HYORAULIC ANALYSES OF WATER-SURFACE PROFILES IN THE VICINITY OF THE COAMO OAM ANO HIGHWAY 52 BRIOGE, SOUTHERN PUERTO RICO: FLOOO ANALYSES AS RELATEO TO THE FLOOD OF OCTOBER 7, 1985

By
Karl G. Johnson, Ferdinand Quiñones, and Ralph González

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DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

Chief, Caribbean District, WRD
U.S. Geological Survey
GPO Box 4424
San Juan, Puerto Rico 00936

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For the convenience of readers who may want to use the International Systems of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	by	To obtain SI units
inches (in)	25.4	millimeters (mm)
	2.54	centimeters (cm)
inches per day (in/d)	25.4	millimeters per day (mm/d)
	2.54	centimeters per day (cm/d)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
miles per hour (mi/hr)	1.609	kilometers per hour (km/hr)
miles per day (mi/d)	1.609	kilometers per day (km/d)
acres	4047.	square meters (m^2)
acre-feet (acre-ft)	1233.	cubic meters (m^3)
degrees Fahrenheit (°F)	0.56(°F-32)	degree Celsius (°C)

Specific Combinations

1 Acre-ft = 226.2 gal/min, during one day

1 ft^3/s = 448.8 gal/min

1 ft^3/s = 0.65 Mgal/d

TABLES

HYDRAULIC ANALYSES OF WATER-SURFACE PROFILES IN THE VICINITY OF THE COAMO DAM AND HIGHWAY 52 BRIDGE, SOUTHERN PUERTO RICO: FLOOD ANALYSES AS RELATED TO THE FLOOD OF OCTOBER 7, 1985

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ABSTRACT

The magnitude, frequency, and extent of the flood of October 7, 1985 at the Río Coamo in the vicinity of the Coamo Dam and Highway 52 bridge in southern Puerto Rico, were investigated. The observed flood profiles were used to calibrate a step-backwater model. The calibrated model was then used to investigate several alternative flow conditions in the vicinity of the bridge.

The peak discharge of the flood at the Highway 52 bridge was 72,000 cubic feet per second. This peak discharge was determined from the peak computed at a reach in the vicinity of the Baños de Coamo, about 1.2 miles upstream from the bridge. The computed discharge at the Baños de Coamo of 66,000 cubic feet per second was adjusted to the dam and bridge location by multiplying it by the ratio of the drainage areas raised to the 0.83 power. The flood had a recurrence interval of about 100 years, exceeding all previously known floods at the site.

The flood overtopped the spillway and levee of the Coamo Dam just upstream of Highway 52. The flow over the spillway was about 54,000 cubic feet per second. Flow over the levee was about 18,000 cubic feet per second. About 10,000 cubic feet per second of the flow over the levee returned to the main channel at the base of the embankment at the northeast approach to the bridge. The remaining 8,000 cubic feet per second flowed south through the underpass on Highway 153. The embankment and shoulder on the northern span of the bridge were eroded with the eventual collapse of the approach slab.

ABSTRACT–Continued

Computed profiles agree with the actual flood profile generally within 0.2 feet. Computed profiles for different flow alternatives showed the following differences relative to the 1985 flood profile:

1. Forcing the entire flood flow over the spillway (no flow over the levee) does not result in significant increases in the water-surface profile downstream from the dam. Velocities would increase about 1.5 feet per second at the bridge entrance section. Upstream from the dam, water-surface elevations would increase as much as 2.9 feet.

2. Removal of the obstructions over the spillway and forcing the entire flood flow over the spillway results in an increase in velocities of about 2.7 feet per second. Water-surface elevations upstream from the dam would increase as much as 2.6 feet.

3. Removal of the spillway, dam structures, and silt accumulated in the reservoir and forcing the entire flood flow through the main channel would result in an increase in velocity of about 2.7 feet per second near the bridge entrance. However, turbulent conditions with an undulating hydraulic jump would occur in a short reach upstream from the highway.

INTRODUCTION

Background

During October 6-7 1985, intense rains and severe flooding occurred throughout southern Puerto Rico. As much as 23 inches of rainfall were recorded during a 24-hour period east of Ponce. Rainfall probably exceeded 16 inches throughout most of the Río Coamo basin (fig. 1). Runoff in the Río Coamo peaked in the early hours of October 7, resulting in extensive flooding downstream from the town of Coamo toward the coast (fig. 2).

The flood waters in the Río Coamo eroded the eastern abutment of the northern span of the bridge on Highway 52 (Las Americas Expressway). The approach slab to the first span of the bridge collapsed into the floodwaters. An unknown number of vehicles moving west on the expressway fell into the stream, with a reported 29 casualties.

The damaged bridge is about 100 yards downstream from the Coamo Dam (fig. 3). The reservoir, constructed around 1910, is almost full of silt and sediments. The flood waters submerged the silted reservoir and overtopped the spillway and a levee to the east of the dam. Damage to the Highway 52 bridge abutment was caused by a combination of flow that overtopped the levee and moved westward (lateral to the embankment) back into the channel, and by direct flow from the spillway against the face of the bridge.

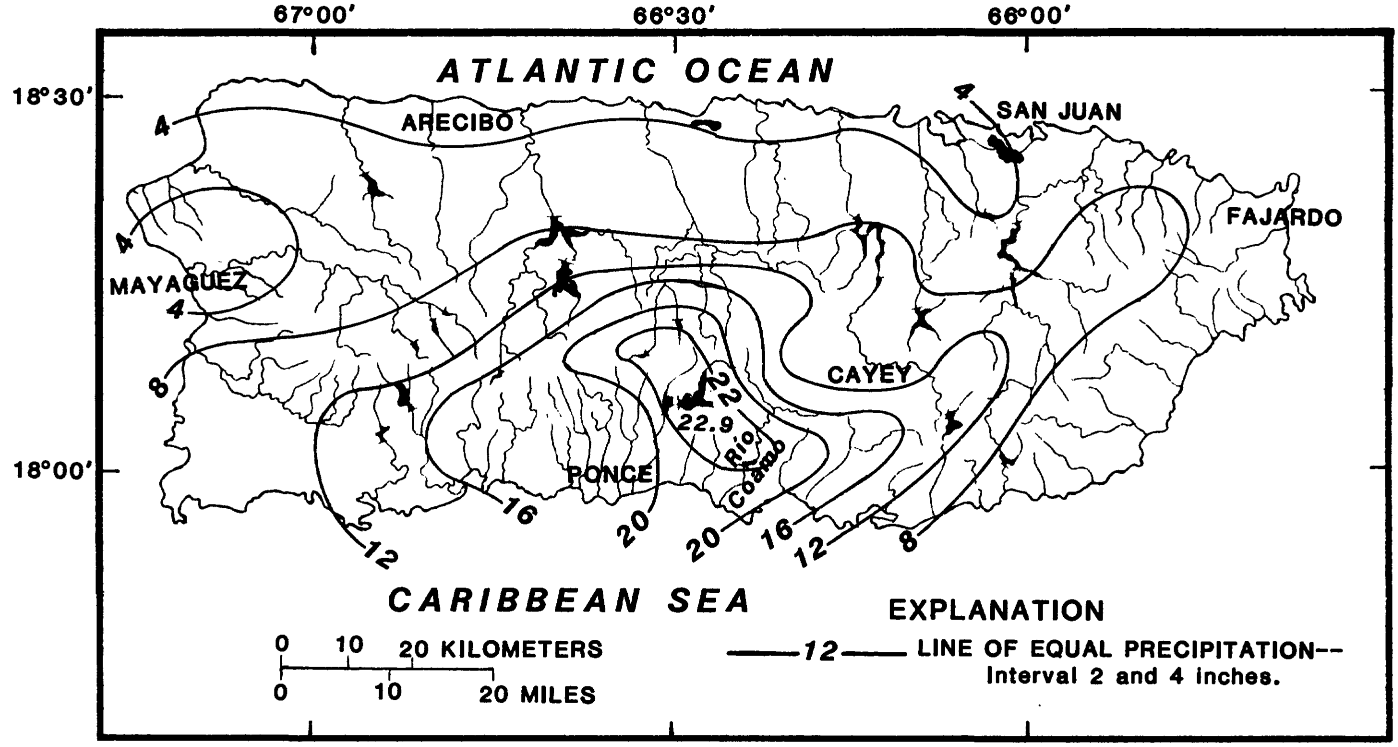


Figure 1.--Cumulative precipitation over Puerto Rico during October 6-7, 1985.

INTRODUCTION-Continued

Purpose and Scope

The U.S. Geological Survey, in cooperation with the Puerto Rico Highway Authority (PRHA) and the Puerto Rico Department of Natural Resources (PRDNR) conducted a comprehensive investigation of the flood event in the vicinity of the dam and bridge. This report describes the results of an investigation to:

1. define the magnitude and frequency of the flood,

2. define the flood profile through the reservoir, the dam, and the bridge, and

3. investigate alternative flow conditions with changes to the dam and structures in its vicinity.

The investigation included two reaches within the Río Coamo. The first reach, which is located about 1.2 miles upstream from the bridge and near the Baños de Coamo resort (fig. 3), was used to determine the peak discharge of the flood. This reach is about 2,000 feet in length; it was chosen because all of the water transported by the river at the peak of the flood was contained in the channel.

The second reach is about 9,000 feet in length and includes the area near the dam and the bridge at Highway 52. This reach was surveyed to determine the flood profile upstream and downstream from the bridge, and to define the flow components upstream from the bridge.

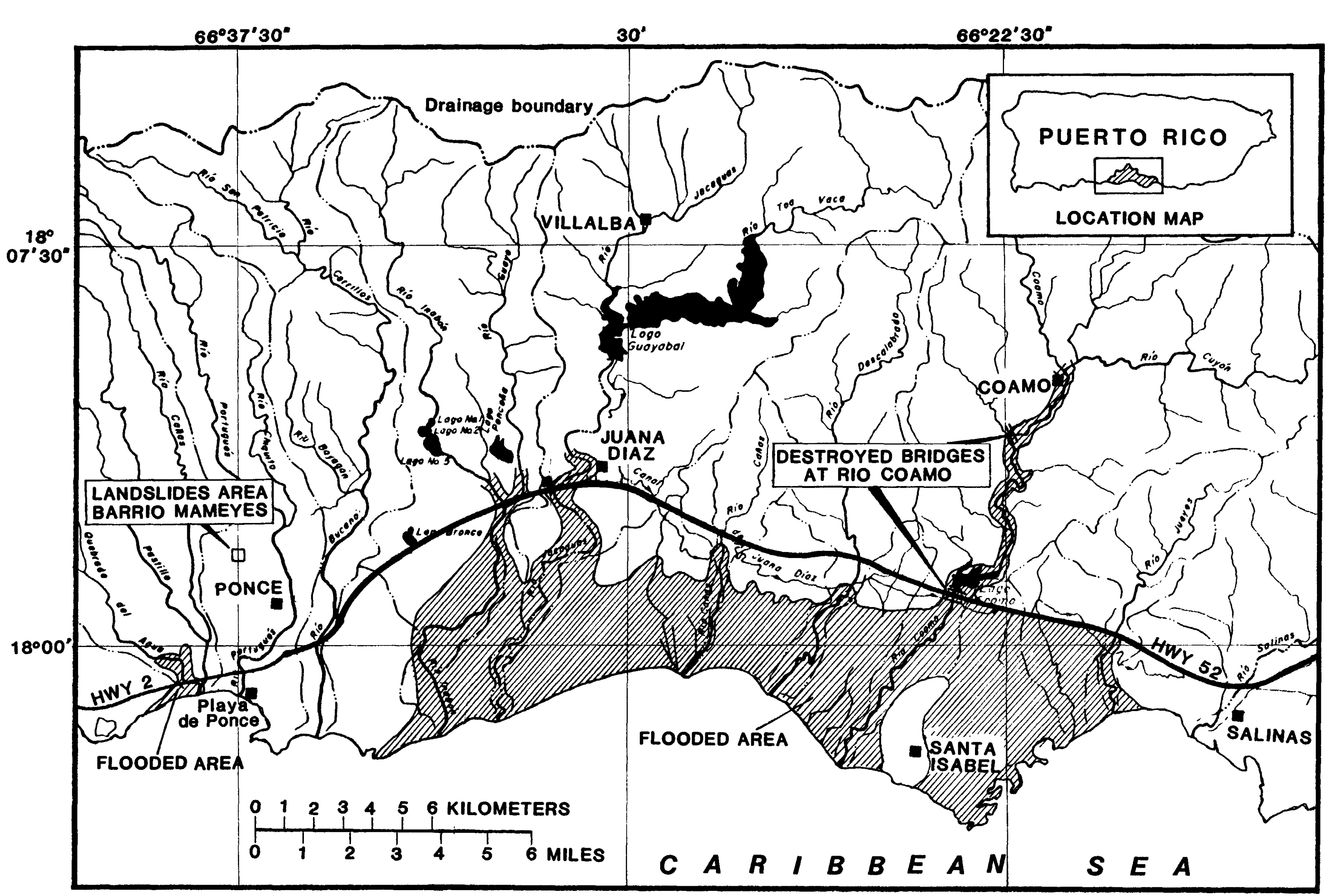
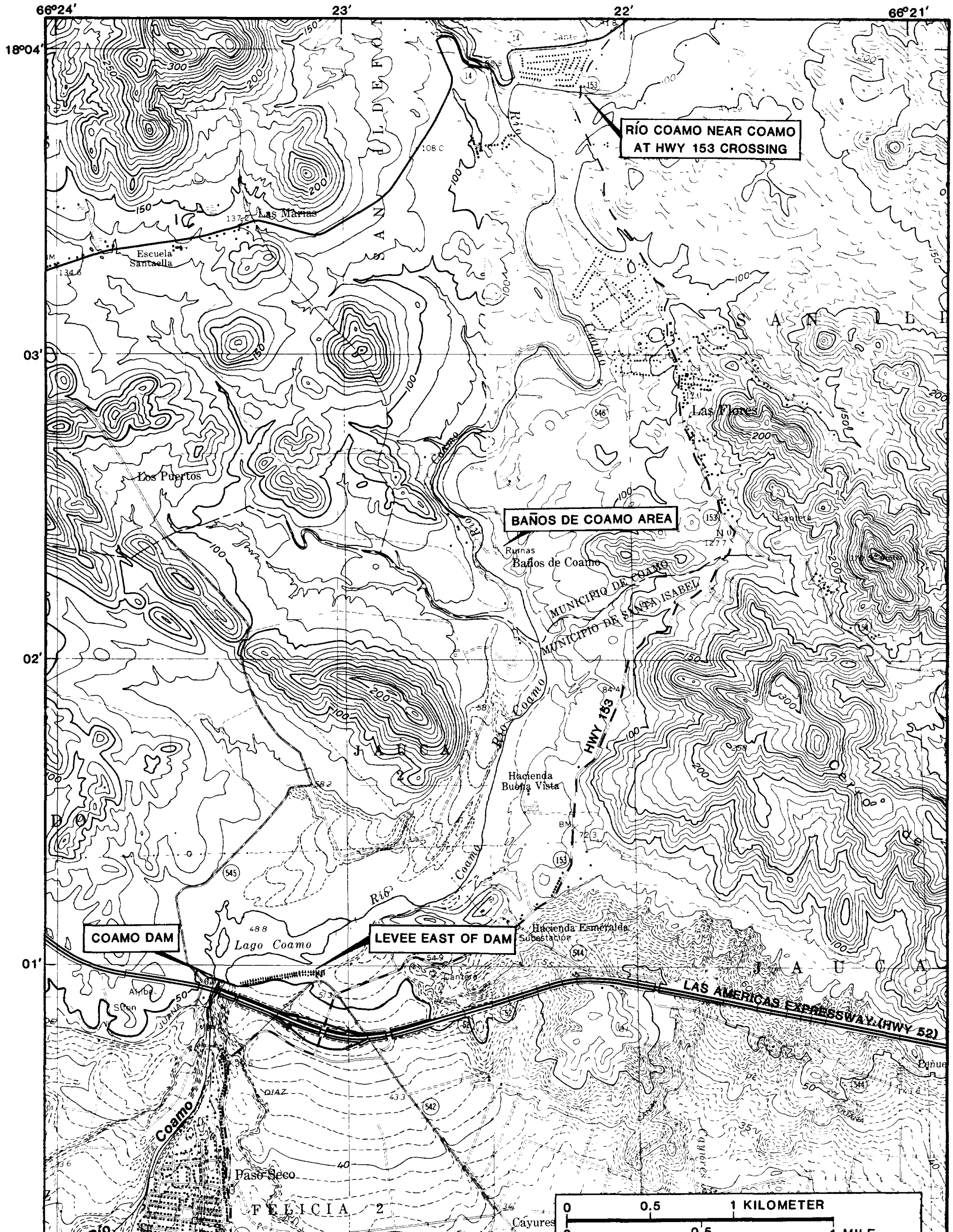


Figure 2.--Areas flooded in southern Puerto Rico during the October 7, 1985 flood.



Base from USGS topographic map, Coamo and Río Descalabrado, PR quads, 1972.

Figure 3.--Location of the Coamo Dam, Highway 52, Baños de Coamo, and vicinity.

METHOD OF STUDY

Field surveys of high-water marks were conducted by Survey personnel shortly after the flood. These surveys were conducted in accordance with procedures outlined by Benson and Dalrymple (1967). The surveys were used to determine the flood magnitude at the Baños de Coamo reach and the flood characteristics (elevation, profile, and extent) at the bridge area.

At the upstream reach (Baños de Coamo resort), the survey included the definition of six (6) cross-sections, high-water profiles, and the bottom profile of the channel. Roughness coefficient values (Manning's "n" values) for the reach were selected in the field by Survey personnel. The flood discharge was determined by several techniques to ascertain its accuracy. The slope-area method described by Dalrymple and Benson (1967) was used to compute the discharge. The step-backwater analysis technique described by Davidian's TWRI Book 3, Chapter 15 was then used to calibrate computed profile to the observed profile. Model simulations were performed by varying the discharge until the computed profile matched the observed profile. Computations of discharge from the slope-area technique closely approximated the final discharge selected through use of the step-backwater method.

The discharge determined at the Baños de Coamo reach was transposed to the Highway 52 bridge. The ratio of the drainage areas between the two points -- 58.8 mi^2 (square miles) at Baños de Coamo and 65.4 mi^2 at the Coamo damsite -- was used to estimate the peak flood discharge at the Highway 52 bridge. The ratio was raised to a power of 0.83 as derived from flood frequency analyses techniques described by López and Colón (1979). The discharge at the Highway 52 bridge also was computed by using the two-section slope area technique. The difference between the two methods (drainage area ratio and slope area) was less than 1.2 percent.

At the damsite and Highway 52 area, a 9,000 feet long reach was surveyed into two subreaches. High-water marks and cross-sections (19) were surveyed downstream and upstream from the dam structure. Details and elevations for the bridge, roadways, culverts, levee, and spillway were defined to local datums. These were later referenced to mean sea level elevations. The location of the cross-sections surveyed are shown in figure 4.

The field surveys and observations had indicated that at the peak of the flood, water had moved across the dam and bridge essentially as shown in figure 4. Most of the water flowed over the spillway (fig. 5) and directly under the bridge. Water overtopping the levee (fig. 6) to the east of the spillway split into two portions, with most of it flowing back toward the bridge along the expressway embankment. A portion of the water overtopping the levee flowed through the Highway 153 underpass to the Las Americas Expressway. A portion of this water flowed back into the channel within this study area while the rest flowed through different channels in the valley into the Caribbean Sea. A very small component, considered insignificant for this study, went through a culvert east of the underpass.

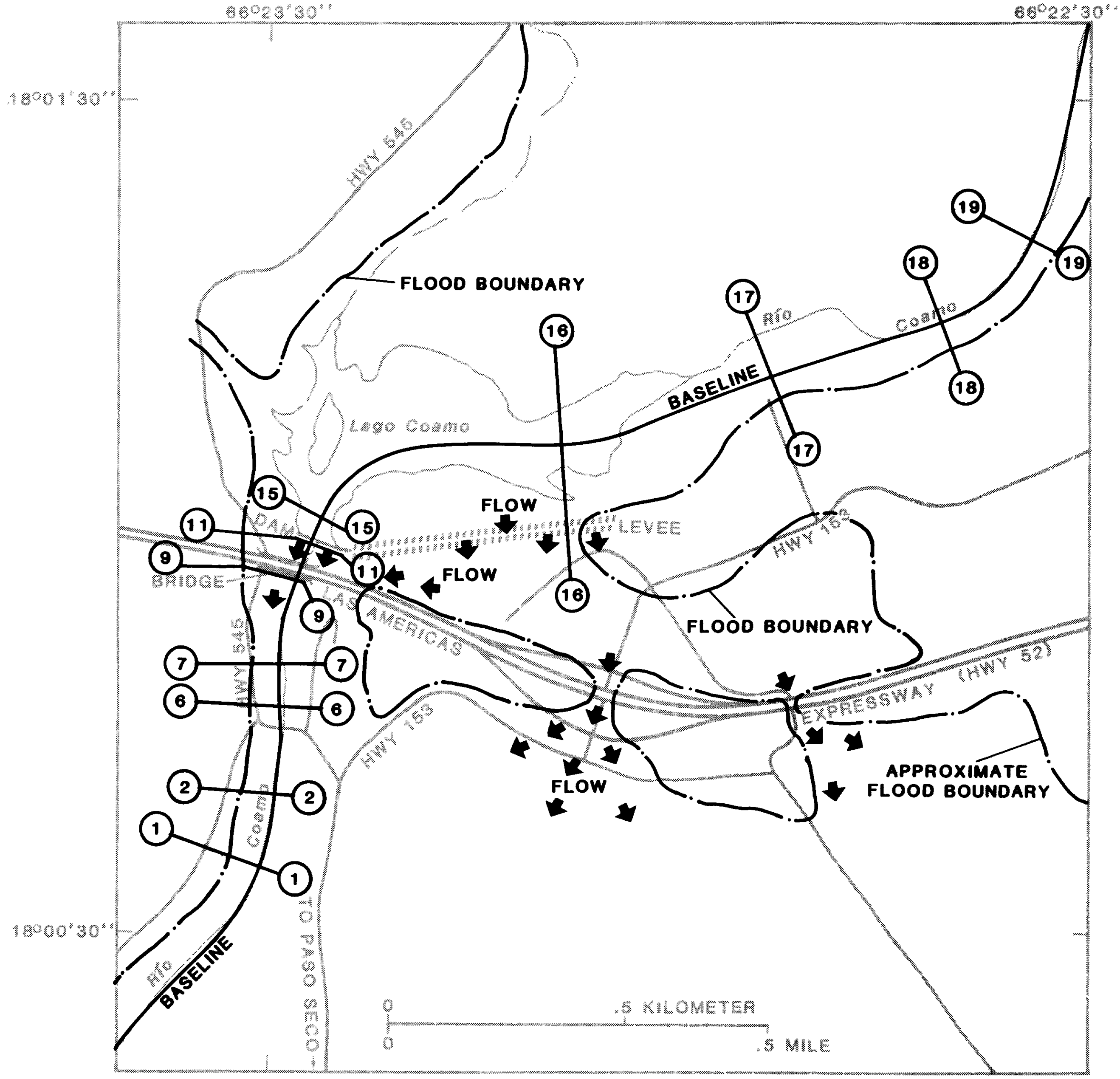


Figure 4.--Location of cross-sections surveyed in the vicinity of the Highway 52 bridge.

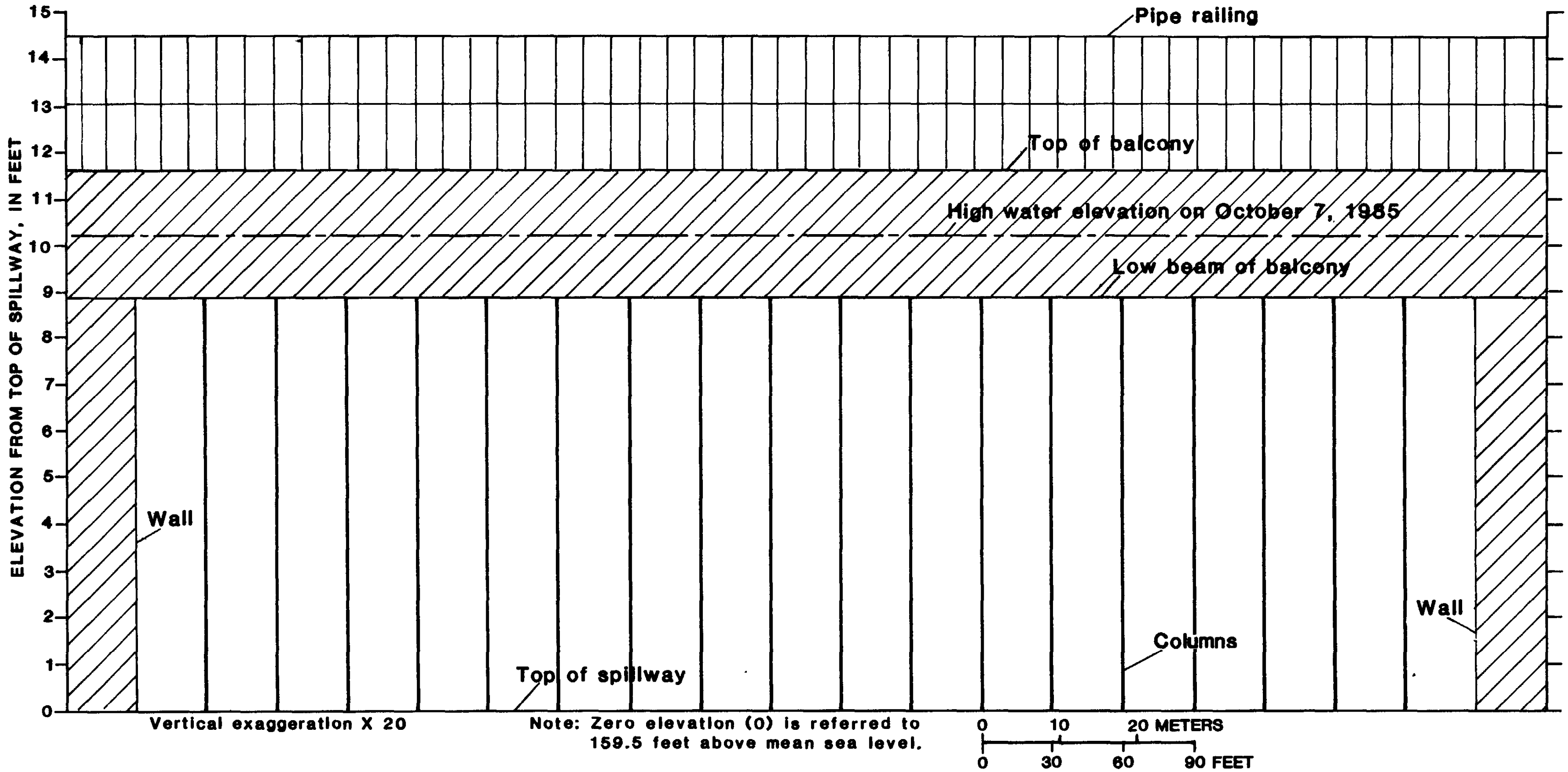


Figure 5.--Cross-section surveyed at the Coamo Dam showing elevation of the October 7, 1985 flood.

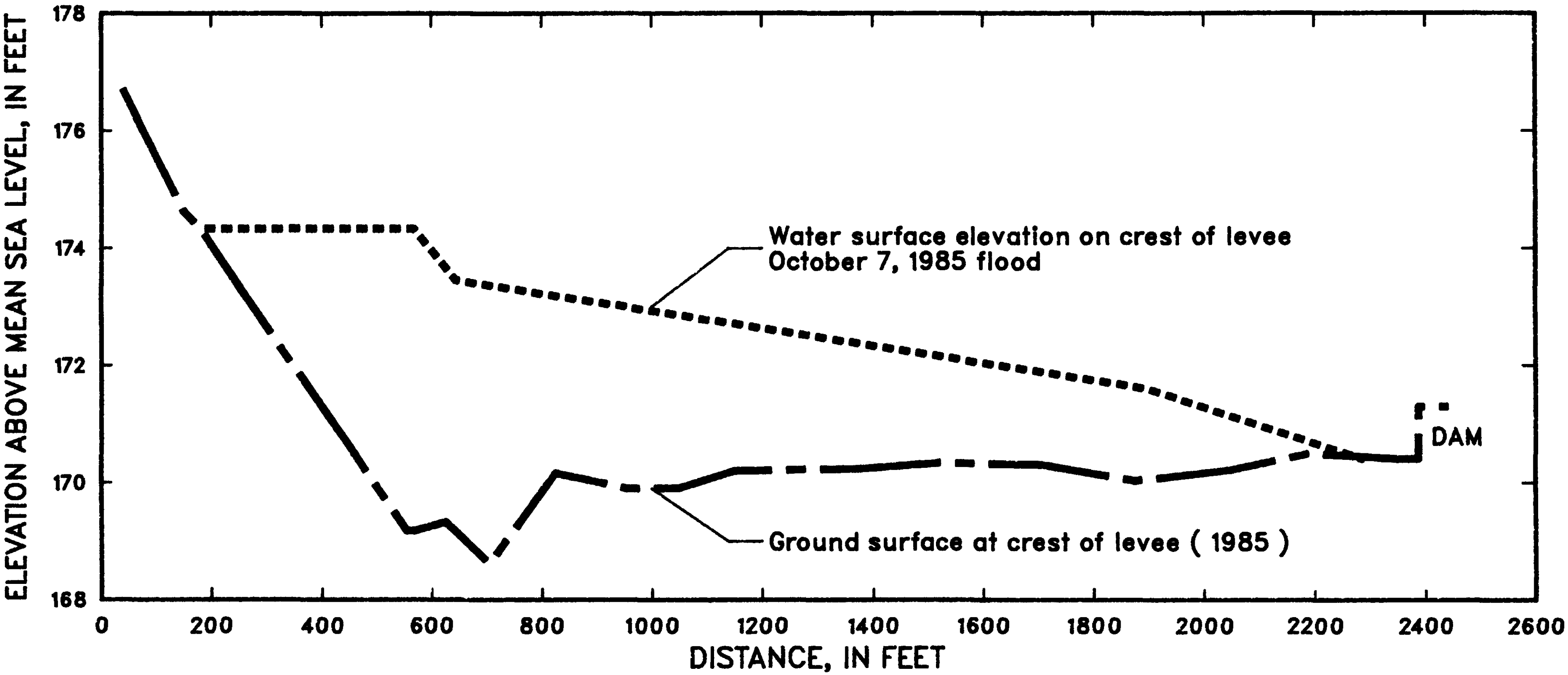


Figure 6.--Flood elevation over the levee east of the Coamo Dam.

The magnitude of each of the flow components was determined using several techniques. The flow over the spillway was computed from high-water marks applied as flow over a broad-crested weir (Matthai, 1967). The computation from the broad-crested weir formula was adjusted for the obstructions created by the balcony and walkway over the spillway and debris trapped on these structures during the flood. A factor of 0.83 was used for the adjustment as determined from the area of the obstructions (This factor is not to be confused with the drainage area ratio coefficient previously described for the total flow computation. Although equal in value, both factors have different meanings.). The flow over the levee was computed as the difference between the total flow and the flow over the spillway. Utilizing field high-water marks applied to the formula for "flow over road" (Hulsing, 1967), the "C" coefficient was "back-computed" and used for the distribution of the flow over the levee. The flow through the Highway 153 underpass was computed using elevations of high-water marks surveyed at the structure applied to the contracted-opening technique described by Mathai (1967). Flow west along the Expressway embankment was determined by the difference between flow over the levee and flow through the underpass. Indirect methods could not be applied to compute this flow independently because the original geometry of the embankment was not known and had changed drastically during the flood.

After determining each of the flow components in the vicinity of the bridge, the step-backwater model was calibrated using the observed profile. Each of the two subreaches was calibrated independently as flow over the dam was supercritical with a hydraulic jump. This prevented a continuous calibration of the entire 19-section reach. Adjustments in the field-estimated roughness coefficients were made at each reach until the computed and field profiles matched reasonably well. The calibrated model was then used to simulate several flow alternatives.

RESULTS OF HYDRAULIC ANALYSES

Peak Discharge at the Baños de Coamo Reach

The results of the computations of the peak discharge at the Baños de Coamo reach were as follows:

1. The slope-area computation utilizing five of the six surveyed cross sections resulted in a peak discharge of 67,000 cubic feet per second (ft^3/s).

2. The step-backwater analysis with initial discharges ranging from 64,000 to 70,000 ft^3/s resulted in a best fit between the observed and computed profiles at 66,000 ft^3/s.

The 66,000 ft^3/s value was assumed correct and used in the remaining computations.

RESULTS OF HYDRAULIC ANALYSES–Continued

Peak Discharge at the Coamo Dam and Highway 52 Bridge

The results of the computations of the peak discharge at the Coamo Dam and Highway 52 bridge were as follows:

1. The discharge in the vicinity of the Coamo Dam was computed from the relation:

Qds = Qus (Ads/Aus)**0.83,

where Qds and Ads are the discharge and drainage area at the Coamo damsite, Qus and Aus are the discharge and drainage area at the Baños de Coamo site, and 0.83 is the area-ratio coefficient. The computation resulted in a peak flood discharge of 72,100 ft^3/s.

2. The two-section slope-area computation that used sections 17 and 18 (fig. 4) resulted in a peak discharge of 71,500 ft^3/s. A value of 72,000 ft^3/s was assumed as representative of the peak discharge at the Coamo damsite.

Peak Discharge Over the Spillway at the Coamo Dam

The peak discharge over the spillway at the Coamo Dam was computed as 54,000 ft^3/s. In this computation the formula for a broad-crested weir:

Q = C L H**3/2

was used. The discharge coefficient, C, was estimated from the hydraulic characteristics of the spillway and the flat part of the crest. A value of 3.04 was used. The weir length, L, was determined from the field survey as 570 feet. The total head, H, was computed from the relation:

H = h + hv,

where h = the elevation of the water above the crest of the spillway at a distance upstream that was outside the zone of drawdown, computed as 10.2 feet.

hv = velocity head, estimated as about 0.8 ft from the step-backwater computations. The computed discharge from the above formula was adjusted by a coefficient of 0.83 to correct for area reductions from the obstructions over the spillway.

Peak Discharge Flowing Over the Levee, East of the Coamo Dam

The flow over the levee (total flow including water through the Highway 153 underpass and water flowing toward the Highway 52 bridge) was computed as the difference between the total peak flood discharge (72,000 ft^3/s) and the flow over the spillway (54,000), or 18,000 ft^3/s. This discharge was then used to "back-compute" a discharge coefficient (C) for the "flow over road" formula

Q = C B h**3/2 ,

where the h value, which ranged from 1.15 to 3.40, was variable on the basis of the head over the levee. The segment of the levee over which water flowed had a weir length (B) of 1,967 feet. The computed discharge coefficient (C=2.24) was used to distribute the flow across the levee to check the flow computations. Water flowing over the levee travelled toward the Highway 153 underpass and west along the expressway embankment.

Peak Discharge Through the Highway 153 Underpass

The peak flow through the Highway 153 underpass was computed from the contracted-opening formula. High-water marks through the underpass and at the approach section generally were satisfactory and the contraction resulted in a fall through the opening of about 2.0 feet. The computation resulted in a peak flow of 8,000 ft^3/s. This water moved through the underpass south toward the Paso Seco community resulting in flooding east of the river channel downstream from the bridge.

Peak Discharge Flowing Parallel to the Expressway toward the Bridge Abutment

The flow component moving toward the Highway 52 bridge parallel to the Expressway embankment was determined by difference. The changes in the embankment caused by erosion prevented a direct and independent computation of this flow component. This flow was computed as about 10,000 ft^3/s.

It is important to emphasize that this water flowed back into the main channel of the Río Coamo at the Highway 52 bridge opening. High-water marks surveyed along the embankment, show a significant fall indicating that this flow along the embankment had relatively high velocity, thereby contributing to the erosion and damages to the bridge approach.

Summary of the Flow Distribution at the Peak of the Flood

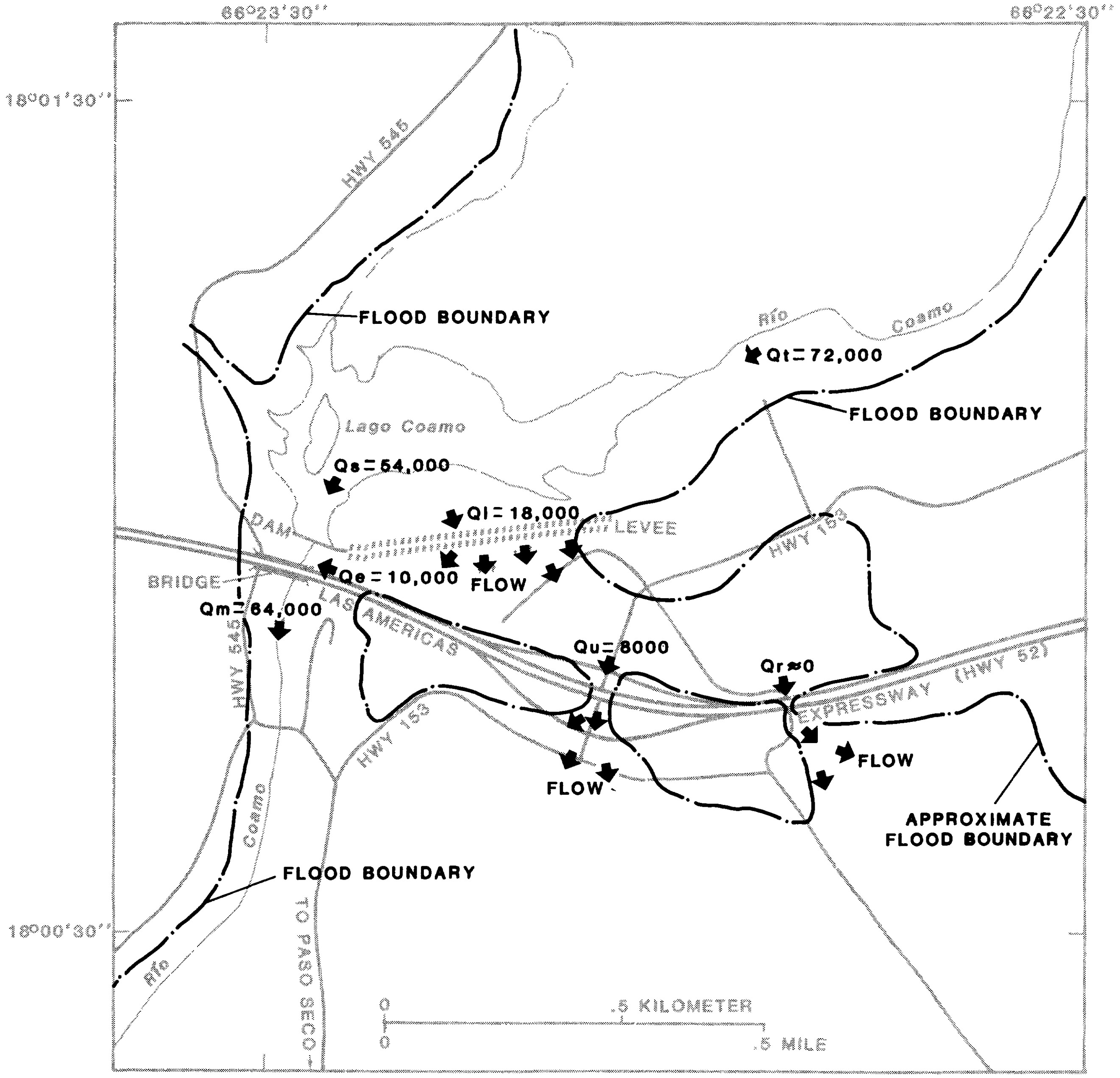
The distribution of the flow components at the peak of the flood is summarized in figure 7. The computed discharge of 72,000 ft^3/s entering the upstream reach at the damsite is labeled as Q_t. The flow of 64,000 ft^3/s in the main channel at the bridge computed as the sum of the flow over the spillway and the flow along the embankment is labeled as Qm. The other components were as follows:

Qs (flow over spillway) = 54,000 ft^3/s
Ql (flow over levee) = 18,000 ft^3/s
Qu (flow through underpass) = 8,000 ft^3/s
Qe (flow along embankment) = 10,000 ft^3/s

FLOOD FREQUENCY

The determination of the frequency of occurrence of a flood event requires data about historical flood events. Such information for the Highway 52 bridge site is limited. A hydrologic atlas prepared by the Survey in 1970 for the lower portion of the Río Coamo does not include the dam and bridge area (Haire, 1970). A flood frequency analysis was prepared by the Survey for the Federal Emergency Management Administration (FEMA) in March, 1983 (fig. 8). The analysis was based on techniques to estimate the magnitude and frequency of floods in Puerto Rico at ungaged sites (López and Colón, 1979).

By using data from the FEMA report (1983), the frequency of the October 1985 flood was estimated at about 100 years. However, a comparison of the flood profiles from the FEMA report 100-year flood and the October 1985 flood reveals significant differences in elevation (fig. 9). The differences are probably due to the following factors:



EXPLANATION

DISCHARGE IN CUBIC FEET PER SECOND

- Qt TOTAL DISCHARGE
- Qs DISCHARGE OVER SPILLWAY
- Ql DISCHARGE OVER LEVEE
- Qe DISCHARGE TOWARD BRIDGE
- Qm DISCHARGE AT MAIN CHANNEL
- Qu DISCHARGE AT HWY 153 UNDERPASS
- Qr RESIDUAL Q≈0

Figure 7.--Magnitude of flow components at the Río Coamo in the vicinity of the Highway 52 bridge during the October 7, 1985 flood.

FLOOD FREQUENCY-Continued

1. Changes in the geometry of the cross sections used in both analyses. Significant vertical and horizontal scouring of the flood channel was evident after the 1985 flood.

2. In the FEMA analyses, the peak flood was routed entirely through the main channel. During the 1985 flood, about 8,000 ft^3/s flowed through the Highway 153 underpass. A portion of this flow returned to the main channel, but an unknown amount flowed toward the Paso Seco Community.

3. An access bridge to the Coamo Dam on Highway 545 under the Expressway and in the vicinity of cross section 6 was destroyed by the flood of October 1985. The bridge was in place for the FEMA flood analyses, probably resulting in higher elevations in its vicinity for that study.

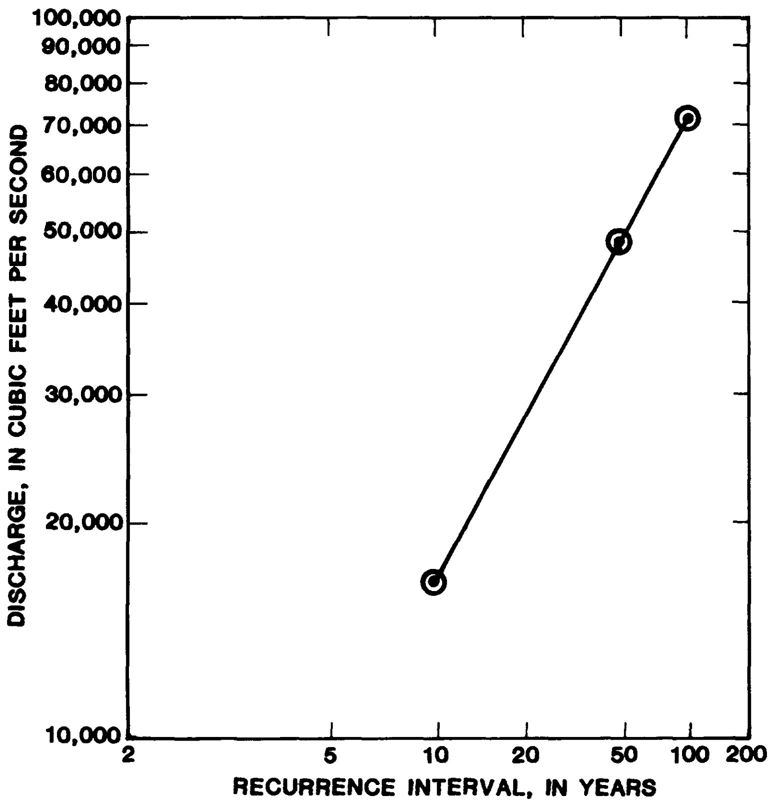


Figure 8.--Frequency curve for the Río Coamo at study site.

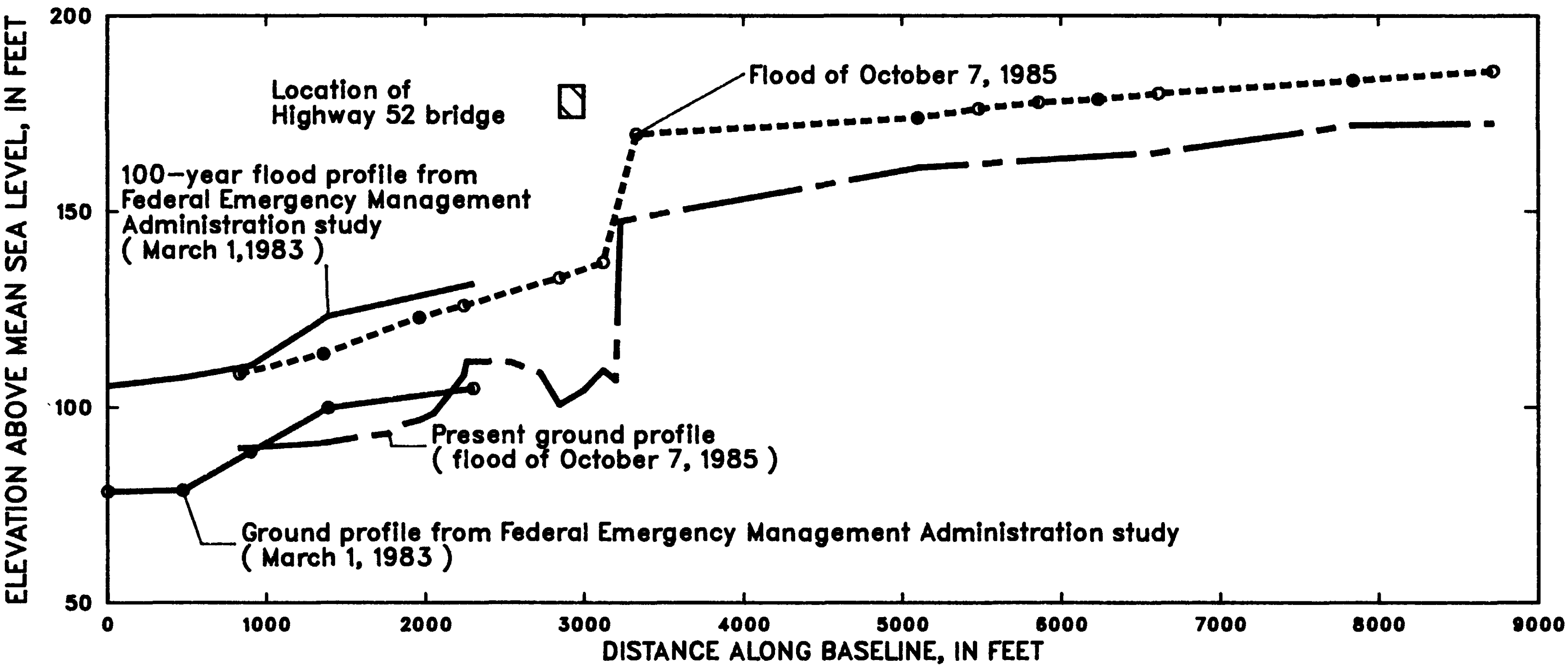


Figure 9.--100-year flood profiles at the Rio Coamo based on Federal Emergency Management Administration study and the October 7, 1985 flood.

PROFILE COMPUTATIONS

Calibration of Step-backwater Model

Shearman (1976) describes U.S. Geological Survey Program E431 which is a step-backwater model for subcritical flow. Some critical and supercritical flows do occur in the vicinity of the dam and the bridge. Therefore, U.S. Geological Survey Program J635, which is a modified version of E431, was used in this study because J635 has capabilities for analyzing critical and/or supercritical flow conditions (J.O. Shearman, written commun., U.S. Geological Survey).

The U.S. Geological Survey computer program J635 was calibrated using the October 1985 flood profile. The model performs step-backwater analyses using a specified discharge, cross-section geometry and roughness factors to compute water-surface elevations.

The peak discharge of 72,000 ft^3/s was used to calibrate the model with the cross sections indicated in figure 4. The calibration achieved is shown in figure 10.

In general, the computed profile matched the October 1985 flood profile within 0.2 feet. The only subreach where a significant departure occurred (about 3.2 feet) between the computed and field-surveyed profiles was in the vicinity of section 6. In this section, high-water marks were scarce. Additionally, this is the area where the Highway 545 bridge was destroyed, probably affecting the observed flood profile.

Simulation of Flow Alternatives in the Vicinity of the Coamo Dam and Highway 52 Bridge

The following alternatives to flood flows through the Coamo Dam and Highway 52 bridge were tested with the calibrated model:

1. The total discharge for the October 7, 1985 flood (72,000 ft^3/s) was routed through the spillway and any flow over the levee east of the spillway was eliminated. For this simulation, the flow was forced over the spillway with the spillway obstructions that existed during the October 1985 flood (balconies, walkway, and debris). The levee was artificially "raised" to prevent overtopping.

The resulting profile from this simulation is shown in figure 11. The profile downstream from the dam did not increase significantly. Upstream from the dam, backwater effects resulted in a maximum increase in the water elevation of about 2.9 feet at section 16. The computed profile converges on the observed profile with no significant difference near section 19. At the upstream face of the dam (section 15) this computed profile is about 2.5 feet higher than the 1985 flood.

Velocities upstream from the dam did not change significantly with the increased water-surface elevations. At section 16, the computed velocity for this alternative was about 3.7 feet per second (ft/s), compared with a computed velocity of about 3.8 ft/s for the October 1985 flood. At section 15, a similar comparison reveals computed velocities of 6.7 and 6.6 ft/s. Downstream from the dam, at the bridge entrance (section 9) the computed velocity was 18.2 ft/s compared with a computed velocity of 16.7 ft/s for the October 1985 flood.

Velocities and elevations for the simulated profile with the discharge of 72,000 ft^3/s at all cross-sections surveyed are summarized in tables 1 and 2. A comparison of the water-surface elevation at a cross-section in the vicinity of the bridge entrance is shown in figure 12.

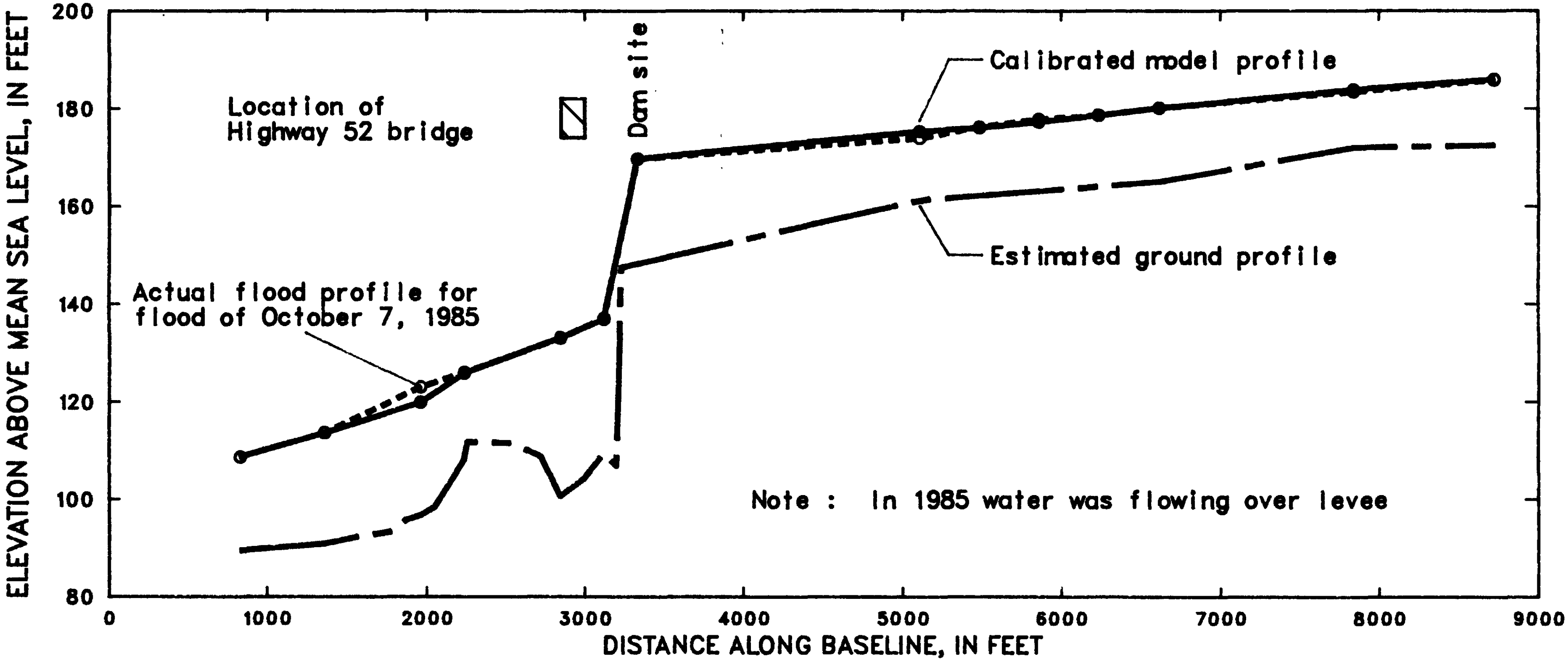


Figure 10.--Computed and actual flood profile for the October 7, 1985 flood at the Rio Coamo.

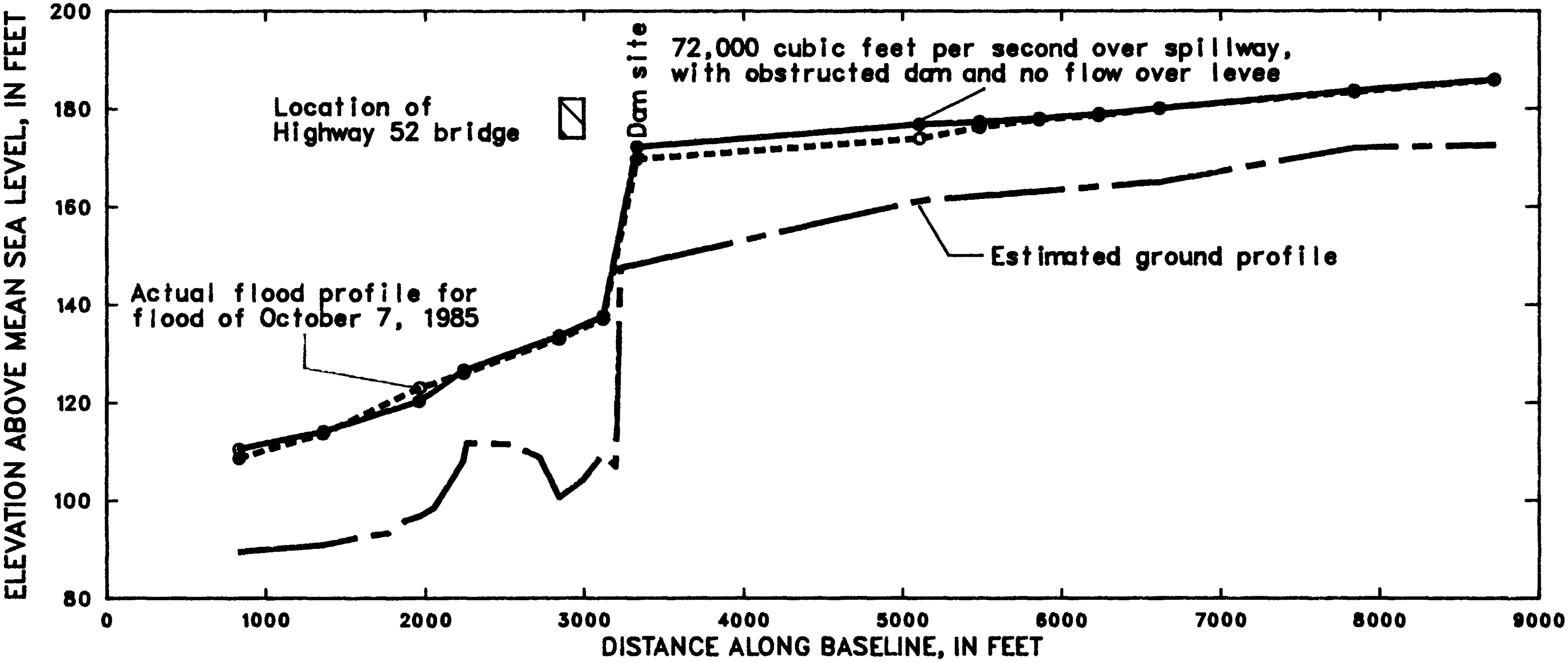


Figure 11.--Comparison of actual flood profile with flood profile at the Rio Coamo for simulated flow of 72,000 cubic feet per second with obstruction on the spillway and no flow over levee.

Table 1. Summary of estimated velocities for different conditions in the vicinity of the Coamo Dam and Highway 52 bridge

[Abbreviation: ft/s = feet per second]

Cross-section	VELOCITY, IN FEET PER SECOND			
	Computed flood profile (ft/s)	Condition 1 (ft/s)	Condition 2 (ft/s)	Condition 3 (ft/s)
1	14.08	12.93	12.93	12.93
2	15.63	16.22	16.22	16.22
6	14.21	14.99	14.99	14.99
7	18.73	19.30	19.30	19.30
9	16.73	18.25	18.25	18.25
11	9.77	12.49	12.49	12.49
15	6.63	6.71	7.98	---
16	3.76	3.70	3.79	11.76
17	5.40	5.42	5.32	10.73
18	5.02	5.10	5.09	5.46
19	4.50	4.54	4.54	3.64

Notes:

Condition 1 - Forcing 72,000 ft^3/s over obstructed spillway, no flow over levee.

Condition 2 - Forcing 72,000 ft^3/s over unobstructed spillway, no flow over levee.

Condition 3 - Forcing 72,000 ft^3/s on main channel, removing dam and silt, no flow over levee.

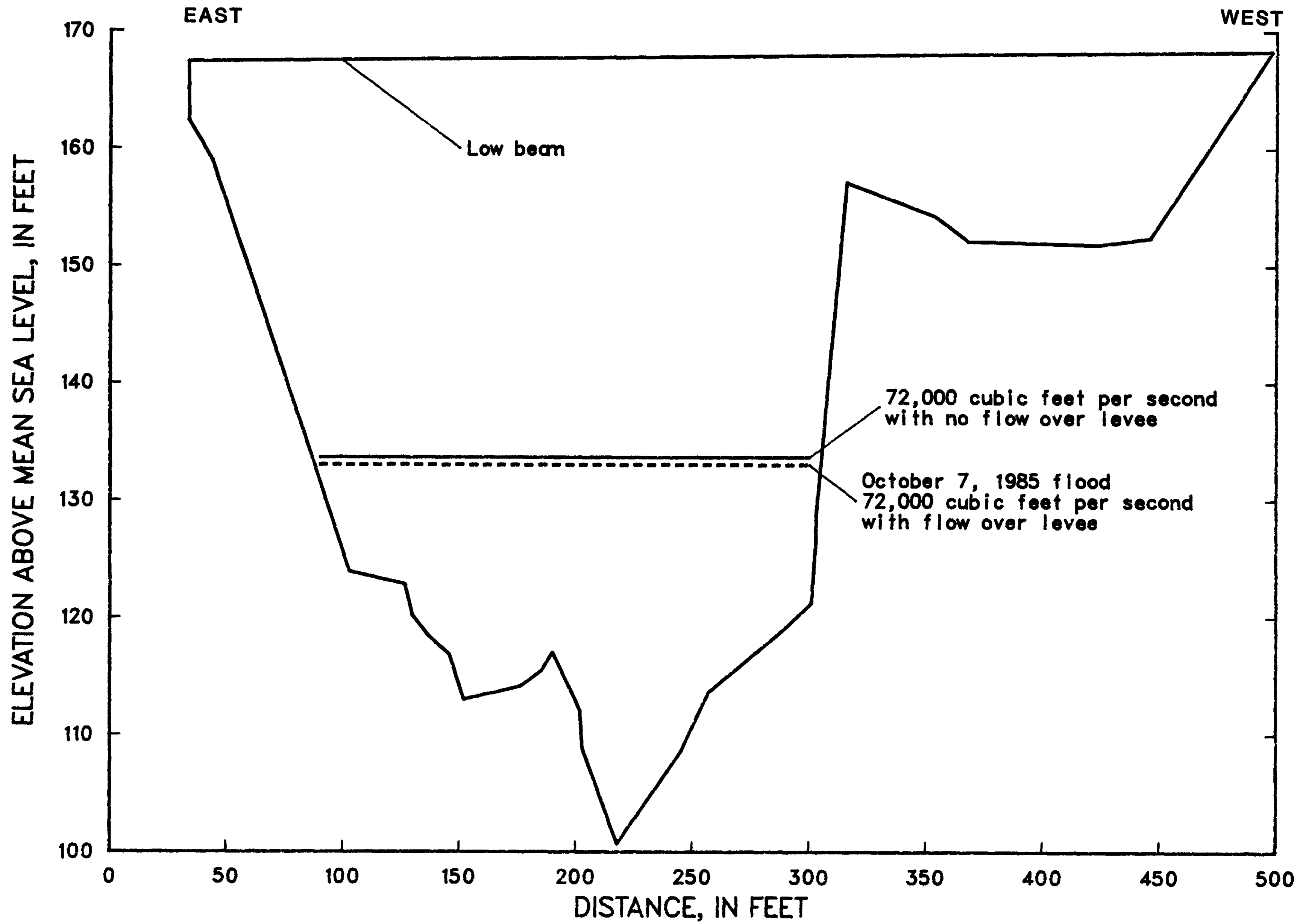


Figure 12.--Flood elevation in the vicinity of the Highway 52 bridge entrance (section 9).

Table 2. Comparison of water-surface elevations in the vicinity of the Coamo Dam for simulations routing the peak flow of October 7, 1985

[Abbreviation: ft = feet]

Cross-section	ELEVATION OF WATER SURFACE, IN FEET ABOVE MEAN SEA LEVEL				
	During flood * (ft)	a/ Computed flood profile (ft)	b/ Condition 1 ** (ft)	c/ Condition 2 ** (ft)	d/ Condition 3 ** (ft)
1	No high-water marks	108.6	110.5	110.5	110.5
2	"	113.6	114.1	114.1	114.1
6	123.0	119.8	120.3	120.3	120.3
7	126.0	125.8	126.6	126.6	126.6
9	133.0	133.1	133.6	133.6	133.6
11	137.0	136.8	137.6	137.6	137.6
15	169.7	169.7	172.2	170.6	(136.2)
16	173.9	175.3	176.8	176.5	151.2
17	180.1	180.1	180.1	180.1	160.0
18	183.4	183.8	183.7	183.7	168.6
19	185.8	186.0	185.9	185.9	170.4

Remarks:

* Actual flood elevations
** Simulation with no flow over levee.

a/ for figure 10
b/ for figure 11
c/ for figure 13
d/ for figure 14
( ) estimated value

PROFILE COMPUTATIONS-Continued

Simulation of flow Alternatives in the Vicinity of the Coamo Dam and Highway 52 Bridge-Continued

2. The second alternative assumed a flow of 72,000 ft^3/s over the spillway with the elimination of any spillway obstructions (balcony, walkway, and debris). In this simulation, flow was again routed over the spillway by "raising" the levee to prevent overtopping.

Downstream from the dam, there were only minor increases in the profile as a result of this simulation. This was logical because the downstream reach for this alternative represents the same condition as in the previous alternative, where the entire flood flow was forced through the bridge.

Upstream from the dam, the elimination of the spillway obstructions resulted in an increase of about 2.6 feet in water-surface elevation at section 16 when compared to the actual flood profile (fig. 13). The computed velocity at section 16 was about 3.8 ft/s, or about the same as the computed 1985 flood velocity. At the approach section to the dam (section 15), prior to the hydraulic jump, the computed velocity was about 8.0 ft/s.

3. Total removal of the dam structures, including the spillway, anchors, and abutments, with the total flow of 72,000 ft/s routed through the bridge and no flow over the levee. For this simulation, all the sediment accumulated in the reservoir was "removed".

For the "removal" of the sediment accumulated behind the dam, data from a capacity study conducted in 1941 by the Puerto Rico Water Resources Authority was used. The original topography upstream from the dam was reconstructed from the historical data and a section survey dated 1910. Cross-sections upstream from the dam were synthesized to represent conditions that would occur if the dam were not in place. The synthesis assumes that all the sediment deposited behind the dam would be removed. These modified cross-sections were used in the simulation.

Removal of the dam structures did not result in significant increase in the water-surface elevations downstream from the bridge (fig. 13). The velocity at section 9 (representing velocities in the vicinity of the entrance to the southern bridge span) was about 18.2 ft/s. This is the same velocity computed for the prior alternatives.

Upstream from the current location of the dam structures, the flood profile and velocities changed significantly with the removal of the dam (fig. 14). The water-surface elevation at section 16 declined about 22 feet. In the vicinity of the current location of the dam (section 15), the flood profile would decline about 34 feet. Velocities upstream from the dam would increase significantly. At section 16, the computed velocity would increase from 3.8 ft/s to about 12 ft/s.

The simulation with the dam removal indicates that a hydraulic jump would still occur between the current dam location and the bridge entrance. The profile in this vicinity consists of standing waves and undular hydraulic jumps.

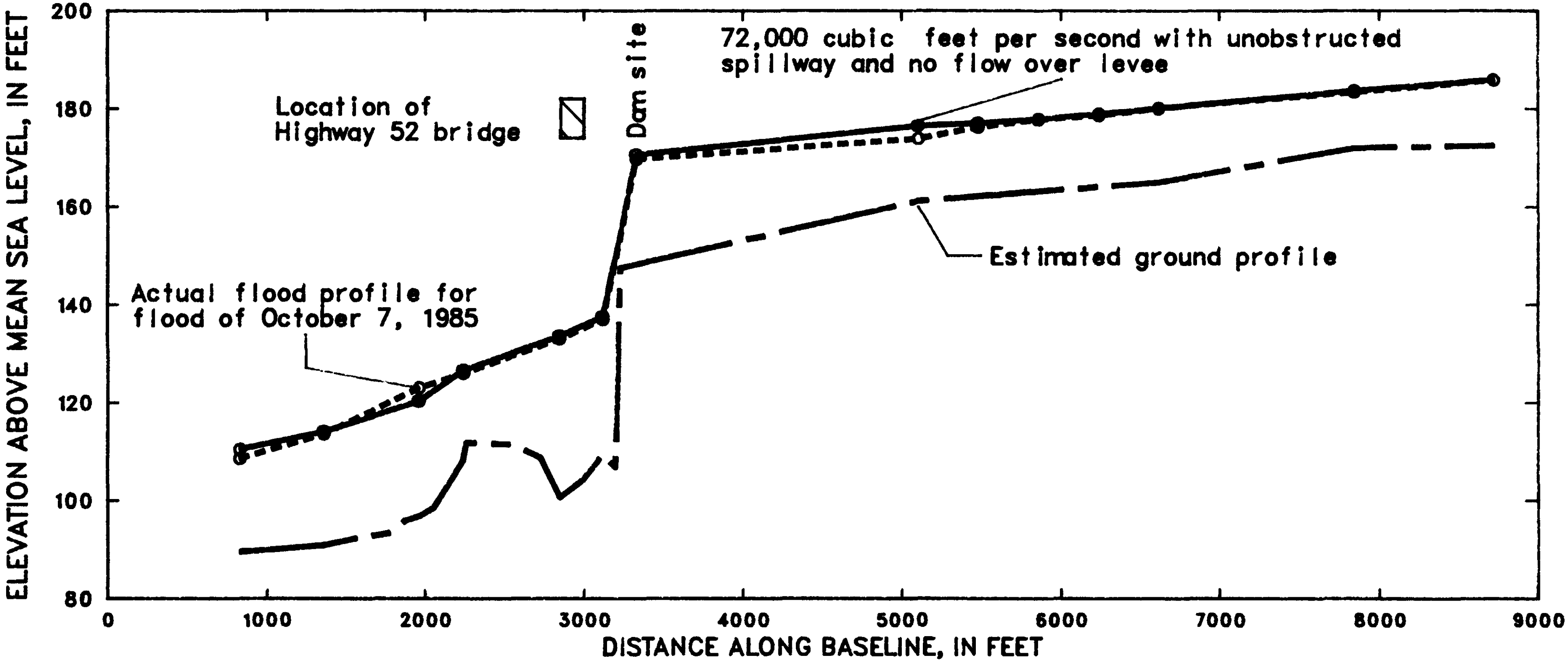


Figure 13.--Comparison of actual flood profile with flood profile at the Rio Coamo for simulated flow of 72,000 cubic feet per second over unobstructed Coamo Dam spillway and no flow over levee.

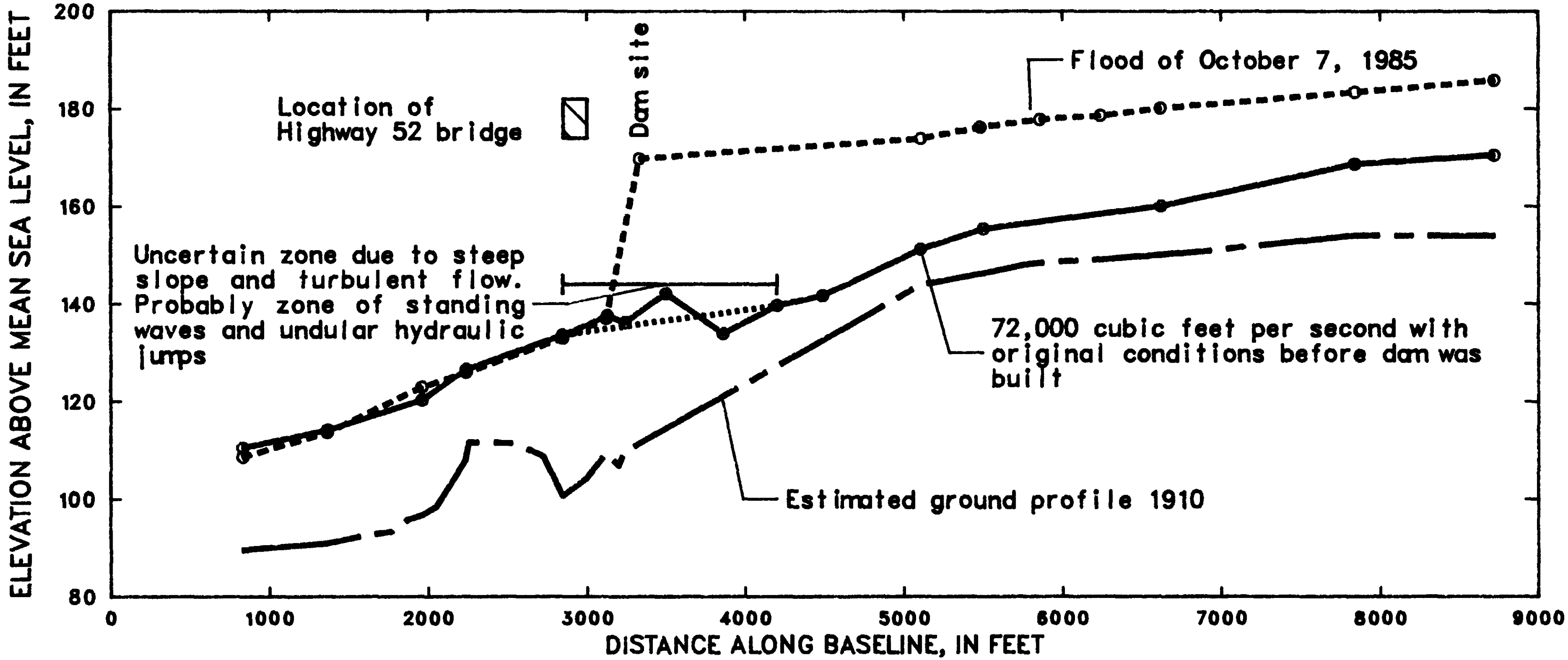


Figure 14.--Flood profiles at the Rio Coamo for simulated flow of 72,000 cubic feet per second with removal of the dam structures and sediment behind the dam.

CONCLUSIONS

The investigation of the flood of October 7, 1985, in the vicinity of the Coamo Dam and the Highway 52 (Las Americas Expressway) bridge indicated that:

1. The peak discharge of the flood was about 72,000 ft^3/s. At the Baños de Coamo area the flood discharge was about 66,000 ft^3/s.

2. The flood had a recurrence interval of 100 years as indicated from previous investigations conducted in the area.

3. Analyses of the flow distribution through the dam and vicinity showed that at the peak of the flood:

a. About 54,000 ft^3/s flowed over the spillway.

b. About 18,000 ft^3/s flowed over the levee to the east of the spillway.

c. About 10,000 ft^3/s of the 18,000 ft^3/s that flowed over the levee returned to the main channnel upstream from the bridge along the expressway embankment.

d. The remaining 8,000 ft^3/s of the flow over the levee flowed through the Highway 153 underpass south toward the sea. Some of this flow eventually returned to the main channel downstream from the study area.

4. The flood profiles in the vicinity of the dam and bridge were used to calibrate a step-backwater model to compute water-surface elevations in a reach upstream and downstream from the dam and bridge. A satisfactory calibration between the field and computed profiles was achieved.

5. The calibrated model was used to simulate different alternatives for flood flows of similar magnitude to the October 7, 1985 flood. The simulations showed that:

a. There were no significant changes in head or velocity downstream from the dam between the different alternatives simulated and the actual flood conditions (Table 2). Even routing the entire peak flow of 72,000 ft^3/s over the spillway and toward the bridge resulted in a maximum change in velocity of about 1.5 ft/s at the bridge entrance section. This is explained from the fact that only the 8,000 ft^3/s that flows through the Highway 153 underpass would be added to the main channel flow.

b. Upstream from the dam, the simulations involving routing of the peak flood flow over the spillway resulted in a maximum backwater effect of about 2.9 feet. The velocity upstream from the dam would not increase.

c. A simulation including the removal of the dam structures and the sediments accumulated behind the dam did not result in significant changes in the water surface elevation or velocities downstream from the dam. Upstream from the dam, heads would decrease as much as 34 feet and velocities would increase to as much as 12 ft/s.

d. The routing of the entire flow over the spillway would eliminate any flow toward the Highway 153 underpass and along the Expressway embankment. This would not completely eliminate the potential for damages to the embankment from future floods, since direct flow through the spillway would still affect the structure. A recent lesser flood (May 1986) eroded the embankment significantly.

e. The simulations indicated that even with the removal of the dam, supercritical flow conditions downstream from the spillway and through the bridge entrance would prevail.

SELECTED REFERENCES

Benson, M.A., and Dalrymple, Tate, 1967, General field and office procedures for indirect measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A1, 30 p.

Edelen, Jr., George W., and Cobb, Ernest D., 1969, Flood Plain Mapping, U. S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chapter E1, 16 p.

Federal Emergency Management Agency, 1983, Río de Coamo Basin Puerto Rico: Flood Insurance Study, 11 p.

Hulsing, Harry, 1967, Measurement of peak discharge at dams by indirect methods: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter A5, 29 p.

López, M.A., Colón-Dieppa, Eloy, 1979, Floods in Puerto Rico Magnitude and Frequency: U.S. Geological Survey, Water-Resources Investigations Report 78-141, 70 p.

Matthai, Howard F., 1967, Measurement of peak discharge at width contractions by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A4, 44 p.

Shearman, James O. 1976, Computer applications for step-backwater and floodway analyses: U.S. Geological Survey Open-File Report 76-499, 103 p.