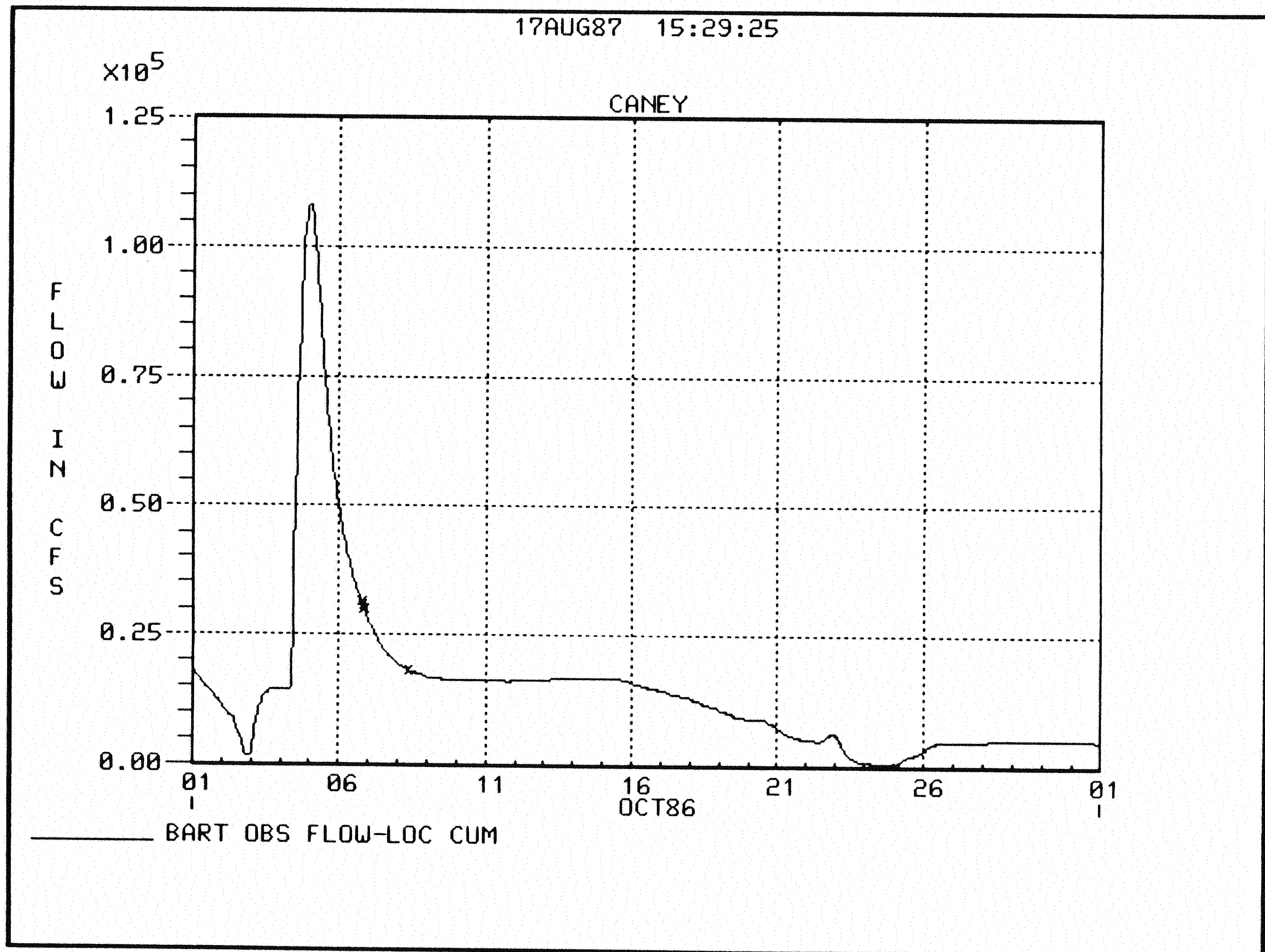

Figure 1. Hydrograph at Bartlesville Gaging Station

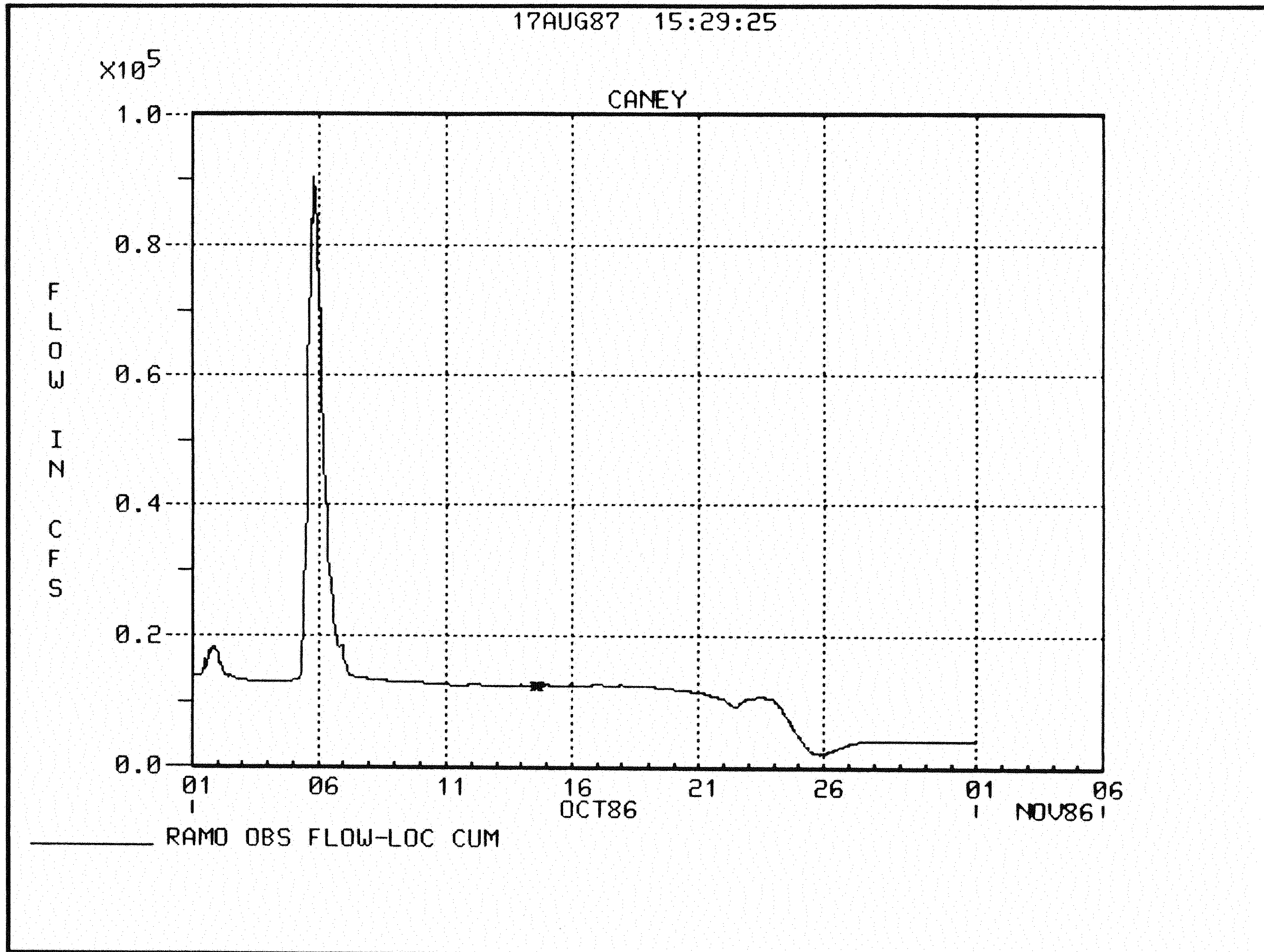

Figure 2. Hydrograph at Ramona Gaging Station

TABLE I. PEAK FLOWS FOR 50- AND 100-YEAR FREQUENCY

Frequency, T, years	Peak Flows, Q, cfs	
	OSU*	FIS**
50	39,600	42,800
100	45,600	51,400

* OSU - This study; see Appendix C
** FIS - Flood Insurance Study (1980)

d) Frequency Analysis of Peak Flows without Hulah and Copan Lakes

Peak flows for 50-, 100- and 500-year frequencies are computed to analyze the water surface profiles under natural conditions in the absence of the U.S. 75 Highway and the Hulah and Copan Lakes. The U.S. Geological Survey approach (1977) techniques for estimating flood discharges for Oklahoma streams is used for peak flows for the three frequencies.

The equations used in computations of peak flows are given below:

$$Q_{50} = 20.0\, A^{0.69}\, S^{0.31}\, P^{0.81} \quad (1)$$

$$Q_{100} = 38.6\, A^{0.70}\, S^{0.32}\, P^{0.67} \quad (2)$$

$$Q_{500} = 140.0\, A^{0.71}\, S^{0.33}\, P^{0.40} \quad (3)$$

where Q_{50}, Q_{100} and Q_{500} = discharges for 50, 100 and 500-year frequencies, cfs

A = drainage area, mi^2

S = slope from elevations at 10% and 85% of distance along the river from the gaging stations to drainage basin divide, ft/mile

P = mean annual precipitation, inches

The values of S and P are determined as 4.53 feet per mile and 37 inches, respectively. Table 2 presents peak flows for 50-, 100-, and 500-years frequencies for Ramona, Ochelata and Bartlesville gaging stations.

In summary, the 50- and 100-year floods for the Caney River near Bartlesville are determined as 39,600 and 45,600 cfs in this section. The peak flow of 1986 flood near Bartlesville is analyzed to be 108,000 cfs of about 500-year frequency. Finally, peak flows from the Caney River watershed prior to the construction of Hulah and Copan lakes are evaluated as 91,011, 115,697 and 172,849 cfs for 50-, 100- and 500-year frequencies. The data generated in this section is used in Section III to determine water surface profiles for four hydraulic conditions.

TABLE 2. PEAK FLOWS FOR RAMONA, OCHELATA AND BARTLESVILLE STATIONS, CANEY RIVER

Gaging Stations	Area	Peak Flows, cfs		
	mi^2	Q_{50}	Q_{100}	Q_{500}
Ramona	1955	111,059	141,591	212,146
Ochelata	1753	103,009	131,186	196,339
Bartlesville	1465	91,011	115,697	172,849

III. FLOOD ANALYSIS

Four scenarios are considered in this study. Case I determines the water surface profiles for 50-year, 100-year, and the 1986 flood in the presence of the new bridge. In Case II, the water surface profiles are computed for the 50-year, 100-year, and the 1986 flood with the old bridge. Water surface profiles for the 50-year, 100-year, and the 1986 flood are presented in Case III without embankment (U.S. 75 Highway). Finally, Case IV shows the profiles for the old bridge without lakes (Hulah and Copan lakes). The peak flows for 50-years and 100-years are 42,800 cfs and 51,400 cfs as shown in FIS study (1980) by the Federal Emergency Management Agency, and the 1986 flood is 108,000 cfs as given by the Corps of Engineers (1987a, 1987b).

WSPRO computer model (1986) developed and adopted by the Federal Highway Administration (FHWA) is used in this investigation to analyze the hydraulic conditions of the 1986 flood at U.S. 75 Highway on the Caney River. Details of this program are presented in a research report published by the FHWA (1986).

Water surface profiles for the four cases are presented below using the WSPRO computer program.

Case I - Profiles for New Bridge (50-year, 100-year and 1986 Flood).

The computer program computes water surface profiles at one bridge length upstream, at the bridge location on U.S 75, and at one bridge length downstream along the Caney River. The water surface elevations at the three locations are computed as 649.73, 648.40, and 648.24 above mean sea level (MSL) for the 50-year flood. For the 100-year flood, the water surface elevations are determined as 650.61, 648.98 and 648.83 feet. The elevations for the 1986 flood are 655.59, 651.74 and 651.58 feet. These profiles are compared in Figure 3 for 50-year, 100-year and the 1986 flood.

Case II - Profiles for Old Bridge (50-year, 100-year, and 1986 flood).

Water surface profiles are determined with the old bridge at U.S. 75 on the Caney River. For 50-year flood, elevations of water surface on upstream, at the old bridge, and downstream of the bridge are determined as 648.99, 648.40, and 648.24, respectively. The water surface profile elevations for the 100-year flood include 649.68, 648.99, and 648.83. For the 1986 flood, the elevations of the water surface profiles are computed as 653.27, 651.75, and 651.58, respectively. Three profiles of the water surface are shown in Figure 4.

Case III- Profiles without Embankment (50-year, 100-year, and 1986 Flood).

This scenario represents the natural condition where no bridge and no highway exist on the Caney River. Elevations of the water surface profiles for the 50-year flood are 648.45, 648.40 and 648.24 feet, respectively. For the 100-year flood, water surface elevations are 649.05, 648.99 and 648.83 feet. Water surface elevations for the 1986 flood are determined as 651.82, 651.75 and 651.58 feet, respectively. Figure 5 presents water surface profiles for the 50-year, 100-year and 1986 flood.

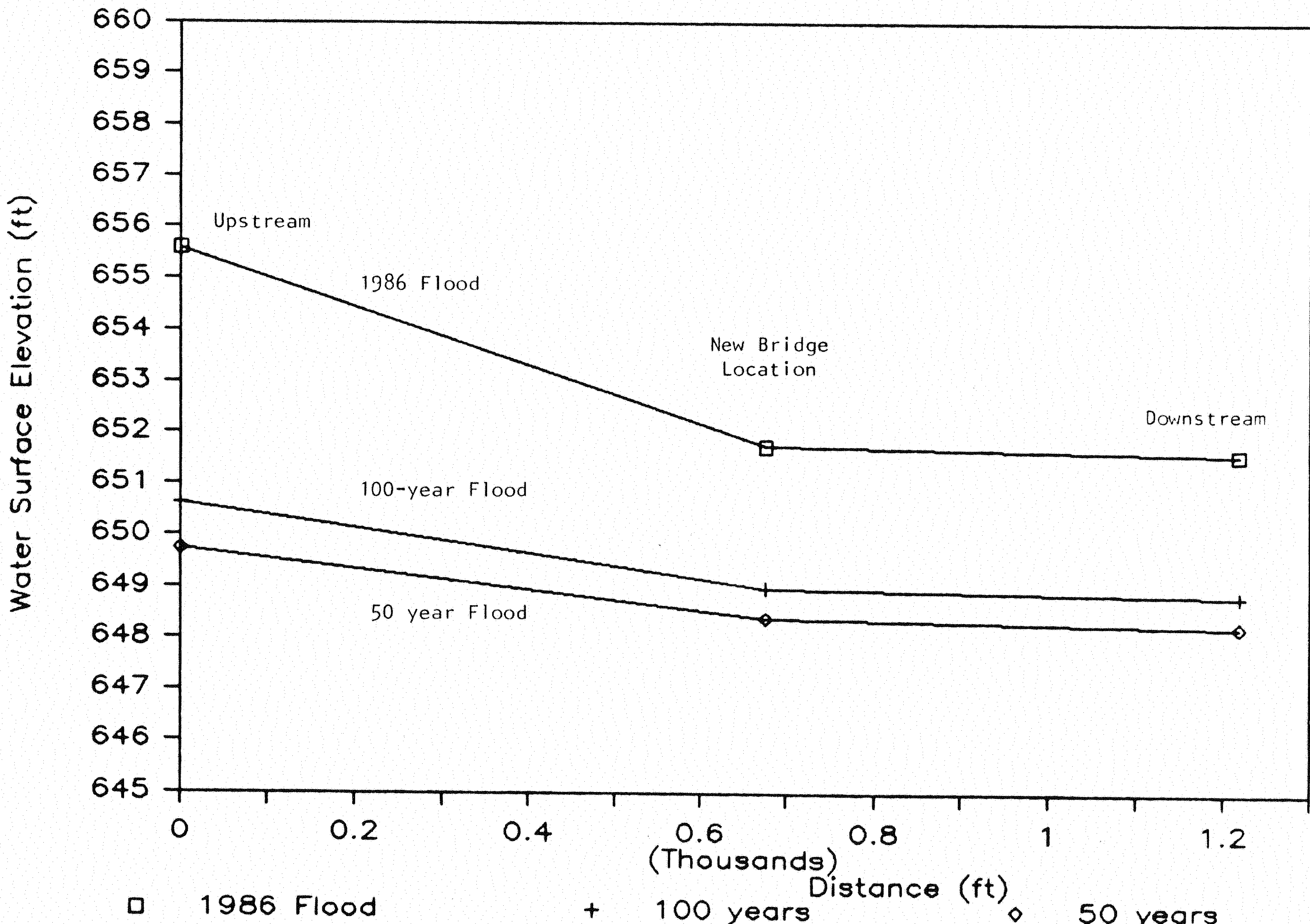

Figure 3. Case 1 - Water Surface Profiles for New Bridge (50-year, 100-year and 1986 Flood)

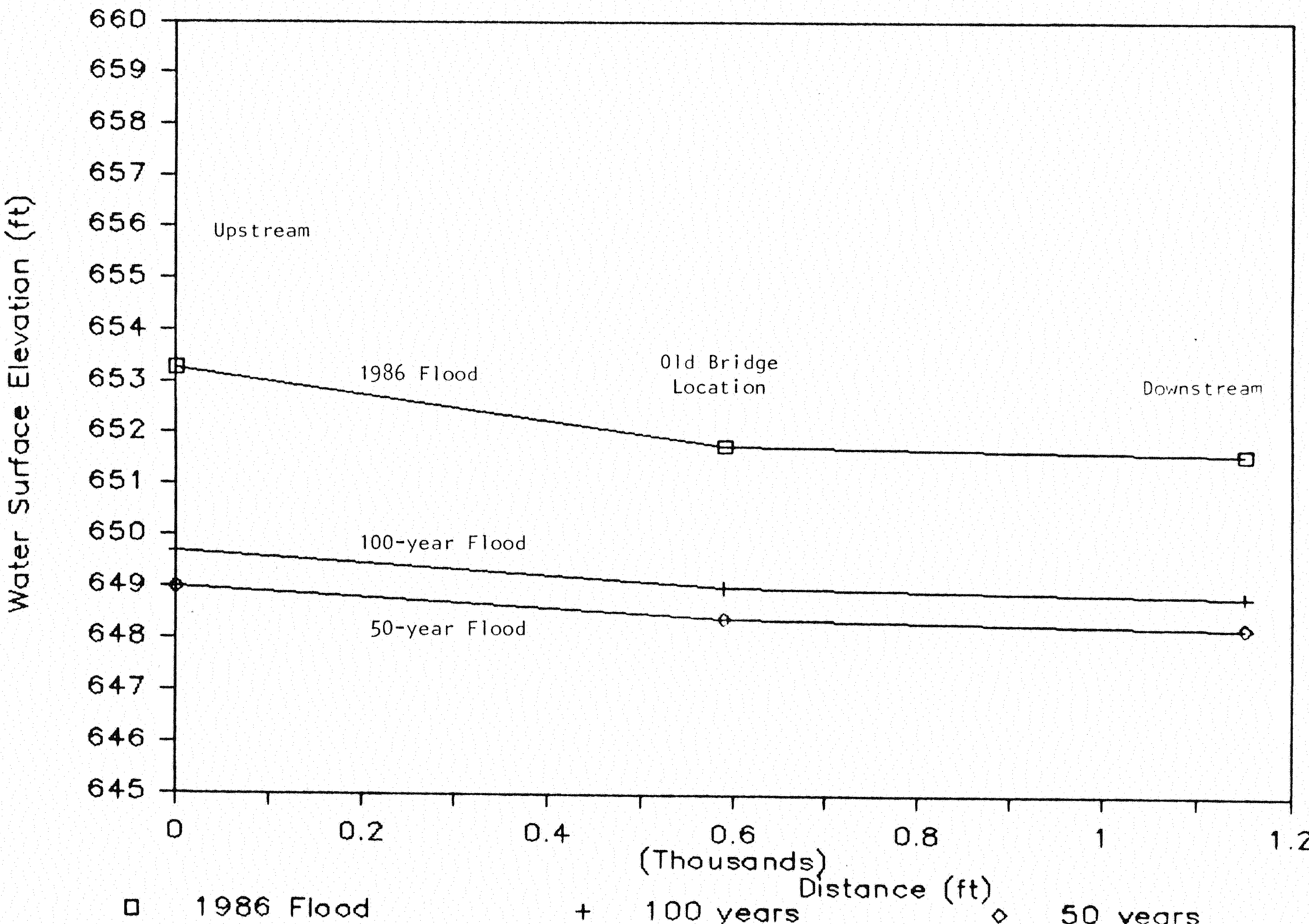

Figure 4. Case II - Water Surface Profiles for Old Bridge (50-year, 100-year and 1986 Flood)

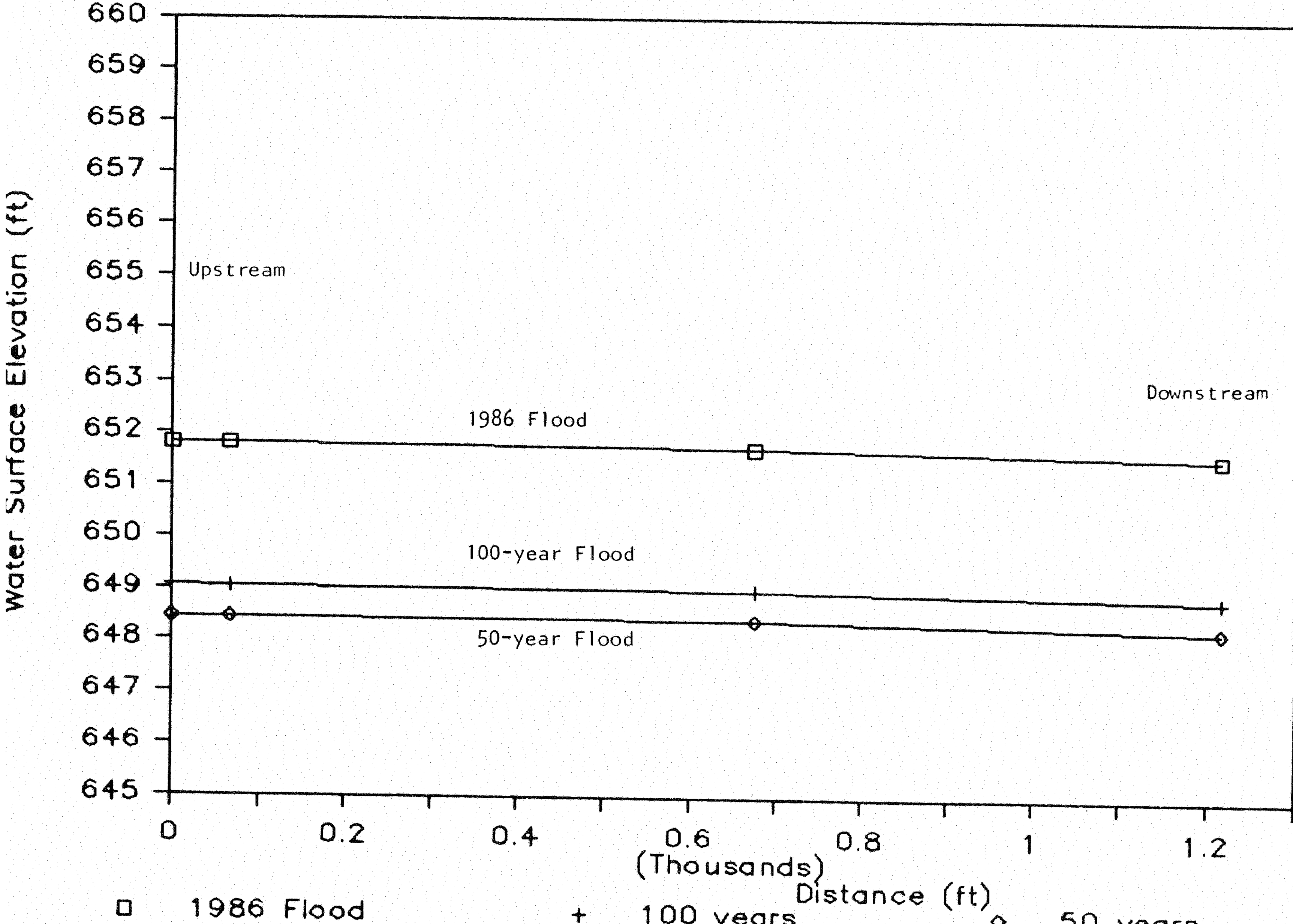

Figure 5. Case III - Water Surface Profiles without Embankment (50-year, 100-year and 1986 Flood)

Case IV - Profiles for Old Bridge without Lakes (50-year and 100-year Flood)

This scenario presents 50-year and 100-year water surface profiles for the old bridge on the Caney River at U.S. 75. The 50-year profile elevations include 652.37, 651.07 and 650.90 feet, respectively. Elevations of the water surface for the 100-year flood are determined as 653.67, 652.04 and 651.87 feet, respectively. These profiles are compared in Figure 6.

Tables 3, 4, 5, and 6 summarize water surface elevations and velocity values at approach, bridge, and exit sections.

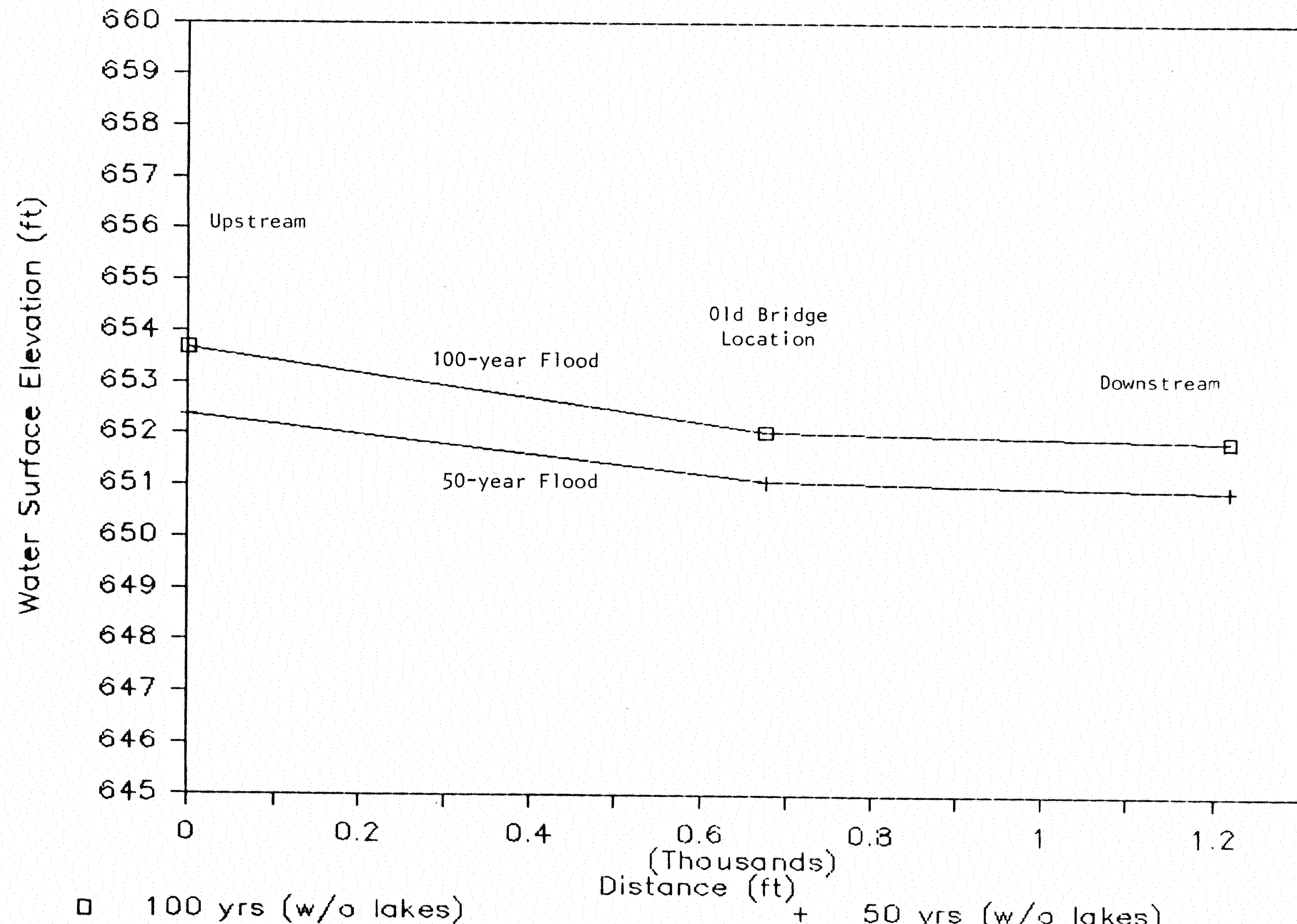

Figure 6. Case IV - Water Surface Profiles for Old Bridge without Lakes (50-year and 100-year Flood)

TABLE 3. CASE I - WATER SURFACE PROFILES FOR NEW BRIDGE

Frequency = 50 years
Peak Flows = 42,800 cfs

Location	Distance, ft.	WSE,ft	Velocity, fps
Approach	0	649.73	0.66
Bridge	676	648.40	5.10[1],5.98[2],5.54[3]
Exit	1218	648.24	1.66

Frequency = 100 years
Peak Flow = 51,400 cfs

Location	Distance, ft	WSE,ft	Velocity, fps
Approach	0	650.61	0.70
Bridge	676	648.98	5.82[1],6.85[2],6.37[3]
Exit	1218	648.83	1.72

Frequency = 500 years
Peak Flood = 108,000 cfs

Location	Distance, ft	WSE,ft	Velocity, fps
Approach	0	655.59	0.88
Bridge	676	651.74	9.99[1],11.64[2],11.00[3]
Exit	1218	651.58	2.08

1 - velocity at Main Structure
2 - velocity at Overflow Structure 1
3 - velocity at Overflow Structure 2

TABLE 4. CASE II - WATER SURFACE PROFILES FOR OLD BRIDGE

Frequency = 50 years
Peak Flows = 42,800 cfs

Location	Distance, ft.	WSE,ft	Velocity, fps
Approach	0	648.99	0.74
Bridge	591	648.40	4.04[1],3.27[2],3.12[3]
Exit	1151	648.24	1.66

Frequency = 100 years
Peak Flow = 51,400 cfs

Location	Distance, ft	WSE,ft	Velocity, fps
Approach	0	649.68	0.80
Bridge	591	648.99	4.50[1],3.75[2],3.60[3]
Exit	1151	648.83	1.72

Frequency = 500 years
Peak Flood = 108,000 cfs

Location	Distance, ft	WSE,ft	Velocity, fps
Approach	0	653.27	1.09
Bridge	591	651.75	6.82[1],6.33[2],6.12[3]
Exit	1151	651.58	2.08

1 - velocity at Main Structure
2 - velocity at Overflow Structure 1
3 - velocity at Overflow Structure 2

TABLE 5. CASE III - WATER SURFACE PROFILES WITHOUT EMBANKMENT

Frequency = 50 years
Peak Flows = 42,800 cfs

Location	Distance, ft.	WSE,ft	Velocity, fps
Approach	0	648.45	0.81
Bridge	676	648.40	0.94
Exit	1218	648.24	1.66

Frequency = 100 years
Peak Flow = 51,400 cfs

Location	Distance, ft	WSE,ft	Velocity, fps
Approach	0	649.05	0.88
Bridge	676	648.99	1.01
Exit	1218	648.83	1.72

Frequency = 500 years
Peak Flood = 108,000 cfs

Location	Distance, ft	WSE,ft	Velocity, fps
Approach	0	651.82	1.27
Bridge	676	651.75	1.41
Exit	1218	651.58	2.08

TABLE 6. CASE IV - WATER SURFACE PROFILES FOR OLD BRIDGE WITHOUT LAKES

Frequency = 50 years
Peak Flows = 91,011 cfs

Location	Distance, ft.	WSE,ft	WES*,ft	Velocity, fps
Approach	0	652.37	651.13	1.01
Bridge	591	651.07	651.07	6.16[1],5.63[2],5.43[3]
Exit	1151	650.90	650.90	1.97

Frequency = 100 years
Peak Flow = 115,697 cfs

Location	Distance, ft	WSE,ft	WES*,ft	Velocity, fps
Approach	0	653.67	652.11	1.12
Bridge	591	652.04	652.04	7.11[1],6.63[2],6.41[3]
Exit	1151	651.87	651.87	2.13

*WSE without embankment.
1 - velocity at Main Structure
2 - velocity at Overflow Structure 1
3 - velocity at Overflow Structure 2

IV. SCOUR AND SILTATION

A floodplain area is defined as an area that is inundated by floods when waters move beyond the banks of the river. Resident properties are in the floodplain of the Caney River. Properties in the floodplain are subject to the probability of flooding depending on the frequency of the flood.

Because of limited backwater effects from the old bridge and new bridge, the water surface profile will gradually approach the normal depth of flow. On the upstream side of U.S. 75 along the Caney River, values of the flow velocity fall to less than 1 foot per second at one bridge distance upstream (see Tables 3 through 6).

Except within one bridge length upstream near the bridge, the flow velocities are less than 2.5 fps and thus lead to sedimentation or deposition of soil. When velocities increase above 2.5 fps, the soil is likely to erode. Erosion is expected on the downstream side of the overflow structures. Appendix K presents an aerial photograph during the 1986 Flood. A jet is issued from the overflow structure as seen in the photograph (COE, 1987b). The jet follows the county road on downstream of the overflow structure. Thus, the damages from scour on the downstream side of the overflow structure are limited along the county road. On the upstream side, silt brought by flood waters is deposited in the floodplain.

V. BACKWATER ANALYSIS

An analysis of water surface elevations was performed for the 1986 flood using WSPRO computer model. A peak flow of 108,000 cfs was used in the analysis for the new bridge and old bridge options. Table 7 presents water surface elevations (WSE) in feet with distance, X, in feet or miles upstream of the exit section selected in previous WSPRO runs for corresponding options. When the difference in water surface elevations in between two successive cross-sections in upstream direction and is within 1 percent, water surface is considered to be free of the backwater effect.

Figure 7 shows the WSE1 and WSE2 for the new bridge and old bridge options, respectively. The river bottom is also plotted in the figure. A close-up of Figure 7 is presented in Figure 8. For the new bridge, the backwater effect is experienced for about 5.55 miles upstream of the exit section. With the old bridge, the backwater effect extends up to 3.66 miles upstream. In both figures, the backwater effect upstream of the exit section is approximated as M1 curve which generally extends to a long distance upstream.

TABLE 7. BACKWATER EFFECT ON CANEY RIVER AT U.S. 75

Discharge = 108,000 cfs

X (ft)	(mi)	YMIN	WSE 1 NEW	H1 (ft)	Delta H (%)	WSE 2 OLD	H2 (ft)	Delta H (%)
1218	0.10	617.00	655.59	38.59		653.27	36.27	
5000	0.92	618.51	655.73	37.22	3.68	653.53	35.02	3.57
10000	1.77	620.51	656.01	35.50	4.85	654.10	33.59	4.26
15000	2.71	622.51	656.51	34.00	4.41	655.06	32.55	3.20
20000	3.66	624.51	657.33	32.82	3.60	656.45	31.94	1.91
25000	4.61	626.51	658.60	32.09	2.27	658.20	31.69	0.79
30000	5.55	628.51	660.25	31.74	1.10	660.10	31.59	0.32
35000	6.50	630.51	662.12	31.61	0.41	662.07	31.56	0.10
40000	7.45	632.51	664.07	31.56	0.16	664.06	31.55	0.03
45000	8.39	634.51	666.06	31.55	0.03	666.06	31.55	0.00
50000	9.34	636.51	668.06	31.55	0.00	668.06	31.55	0.00
55000	10.29	638.51	670.06	31.55	0.00	670.06	31.55	0.00
60000	11.24	640.51	672.06	31.55	0.00	672.06	31.55	0.00
65000	12.18	642.51	674.06	31.55	0.00	674.06	31.55	0.00
70000	13.13	644.51	676.06	31.55	0.00	676.06	31.55	0.00
75000	14.08	646.51	678.06	31.55	0.00	678.06	31.55	0.00
80000	15.02	648.51	680.06	31.55	0.00	680.06	31.55	0.00
85000	15.97	650.51	682.06	31.55	0.00	682.06	31.55	0.00
90000	16.92	652.51	684.06	31.55	0.00	684.06	31.55	0.00
95000	17.86	654.51	686.06	31.55	0.00	686.06	31.55	0.00
100000	18.81	656.51	688.06	31.55	0.00	688.06	31.55	0.00
105000	19.76	658.51	690.06	31.55	0.00	690.06	31.55	0.00
110000	20.71	660.51	692.06	31.55	0.00	692.06	31.55	0.00
115000	21.65	662.51	694.06	31.55	0.00	694.06	31.55	0.00
120000	22.60	664.51	696.06	31.55	0.00	696.06	31.55	0.00
125000	23.55	666.51	698.06	31.55	0.00	698.06	31.55	0.00
130000	24.49	668.51	700.06	31.55	0.00	700.06	31.55	0.00
135000	25.44	670.51	702.06	31.55	0.00	702.06	31.55	0.00
140000	26.39	672.51	704.06	31.55	0.00	704.06	31.55	0.00
145000	27.33	674.51	706.06	31.55	0.00	706.06	31.55	0.00
150000	28.28	676.51	708.06	31.55	0.00	708.06	31.55	0.00

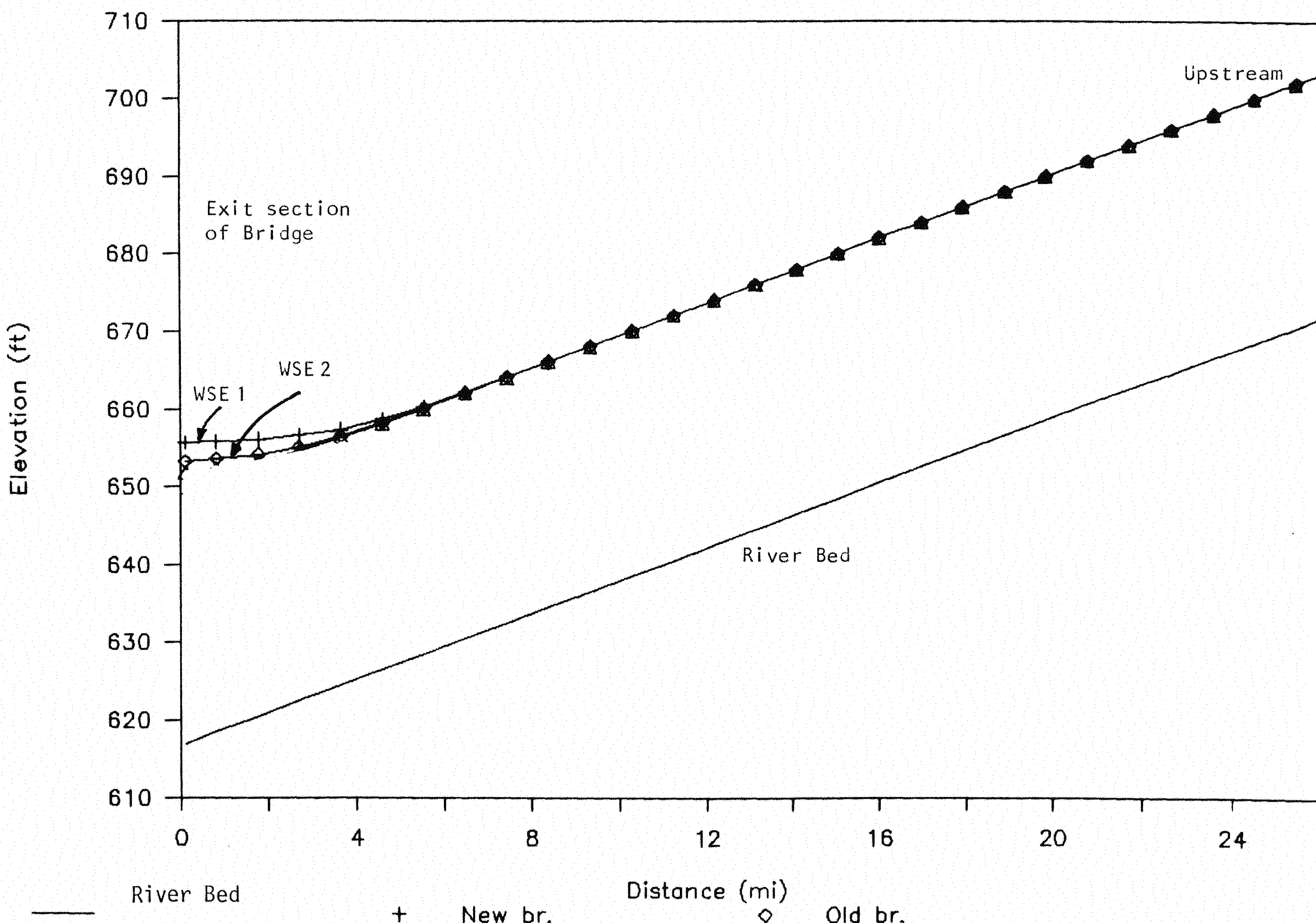

Figure 7. Backwater Effect Upstream of Exit Section of New and Old Bridge Options

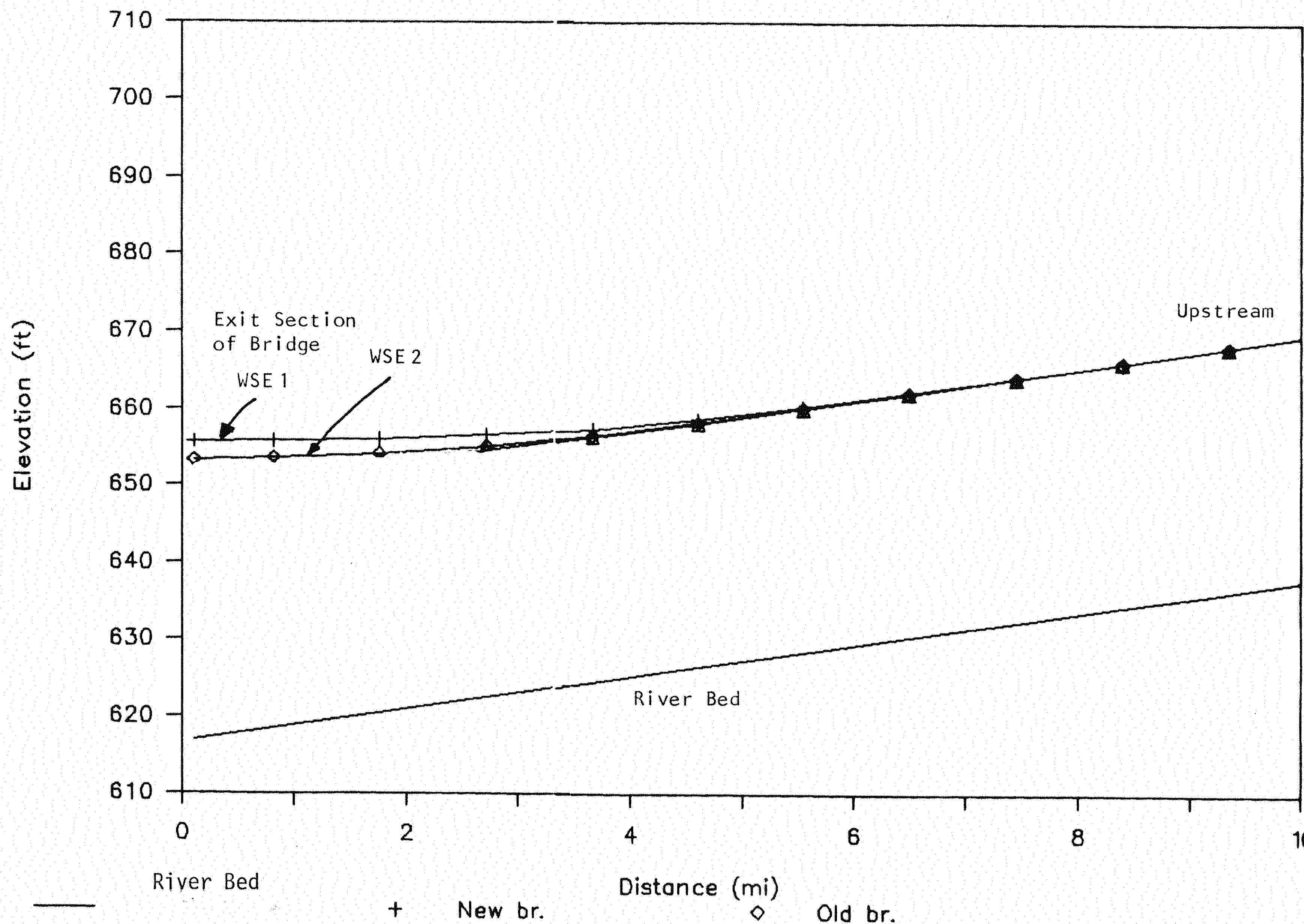

Figure 8. Closeup of Backwater Effect Upstream of Exit Section of New and Old Bridge Options

VI. DISCUSSION

Four cases of hydraulic conditions are considered to evaluate the impact of the new bridge and the old bridge on water surface elevations in Caney River near Bartlesville. Section III presents these cases---Case I through Case IV.

Backwater effect of water surface behind the new bridge may be defined as the difference in elevations of water surface profiles of the new bridge (Case I) and the water surface profiles without embankment (Case III) for 50- and 100-year floods and the 1986 Flood. It should be noted that Case III represents water surface elevations assuming that U.S. 75 and the bridge do not exist. This is a natural condition prior to construction of the bridge and U.S. 75.

Similarly, the backwater effect is computed for the old bridge by comparing Case II with Case III after 50- and 100-year floods and the 1986 Flood. Finally, 50-and 100-year water surface profiles of Case I for the new bridge are compared with those of Case IV. Case IV includes profiles for the old bridge without Hulah and Copan Lakes.

Figures 9 and 10 present the backwater effect for 50-year flood. Comparing Cases I and III and Cases II and III indicates that the backwater effect is 1.28 feet with the new bridge and 0.54 feet with the old bridge. See Figures 11 and 12 for the 100-year flood backwater effect. The backwater effect due to the 1986 flood of about 500-years frequency is 3.77 feet for the new bridge and 1.45 feet for the old bridge as shown in Figures 11 and 12. Table 8 summarizes the backwater effect for 50-year, 100-year, and the 1986 flood.

Appendix J presents the policies and procedures of bridge design adopted in 1969. These policies have been adopted by the commissioners of the Oklahoma Department of Transportation.

Policies of flood frequency indicate that bridges on primary highways should be designed for 50-year flood or the greatest historical flood, whichever is greater. Design frequency is the frequency of the design discharge and is fixed by design policy. In addition, bridges should be checked for 100-year flood frequency to evaluate the damage if a higher runoff should occur.

Policies further indicate that allowable velocities should average between 6 to 8 feet per second and that allowable backwater depth should be between 1 and 2 feet. The Federal Highway Administration (FHWA) conducted extensive studies and outlined procedures to conduct cost-risk evaluation and design frequency and check frequency for primary bridges. The 50-year design frequency for interstate highways such as U.S.75 is based on the recommendations of FHWA and is adopted by ODOT as shown in Appendix J.

Table 8 indicates that the backwater effect due to the new bridge and the old bridge is within the range of 1 to 2 feet for the 50-year flood, which is the design frequency for interstate highways set by the FHWA and ODOT (Appendix J) Furthermore, for the check frequency of 100-years, the backwater effect is also within 1 to 2 feet range. In addition, Tables 3 through 6 present values of the flow at approach, bridge and exit sections for 50-year and 100-year floods. The range of velocity values is from 0.66 to 7.11 feet per second (fps), well within the criteria of allowable limits adopted by FHWA and ODOT. It may be noted that for the 1986 Flood of about 500-

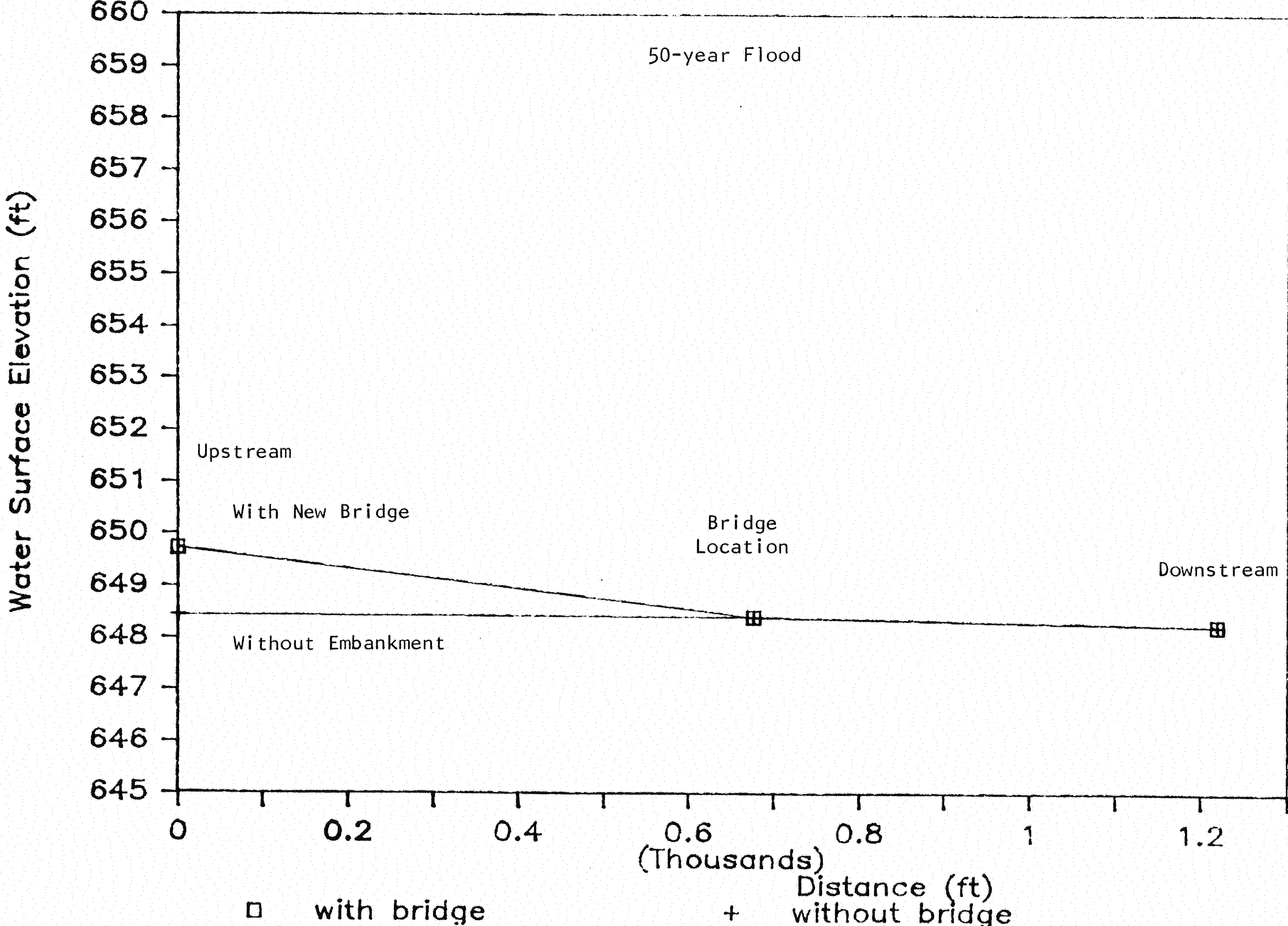

Figure 9. Profiles for 50-year Flood with New Bridge and without Embankment (Cases I & III)

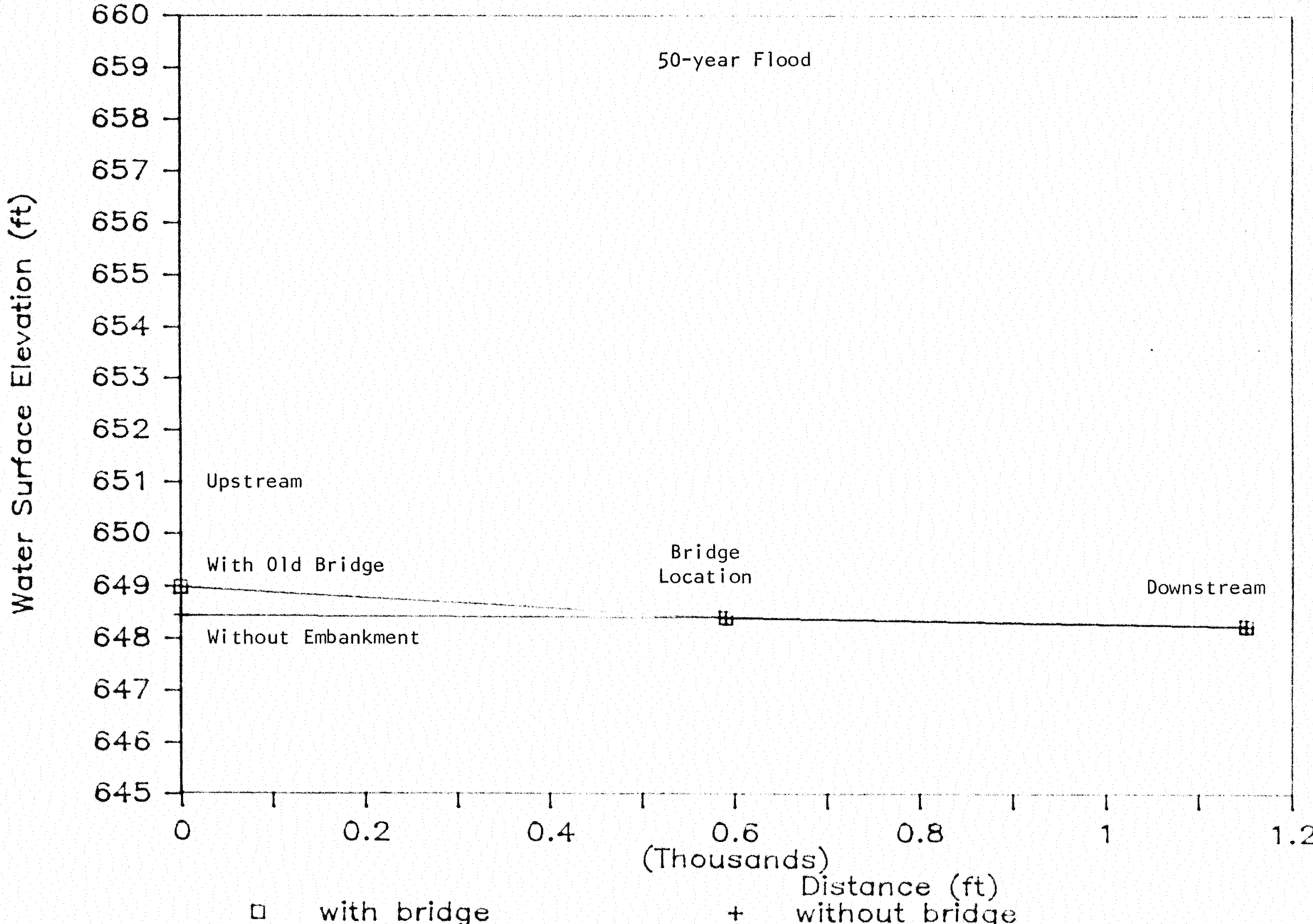

Figure 10. Profiles for 50-year Flood with Old Bridge and without Embankment (Cases II & III)

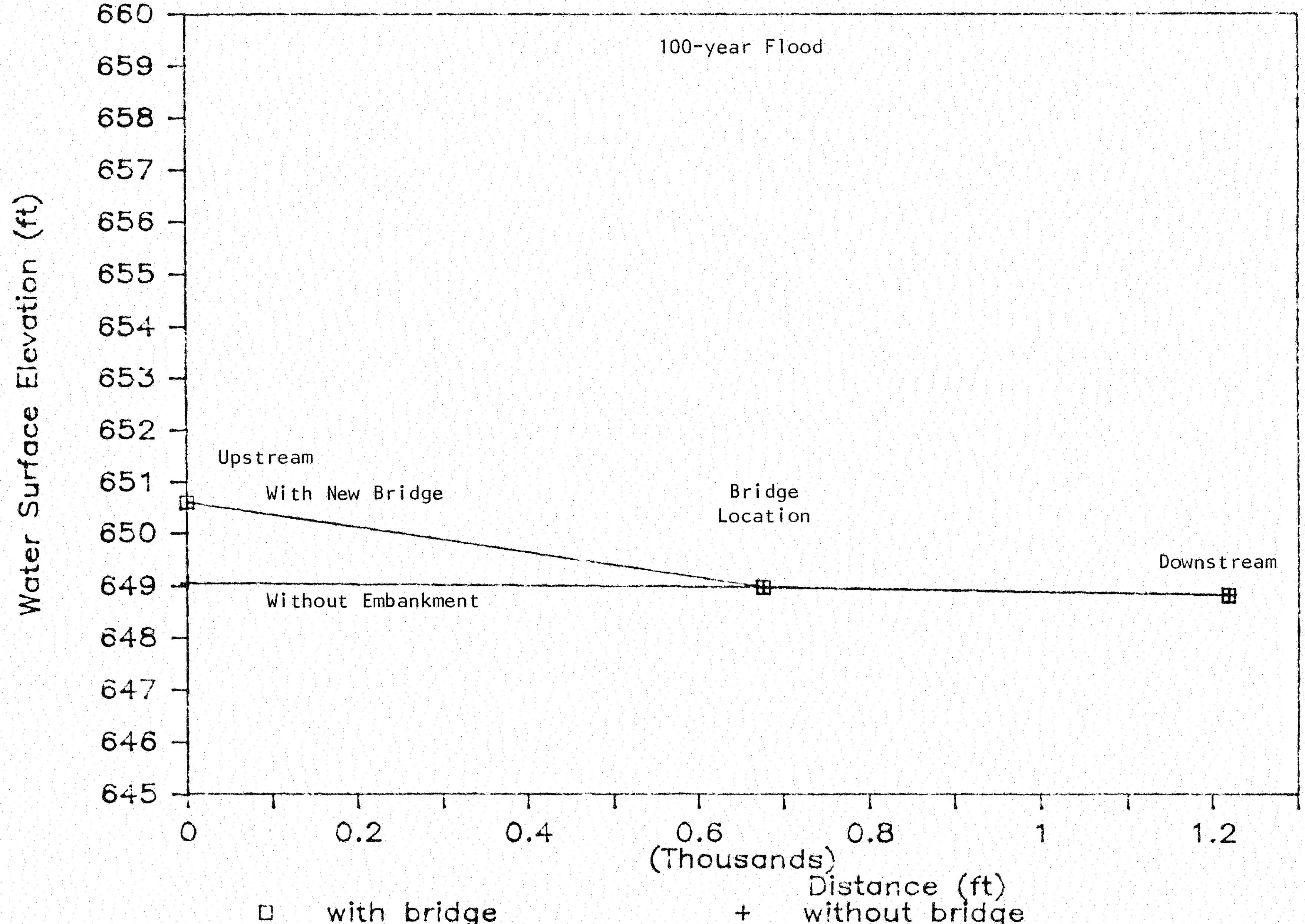

Figure 11. Profiles for 100-year Flood with New Bridge and without Embankment (Cases I & III)

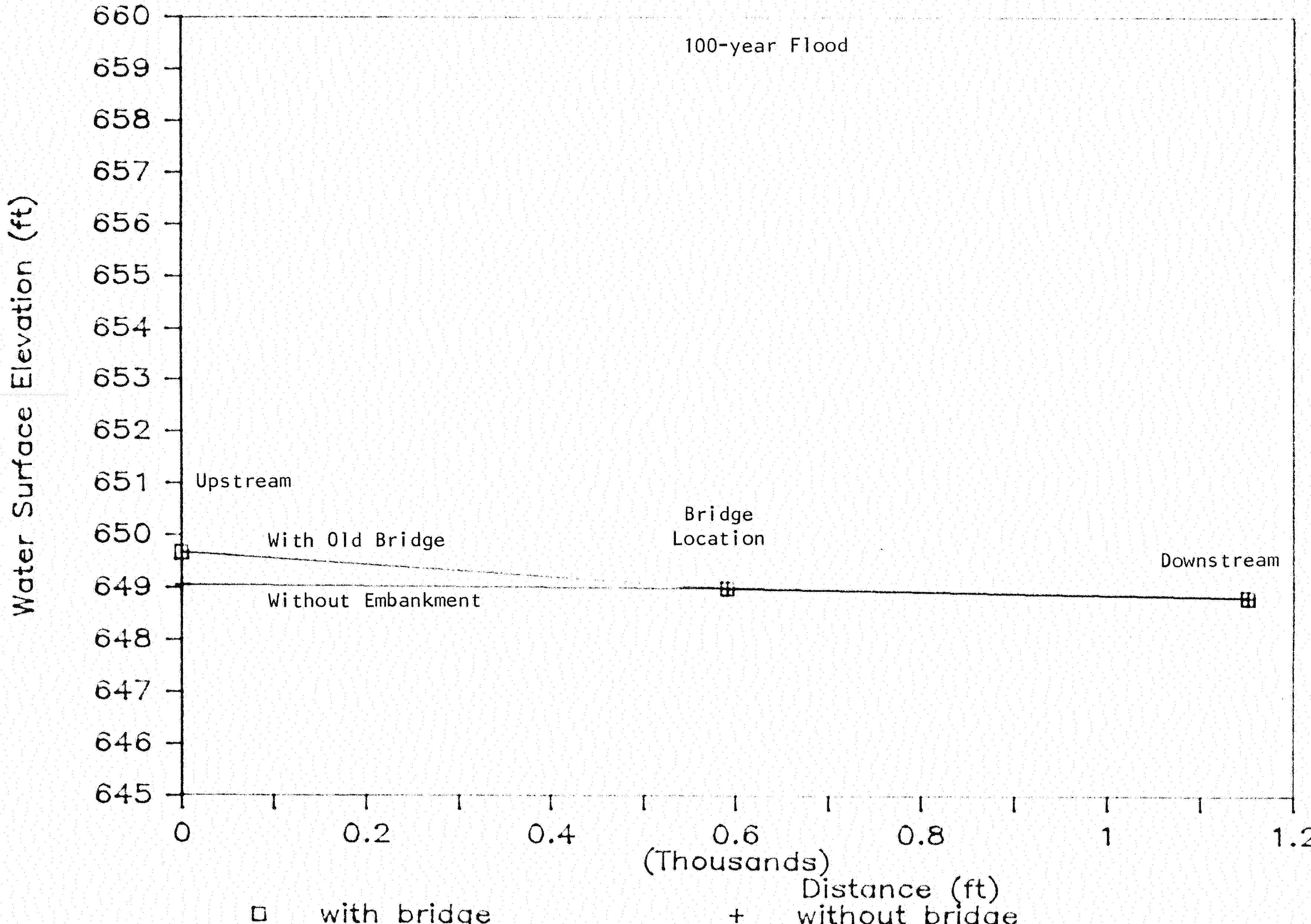

Figure 12. Profiles for 100-year Flood with Old Bridge and without Embankment (Cases II & III)

TABLE 8. BACKWATER EFFECT OF BRIDGES ON WATER SURFACE ELEVATIONS

T,years	Cases	Backwater Effect, ft
50	I & III	1.28
50	II & III	0.54
50	IV	1.24
100	I & III	1.56
100	II & III	0.63
100	IV	1.56
1986	I & III	3.77
1986	II & III	1.45

year frequency the range of velocity of flow is from 0.88 to 9.99 fps. Of course, the old bridge or new bridge were not designed for a 500-year flood because it would not be cost-effective to spend taxpayer's money on such a high frequency design.

A question is raised regarding the hydraulic efficiency of the new bridge constructed in 1984. Cases I and IV are compared in Figures 15 and 16 for 50- and 100-year floods. Case I represents water surface profiles for 50-year and 100-year floods, and Case IV includes water surface profiles for old bridge without Hulah and Copan Lakes (a condition that existed for the old bridge prior to construction of the two lakes in the 1940's). The construction of the new bridge in 1984 lowers the water surface by 2.64 and 3.06 feet for 50- and 100-year floods.

A comparison of discharges, velocities, and bridge backwater effect between the old design (Case IV--no controls upstream) and the new design (Case I - Controls upstream and reduced overflow structures) is presented in Table 9. Although the 50- and 100-year discharges for the old design are much higher than those for the new design, the velocities and the backwater effects between the two designs are very close indeed and are within the policies and procedures of FHWA and ODOT.

In summary, the new bridge constructed in 1984 is hydraulically more effective than the old bridge constructed in the 1930's without the two lakes. In addition, water surface profile analyses for Cases I through IV indicate that allowable backwater effect ranges within 1 to 2 feet and allowable flow velocity is within 6 to 8 fps for 50-year design frequency and 100-year check frequency for U.S. 75. These criteria are established for interstate highways by FHWA and adopted by ODOT as shown in Appendix J.

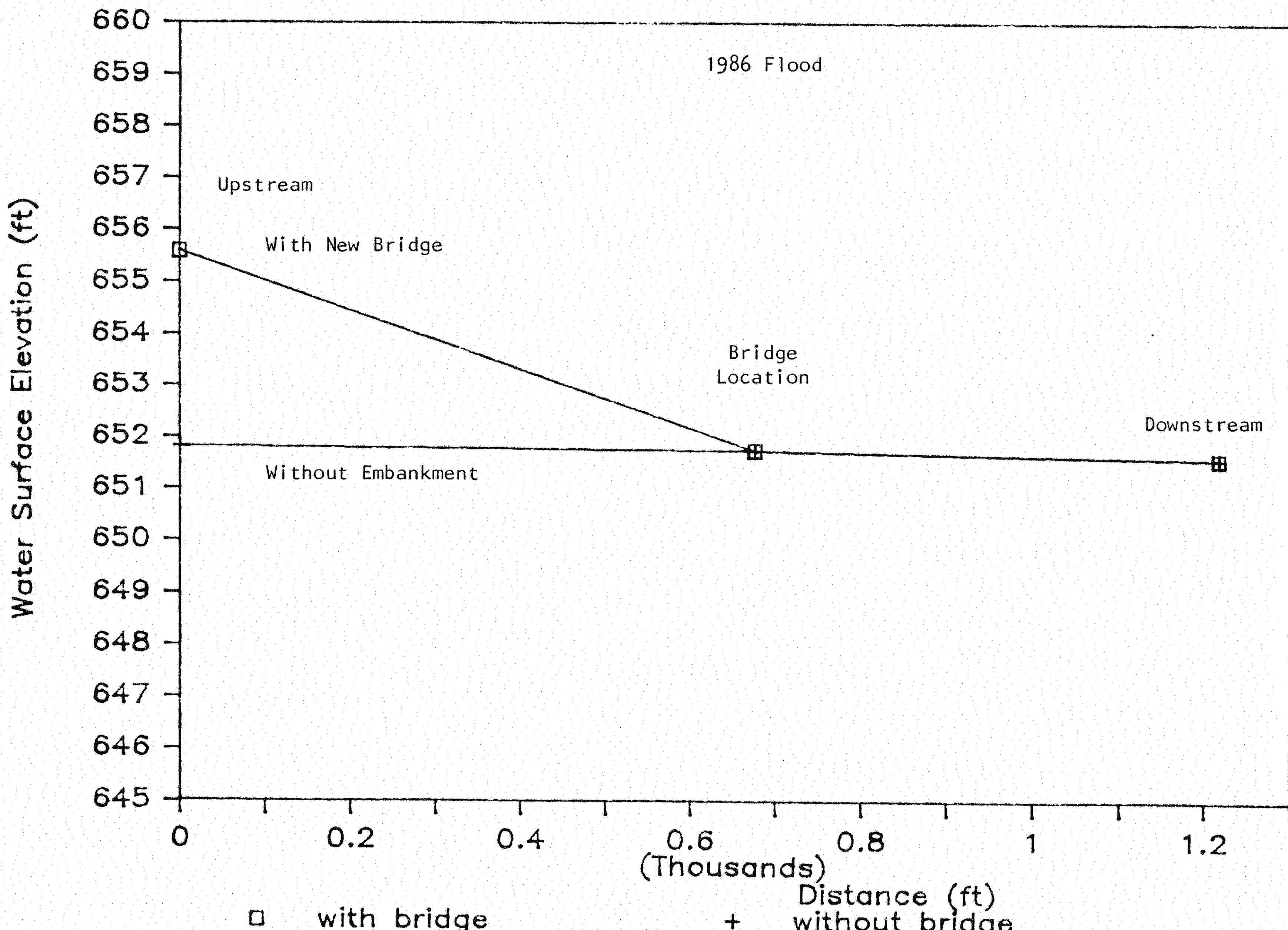

Figure 13. Profiles for 1986 Flood with New Bridge and without Embankment (Cases I & III)

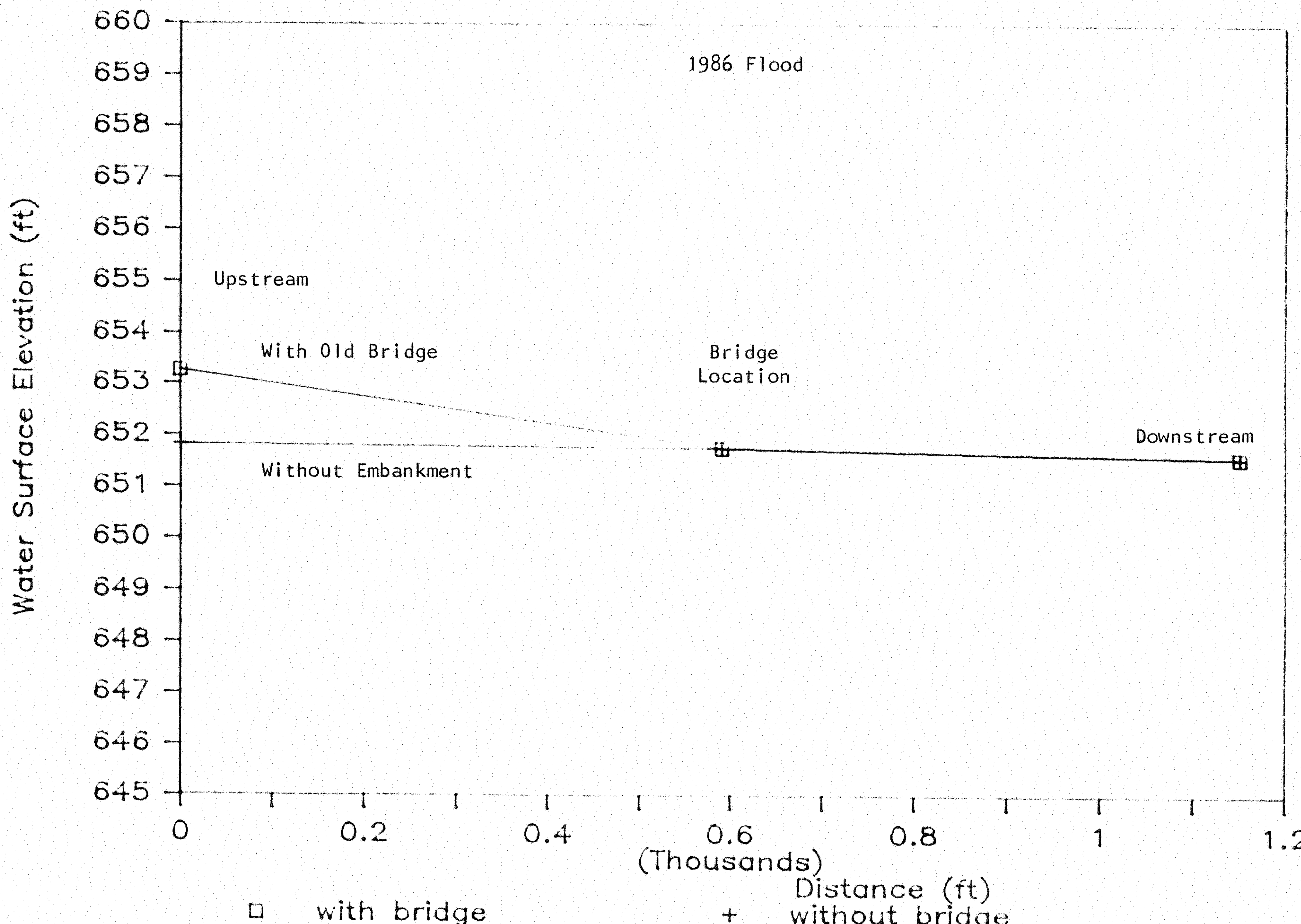

Figure 14. Profiles for 1986 Flood with Old Bridge and without Embankment (Cases II & III)

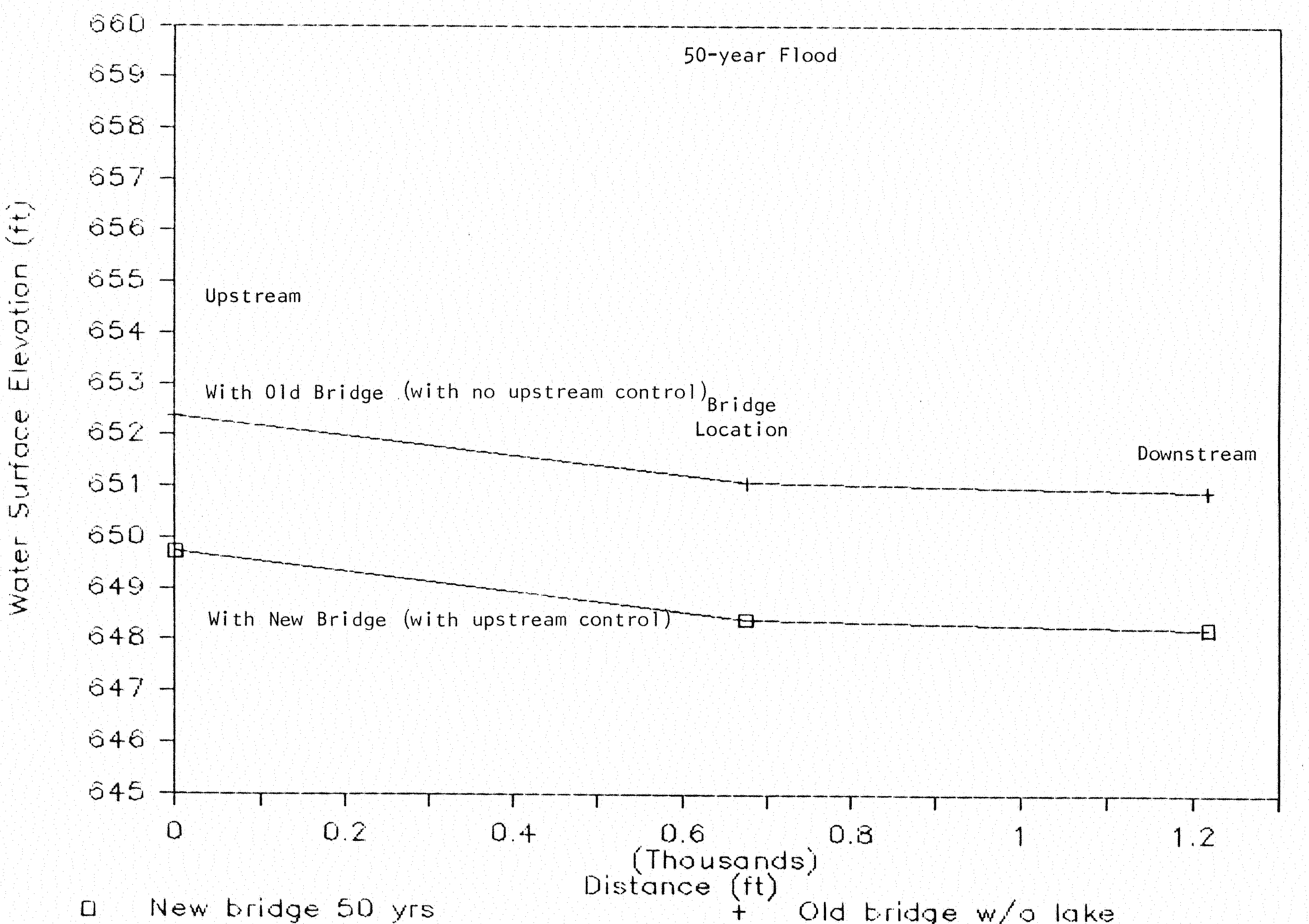

Figure 15. Profiles for 50-year Flood with New Bridge (with upstream control) and Old Bridge (with no upstream control) (Cases I & IV)

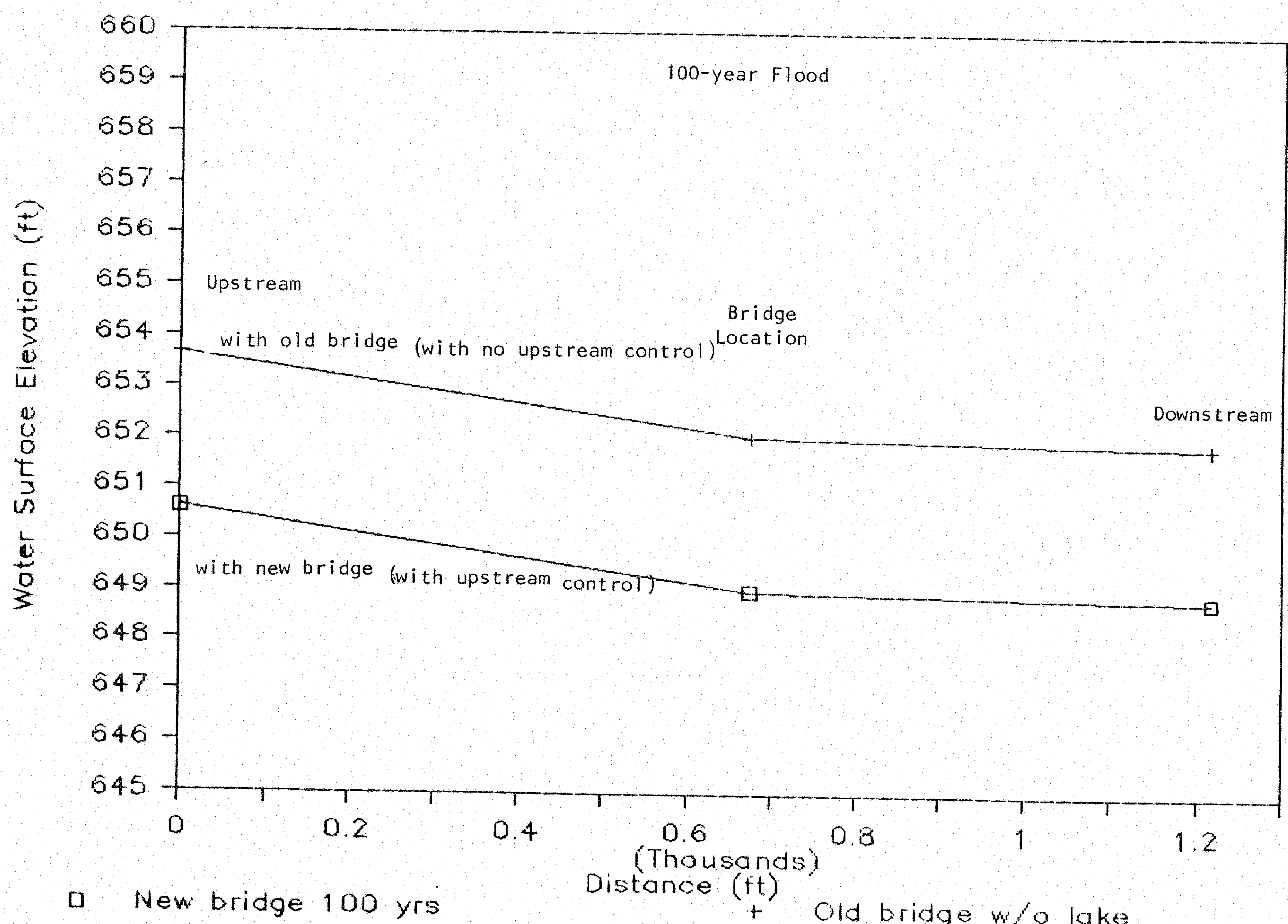

Figure 16. Profiles for 100-year Flood with New Bridge (with Upstream Control) and Old Bridge (with no Upstream Control) (Cases I & IV)

TABLE 9. COMPARISON OF VELOCITIES AND BACKWATER EFFECT BETWEEN OLD DESIGN AND NEW DESIGN

	Old Design	New Design
50-year flood discharge (Q_{50})	91,011 cfs	42,800 cfs
100-year flood discharge (Q_{100})	115,697 cfs	51,400 cfs
50-year velocity at Main Structure (V_{50})	6.16 fps	5.10 fps
50-year velocity at Overflow Structure 1 (V_{50})	5.63 fps	5.98 fps
50-year velocity at Overflow Structure 2 (V_{50})	5.43 fps	5.54 fps
100-year velocity at Main Structure (V_{100})	7.11 fps	5.82 fps
100-year velocity at Overflow Structure 1 (V_{100})	6.63 fps	6.85 fps
100-year velocity at Overflow Structure 2 (V_{100})	6.41 fps	6.37 fps
Backwater effect for 50-year flood	1.22 ft	1.28 ft
Backwater effect for 50-year flood	1.55 ft	1.56 ft

VI. CONCLUSIONS

The following conclusions are drawn based on this investigation.

1. The 1986 flood that occurred during September 29-October 4 was of about a 500-year frequency, an unusually high flood frequency.
2. A review of the Flood Insurance Study and the OSU Study reveals the magnitude of 50- 100-year floods. The magnitudes are 42,800 and 51,400 cubic feet per second.
3. Four hydraulic conditions were analyzed to determine the backwater effects due to the old and new bridges at U.S. 75.
4. A review of procedures and policies developed by the Federal Highway Administration (FHWA) and adopted by the Oklahoma Department of Transportation (ODOT) recommended that the bridge be designed for 50-year floods and checked for 100-year floods.
5. The backwater effect due to the new bridge is 1.28 and 1.56 ft. for 50-year and 100-year floods.
6. The backwater effect due to the old bridge is 0.54 and 0.63 feet for 50-year and 100-year floods.
7. The backwater effect due to the old bridge with Hulah and Copan Lakes, the condition present at the time of construction of the old bridge, is 1.23 and 1.55 feet for 50-year and 100-year floods.
8. The backwater effects in Conclusions 5, 6, and 7 are within 1-2 ft. and the velocity values in the range of 6-8 ft. per second.
9. The backwater effects due to the old and new bridges as well as the velocities of flow range are within criteria of bridge design adopted by ODOT as developed by FHWA.
10. A design frequency of 50-year and check frequency of 100-year floods is based on the cost effectiveness and the expected life of a reinforced concrete bridge (30-50 years).
11. If a bridge is designed for a frequency of more than 50-year and checked for 100-year floods, it would be a waste of the taxpayers money and public funds.
12. The siltation in the flood occurred on the upstream side in the flood plains of the new and old bridges. A limited loss of soil would occur within 150-180 feet upstream of the overflow structures. Slight damage would be experienced due to soil loss, depending on the right-of-way from U.S. 75. The scour due to high velocity on the downstream side is limited to the county roads and may damage them.
13. The backwater effect upstream of the exit section of the bridges is computed for 500-year flood or a discharge of 108,000 cfs. Using the WSPRO model, this effect due to new and old bridge options is determined extending to 5.55 and 3.66 miles upstream from U.S. 75.
14. Residents have built dikes along the Caney River in the flood plain of the main bridge. When the floodwater passes the main bridge, the dikes hold water on the resident's properties in the flood plain. It takes a long time to drain ponded water thru the overflow structures which have a limited capacity to discharge water, unlike the main bridge.
15. The concept of floodplain utilization is that it can be used for agriculture but is expected to flood at high frequency of floods such as 50-100-, and 500-year (the 1986 flood) frequencies. Obviously crop damages are expected to occur, but these are not caused by the construction of the new bridge and U.S. 75.

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