

SEDIMENTATION SURVEY OF LAGO DOS BOCAS, PUERTO RICO, JUNE 1985

By Ferdinand Quiñones, Frank Melendez, and Carlos Bonnet

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DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information write to

District Chief
U.S. Geological Survey
GSA Center, Building 652
Highway 28, Km. 7.2, Pueblo Viejo
San Juan, Puerto Rico 00936

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For the convenience of readers who may want to use metric units, the inch-pound units used in this report may be converted by using the following factors:

| Multiply inch-pound unit | by | To obtain SI unit |
|--|-----------|--|
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| square foot (ft ²) | 0.09290 | square meter (m ²) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile (mi ²) | 2.590 | square kilometer (km ²) |
| acre | 4,047 | square meter (m ²) |
| acre-feet (acre-ft) | 1,233 | cubic meter (m ³) |
| million gallons per day (Mgal/d) | 0.04381 | cubic meters per day (m ³ /d) |
| cubic foot per second (ft ³ /s) | 0.02832 | cubic meter per second (m ³ /s) |

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ABSTRACT

A survey of the sedimentation of Dos Bocas reservoir, in central Puerto Rico, was conducted during July 1985. The survey showed that the capacity of the reservoir has declined from 30,420 acre-feet in 1942 to about 19,620 acre-feet. Sediment is accumulating in the reservoir at an average rate of about 251 acre-feet per year, or about 0.83 percent per year of the original capacity. The expected usable life of the reservoir on the basis of the long-term sedimentation rate is about 78 years. However, the sedimentation rate appears to have increased significantly since 1979. During the last six years, the average sedimentation rate has exceeded 600 acre-feet per year. If this rate is maintained, the expected usable life of the reservoir would be about 32 years.

INTRODUCTION

Lago Dos Bocas, a reservoir located in central Puerto Rico, is used for hydroelectric power generation and flood control. The reservoir is located within the basin of the Río Grande de Arecibo, one of the largest watersheds in Puerto Rico (fig.1). Development of the basin has been limited, although significant agricultural activity occurs within the rural areas near the towns of Adjuntas, Utuado, and Jayuya. The 1980 population in the basin upstream from the reservoir was about 68,000 (U.S. Department of Commerce, 1982).

In 1985, the U.S. Geological Survey (USGS), Water Resources Division, in cooperation with the U.S. Department of Agriculture, Soil Conservation Service (SCS), conducted a comprehensive survey of the Dos Bocas reservoir to determine its current capacity and the sedimentation rate. The survey was designed to include a large number of transects to improve its reliability.

DAM AND RESERVOIR CHARACTERISTICS

The Dos Bocas reservoir dam was completed in 1942, on the Río Grande de Arecibo about 10 miles upstream from the river's mouth to the Atlantic Ocean. The original capacity of the reservoir was about 30,420 acre-feet (acre-ft) at normal pool elevation (297.5 feet), of which about 24,070 were available for power generation above 240.0 feet (fig. 2). The hydroelectric power generating plant at the damsite is rated at 22,500 kilowatts (Pedro Toutant, 1985, personal commun., Puerto Rico Electric and Power Authority). It consists of three intakes with three 7,500 kilowatt turbines. Power is generated during peak hours and seasonally to supplement other power sources in Puerto Rico. Monthly total power generation in 1983 ranged from a low of 967 megawatt-hours during February to 5,552 megawatt-hours during May (fig. 3). Total power generation in 1983 was 28,940 megawatt-hours. The average water discharge from the reservoir due to power generation

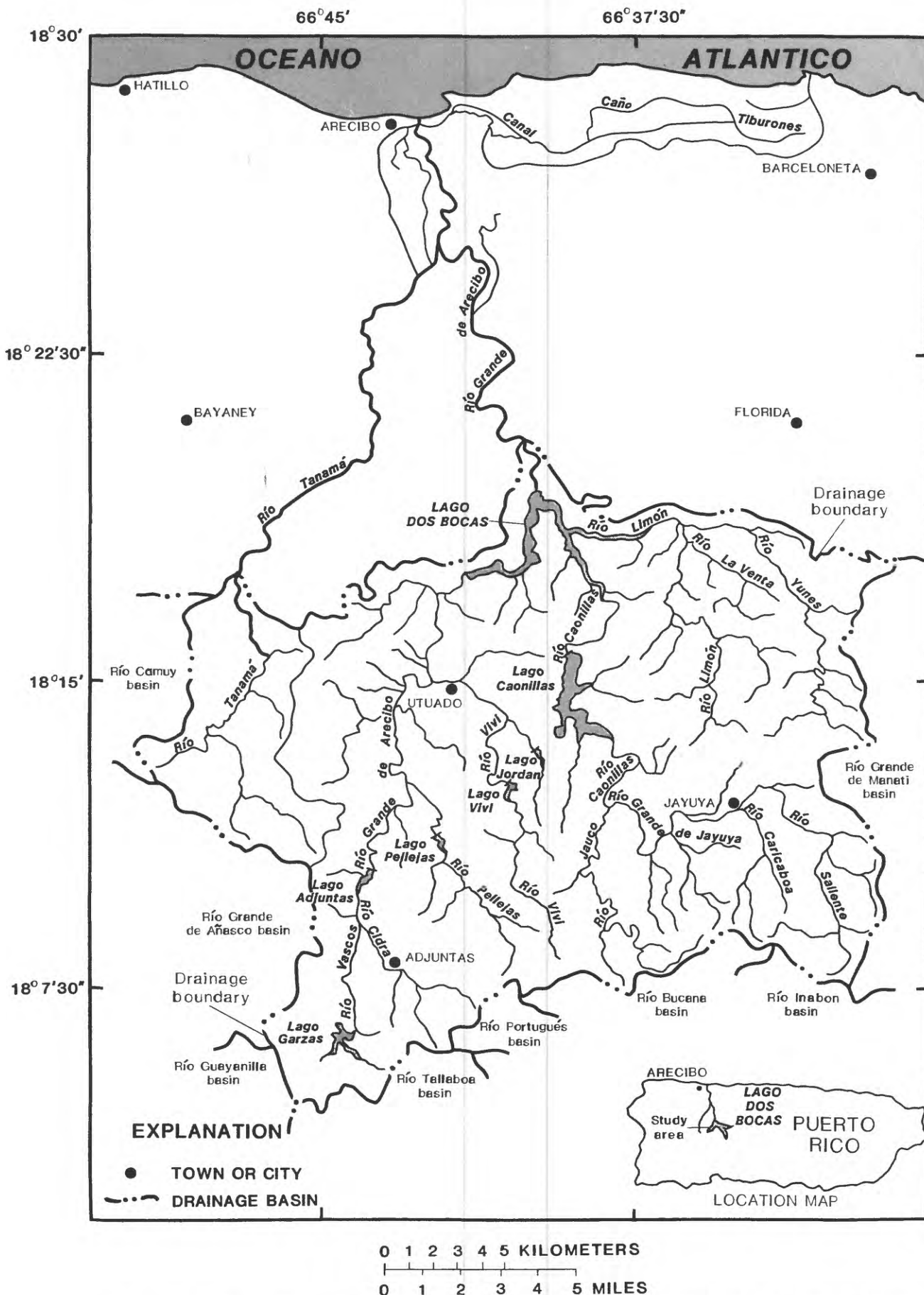


Figure 1.--Location of Lago Dos Bocas in the Río Grande de Arecibo basin.

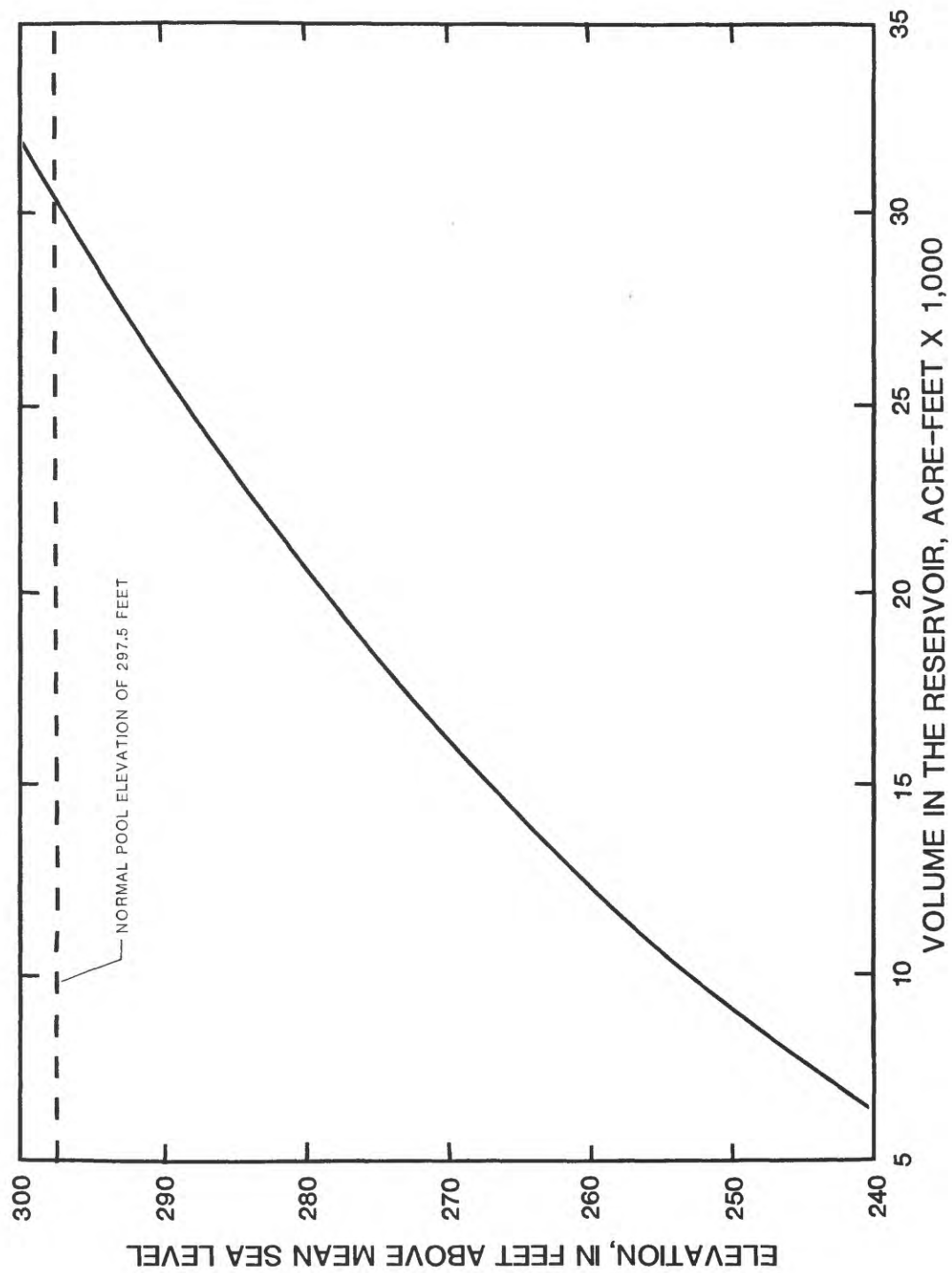


Figure 2.--Capacity curve for Lago Dos Bocas, 1942 (Pedro Toutant, Puerto Rico Electric and Power Authority, personal commun., 1985).

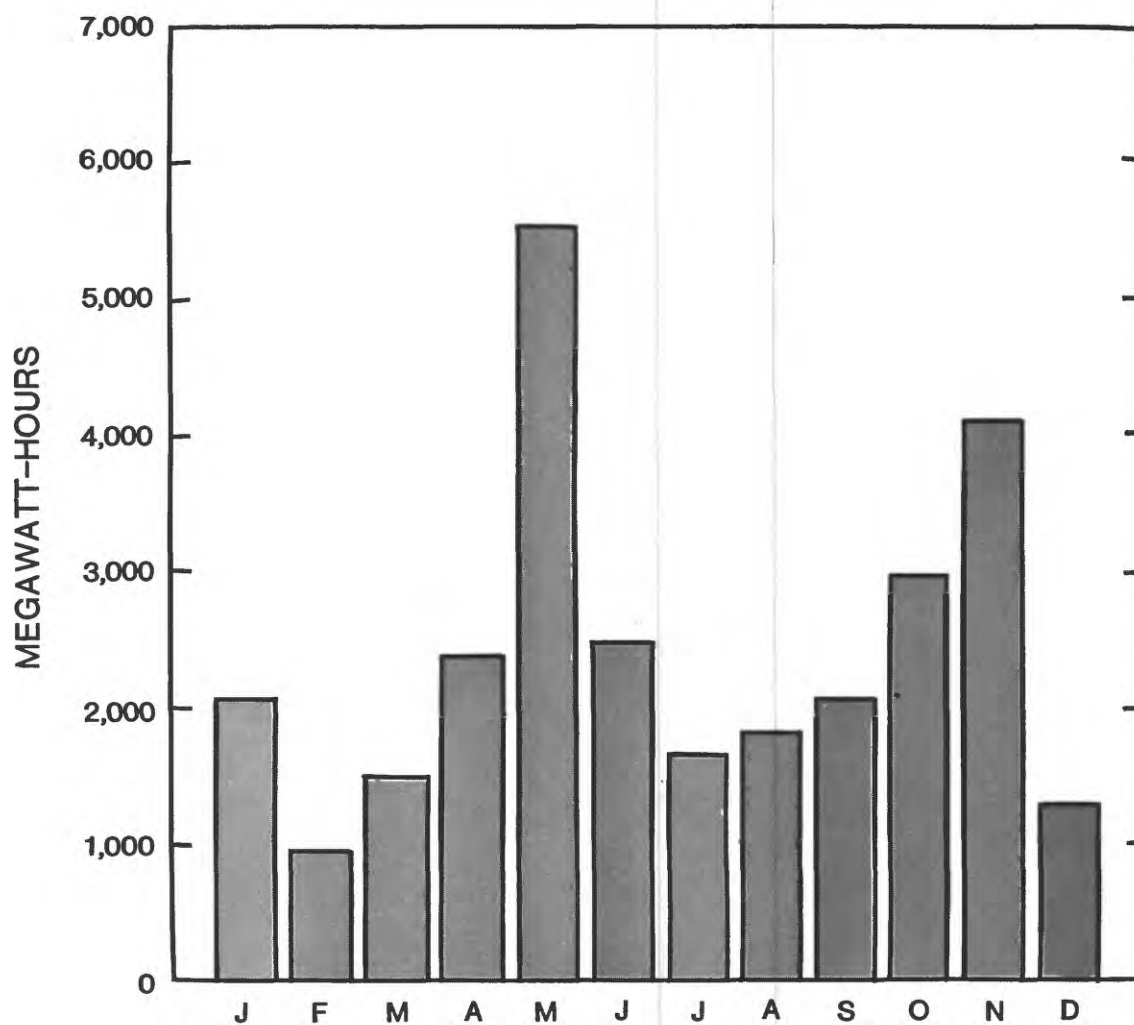


Figure 3.--Hydroelectric power generation at Lago Dos Bocas during the year 1983
(Data from Soil Conservation Service, 1983).

during 1983 was about 220 million gallons per day. Most of this water eventually reached the ocean near the town of Arecibo. The principal characteristics of the dam and reservoir are summarized in table 1.

METHOD OF SURVEY

The actual capacity of the reservoir was determined from bathymetric surveys. Ranges (fig. 4) were surveyed utilizing an "Innerspace Model 412 Auto Track Digital Fathometer." The instrument is equipped with a printer to record depth of the water from the surface to the top of the sediment deposits. A transducer coupled to an Ott velocity meter mounted on a boat provides depth and distance from a reference point along the range. All recordings were made to a local datum and later corrected to mean sea level. The instrument operates over a range from 2 to 1,000 feet, with less than 0.5-foot error in the 1- to 100-foot range. The instrument was calibrated frequently to a known depth in shallow water with a handheld sounding device.

A total of 43 ranges were surveyed during this investigation. These were used to define a bathymetric map of the reservoir. The map was used to define auxiliary ranges used for the volume computations.

The actual capacity of the reservoir was computed using the "Range Method" described in the USDA National Engineering Handbook, Chapter 6 (1983). The amount of sediment in the lake was obtained by subtracting the current capacity from the initial capacity.

PREVIOUS SURVEYS

The original survey of Lago Dos Bocas was conducted in 1942 at the time the dam was under construction by the Water Resources Authority of Puerto Rico (records about this survey were not available at the time of this investigation). An original capacity of 30,420 acre-ft was computed at an elevation of 295.2 feet above mean sea level. This includes about 6,350 acre-ft of dead storage below the top of the intake tunnel at elevations below 240.0 feet.

Table 1.--Principal characteristics of Lago Dos Bocas and structures

| | |
|--|------------------|
| Length of dam | 1,317 feet |
| Altitude of crest of spillway | 295.0 feet |
| Discharge intakes (3), penstock type | 9.0 feet |
| Original capacity (1942) | 30,420 acre-feet |
| Maximum flood-level storage | 50,000 acre-feet |
| Spillway crest-level storage | 30,420 acre-feet |
| Surcharge storage | 19,580 acre-feet |
| Installed powerplant capacity | 22,500 kilowatts |
| Drainage area at damsite* | 170 square miles |
| Design flooded area (elevation of 290.33 feet) | 634 acres |
| Flooded area during 1985 survey | 457.9 acres |
| Maximum height of dam | 188 feet |
| Maximum original depth of normal pool | 155 feet |
| Maximum depth during 1985 survey (relative to normal pool) | .99 feet |

*Includes about 50.4 square miles draining to Lago Caonillas, upstream from Lago Dos Bocas.

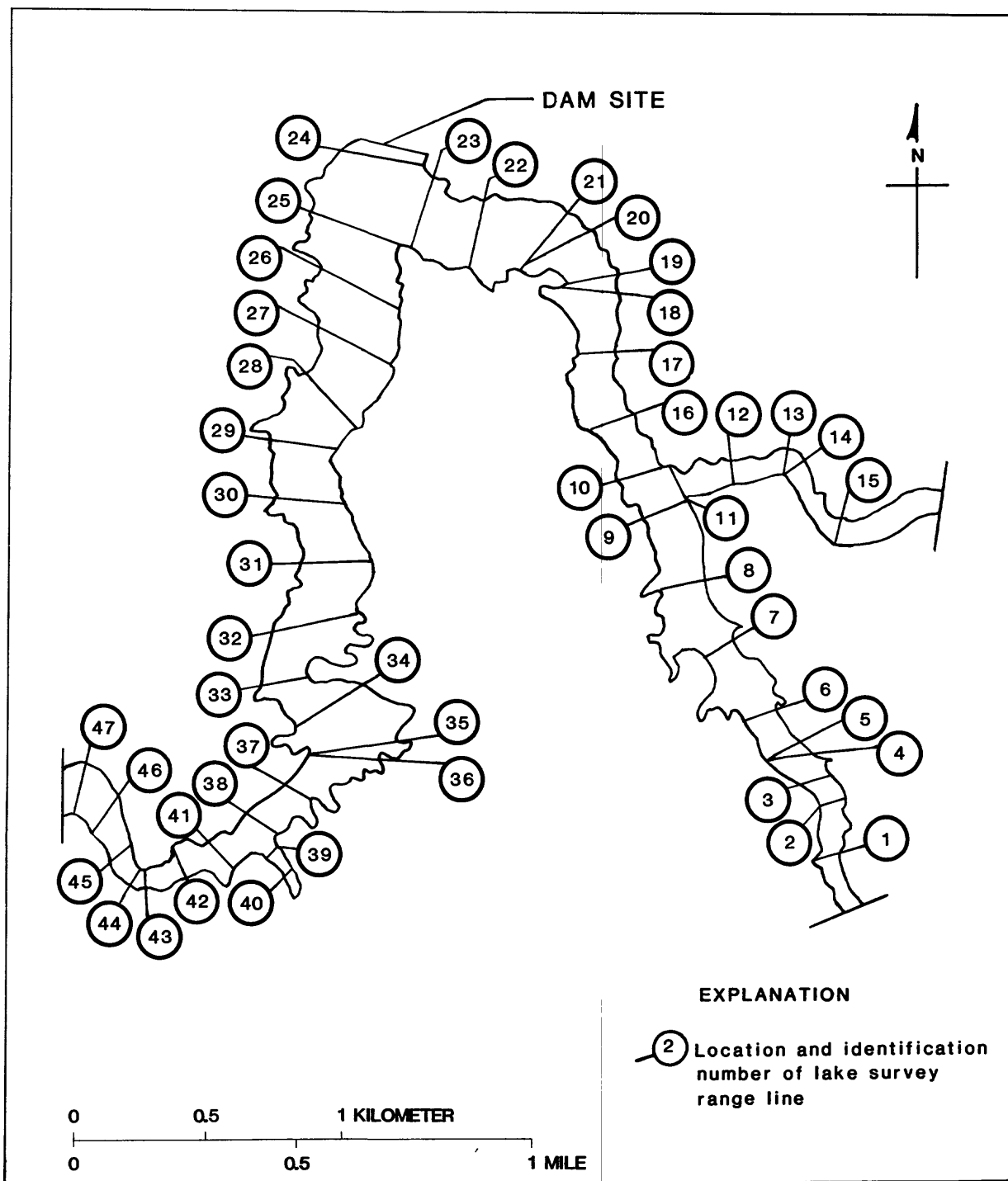


Figure 4.--Ranges surveyed at Lago Dos Bocas during July 1985.

A comprehensive survey of the lake capacity and sedimentation was conducted by Gómez-Gómez in 1979 (Fernando Gómez-Gómez, personal commun., 1985). Forty-two transects were surveyed throughout the reservoir using a Raytheon fathometer mounted on a boat and connected to an Ott velocity meter to compute velocities and distances. The survey resulted in a volume computation of about 23,340 acre-ft.

ACTUAL CAPACITY AND SEDIMENTATION

The actual (July 1985) capacity of Lago Dos Bocas was computed as 19,620 acre-ft. This

capacity includes the dead storage below the intake tunnels to the turbines at an elevation lower than 240 feet above mean sea level. The results of the current and previous surveys are summarized in tables 2 and 3.

A comparison of several cross sections surveyed throughout the reservoir in 1979 and 1985 confirms that the sedimentation of the lake has accelerated significantly (fig. 5). From 1979 to 1985 a total of about 3,760 acre-ft of sediment appears to have accumulated in the reservoir. This is equivalent to a sedimentation rate of about 620 acre-ft/yr, or more than twice the long-term rate of 251 acre-feet per year (acre-ft/yr). Several factors may have contributed to the increased sedimentation rate:

Table 2.--*Comparison of prior and current sedimentation surveys of Lago Dos Bocas, Puerto Rico*

| | 1942 | 1979 | 1985 |
|--|---------------------|---------------------|--------|
| Capacity (acre-feet). | 30,400 ¹ | 23,340 ² | 19,620 |
| Years since construction | - | 37 | 43 |
| Sediment accumulated (acre-feet). | 0 | 7,060 | 10,780 |
| Storage loss (percent). | 0 | 23.2 | 35.5 |
| Annual loss capacity (percent). | 0 | 0.63 | 0.83 |
| Sedimentation rate (acre-feet per year). | 0 | 191 | 251 |
| Remaining life (years) ³ | - | 122 | 78 |

¹Includes dead storage volume (6,350 acre-ft) and "power generation volume" (24,070 acre-ft).

²Unpublished survey conducted by the USGS in early 1979. Volume adjusted to normal pool elevation.

³Based on the 43 years since the reservoir was built.

Table 3.--Summary of 1985 sedimentation survey

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICESCS-ENG-034
02-85

RESERVOIR SEDIMENT DATA SUMMARY

Dos Bocas, Puerto Rico

1

NAME OF RESERVOIR

DATA SHEET NO.

| | | | | | | | | | | | | | | | | |
|-----------------------------------|--|-----------------------------------|-------------------------------------|-------------------------------------|------------------------------------|---|----------------------------------|-----------------------------|--|-----------|----------------------------------|-----------------|-------------------------|--|-------------------------------------|--|
| DAM | 1. OWNER P.R. Energy & Power Auth. | | | 2. STREAM Grande de Arecibo | | | 3. STATE Puerto Rico | | | | | | | | | |
| | 4. SEC. TWP. RANGE | | | 5. NEAREST P.O. | | | 6. COUNTY | | | | | | | | | |
| | 7. LAT. ' ' ' ' LONG. ' ' ' ' " | | | 8. TOP OF DAM ELEVATION | | | 9. SPILLWAY CREST ELEV. 295.0 | | | | | | | | | |
| RESERVOIR | 10. STORAGE ALLOCATION | | 11. ELEVATION TOP OF POOL | | 12. ORIGINAL SURFACE AREA, ACRES | | 13. ORIGINAL CAPACITY, ACRE-Feet | | 14. GROSS STORAGE, ACRE-Feet | | 15. DATE STORAGE BEGAN | | | | | |
| | a. FLOOD CONTROL | | | | | | 50,000 | | | | 1942 | | | | | |
| | b. MULTIPLE USE | | | | | | 30,420 | | | | | | | | | |
| | c. POWER | | | | | | 24,070 | | | | | | | | | |
| | d. WATER SUPPLY | | | | | | | | | | 16. DATE NORMAL OPER. BEGAN | | | | | |
| | e. IRRIGATION | | | | | | | | | | | | | | | |
| | f. CONSERVATION | | | | | | | | | | | | | | | |
| | g. INACTIVE | | | | | | 6,350 | | | | 1942 | | | | | |
| 17. LENGTH OF RESERVOIR 2.5 MILES | | | | | AV. WIDTH OF RESERVOIR 0.22 MILES | | | | | | | | | | | |
| WATERSHED | 18. TOTAL DRAINAGE AREA 170 SQ. MI. | | | | | 22. MEAN ANNUAL PRECIPITATION 78.8 INCHES | | | | | | | | | | |
| | 19. NET SEDIMENT CONTRIBUTING AREA 119.6 SQ. MI. | | | | | 23. MEAN ANNUAL RUNOFF 30.5 INCHES | | | | | | | | | | |
| | 20. LENGTH MILES | | | | | 24. MEAN ANNUAL RUNOFF 325,000 AC.-FT. | | | | | | | | | | |
| | 21. MAX. ELEV. MIN. ELEV. | | | | | 25. ANNUAL TEMP.: MEAN RANGE | | | | | | | | | | |
| SURVEY DATA | 26. DATE OF SURVEY | | 27. PERIOD YEARS | | 28. ACCL. YEARS | | 29. TYPE OF SURVEY | | 30. NO. OF RANGES OR CONTOUR INT. | | 31. SURFACE AREA, ACRES | | 32. CAPACITY, ACRE-Feet | | 33. C/I. RATIO, AC.-FT. PER AC.-FT. | |
| | 1942 | | - | | - | | - | | 42 | | - | | 30,400 | | 0.06 | |
| | 1979 | | 37 | | 37 | | range | | 47 | | 458 | | 23,340 | | | |
| | 1985 | | 36 | | 43 | | range | | | | 19,620 | | | | | |
| | 26. DATE OF SURVEY | | 34. PERIOD ANNUAL PRECIPITATION | | 35. PERIOD WATER INFLOW, ACRE-Feet | | | | | | 36. WATER INFL. TO DATE, AC.-FT. | | | | | |
| | | | | | a. MEAN ANNUAL | | b. MAX. ANNUAL | | c. PERIOD TOTAL | | a. MEAN ANNUAL | | b. TOTAL TO DATE | | | |
| | | | | | ----- | | SEE TABLE 2 | | ----- | | | | | | | |
| | 26. DATE OF SURVEY | | 37. PERIOD CAPACITY LOSS, ACRE-Feet | | | | | | 38. TOTAL SED. DEPOSITS TO DATE, ACRE-Feet | | | | | | | |
| | | | a. PERIOD TOTAL | | b. AV. ANNUAL | | c. PER SQ. MI.-YEAR | | a. TOTAL TO DATE | | b. AV. ANNUAL | | c. PER SQ. MI.-YEAR | | | |
| | | | | | ----- | | SEE TABLE 2 | | ----- | | | | | | | |
| 26. DATE OF SURVEY | | 39. AV. DRY WGT. LBS. PER CU. FT. | | 40. SED. DEP., TONS PER SQ. MI.-YR. | | 41. STORAGE LOSS, PCT. | | 42. SED. INFLOW, PPM | | | | | | | | |
| | | | | a. PERIOD | | b. TOTAL TO DATE | | a. AV. ANN. b. TOT. TO DATE | | a. PERIOD | | b. TOT. TO DATE | | | | |
| | | | | ----- | | SEE TABLE 2 | | ----- | | | | | | | | |

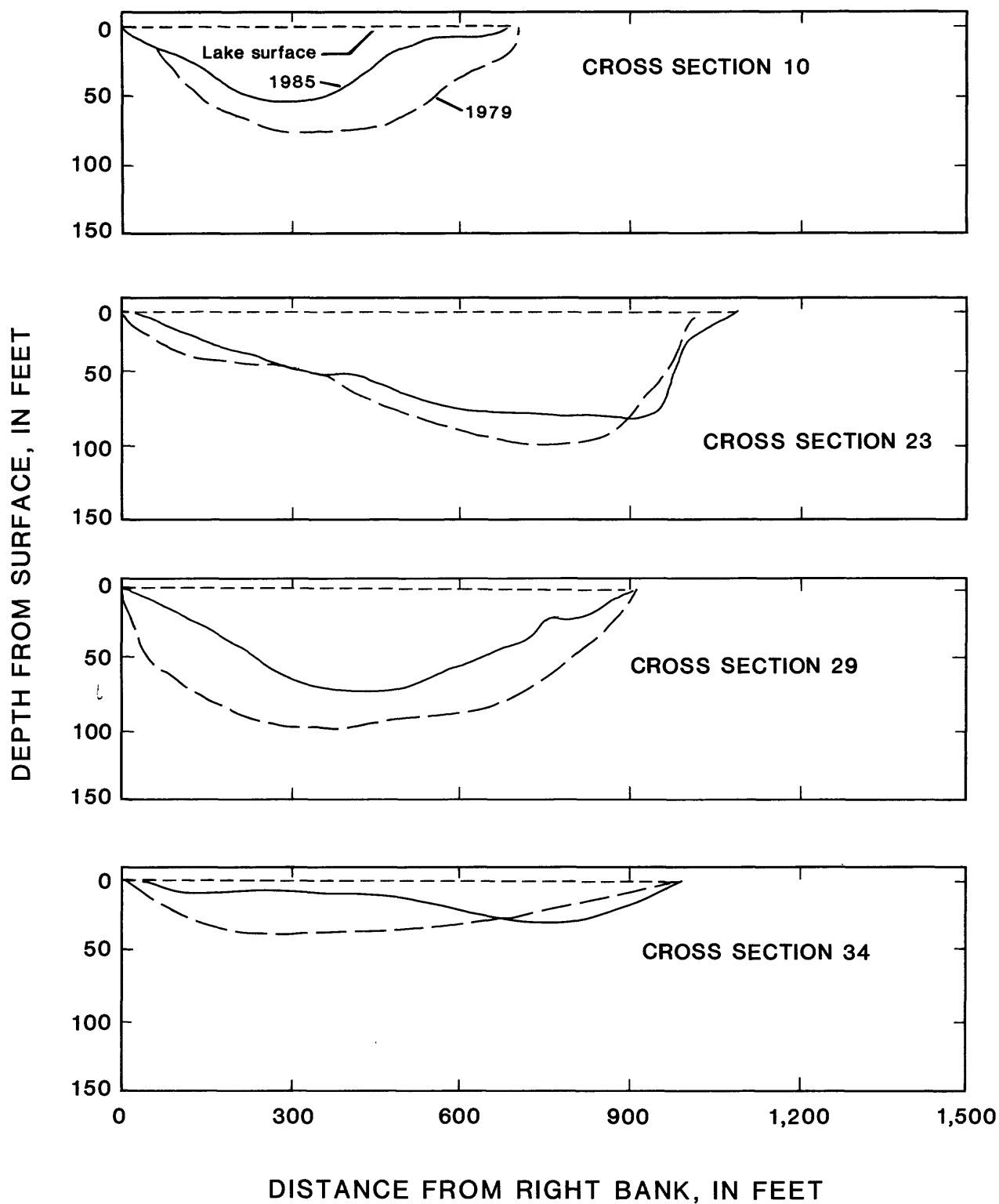


Figure 5.--Cross sections surveyed at Lago Dos Bocas in 1979 and 1985 (Cross section numbers refer to figure 4.).

1. Changes in land use in the basin. There are no data to compare any changes, but agricultural developments and reductions in the forested areas upstream from the reservoir have occurred.

2. Changes in the operational conditions at the reservoir reducing the amount of sediment discharged through the intake tunnels during floods.

3. Increases in sediment loads as a result of the floods of 1979, 1981, and 1985. In the Loíza basin, near San Juan, storms during these periods resulted in sediment loads to the Loíza reservoir of as much as 500 acre-ft during one storm (Quiñones and others, 1989). The peak of the flood of May 1985 at the Río Grande de Arecibo near Arecibo was about 50,000 ft³/s. The actual peak flow into the reservoir was probably at least twice that amount (peak flow at the Río Grande de Manati basin, adjacent to the Arecibo watershed and with a similar drainage area, was 140,000 ft³/s). Preliminary sediment transport data for this storm suggests that as much as 800 acre-ft of sediment could have been discharged to the reservoir during this single event. More recently, the flood of October 1985 may have contributed a similar sediment load to Lago Dos Bocas.

The importance of storm events in the sedimentation of reservoirs in Puerto Rico is masked when average sedimentation rates are compared. Future sedimentation investigations in Puerto Rico need to address the contribution of individual storms. The average computations of sedimentation rates over the years may vary significantly from one year to the next due to storm events.

The remaining life of the reservoir was estimated from the mean-annual sedimentation rate and the remaining capacity. However, if the average sedimentation rate of the last 6 years is used, the remaining usable life of the reservoir

could be of the order of 32 years. When compared with other reservoirs recently surveyed in Puerto Rico (Loíza, La Plata), the long-term sedimentation rate of Lago Dos Bocas appears to be the lowest. On the basis of the last 6 years, it would be the highest.

TRAP EFFICIENCY OF THE RESERVOIR

The average trap efficiency for Lago Dos Bocas was computed from flow data at Río Grande de Arecibo near Arecibo, about 8 miles downstream from the damsite. The flow at the gaging station was adjusted for differences in drainage area and known inflows. The main tributary to Río Grande de Arecibo between the reservoir and the gaging station is Río Tanama. The average flow of Río Tanama near Charco Hondo (north of Arecibo) is about 35,000 acre-ft/yr. The average discharge of Río Grande de Arecibo at Arecibo is about 364,000 acre-ft/yr (Curtis and others, 1985). An adjusted discharge of 325,000 acre-ft/yr was estimated for the damsite. On the basis of the actual capacity of 19,620 acre-ft, the capacity-inflow ratio (C/I) is 0.06. Utilizing Brune's relation (Brune, 1953), the trap efficiency is about 80 percent. The total amount of sediment that has passed through the reservoir downstream is about 2,160 acre-ft (30,420 acre-ft of original capacity less 19,620 acre-ft of actual capacity times 0.20). This is equivalent to an annual downstream discharge of about 50 acre-ft/yr.

The sediment yield per acre from the drainage basin is about 1.5 acre-feet per square mile per year (acre-ft/mi²/yr) (10,800 acre-ft sediment inflow divided by the drainage area of 170 mi² and by the 43 years since the reservoir was built). However, this value is not representative of the basin because the drainage area includes Lago Caonillas. At Lago Caonillas, most of the sediment production of about 50.4 mi² is trapped in the reservoir.

BOTTOM PROFILES

Profiles of the bottom of the Dos Bocas reservoir were developed from the field data collected. The deepest point in each range was plotted against the distance upstream from the dam structure. Separate profiles were developed for each branch of the reservoir. The auxiliary ranges developed from the bathymetric map were not used to define the profile. The 1985 profiles were compared to the 1979 profiles (figs. 6a, 6b). The original profiles were not available for comparison.

Comparison of the 1979 and 1985 profiles show a significant accumulation of sediment in the deepest sections of the reservoir principally along the western branch. A sediment layer about 20 feet thick has accumulated from the vicinity of the dam for about 10,000 feet upstream. Along the eastern branch, most of the sediment is deposited in the first 3,000 feet upstream from the dam. Since the eastern branch flows from Lago Caonillas, less sediment accumulation along this area of the reservoir should occur.

FUTURE INVESTIGATIONS

The apparent increase in the sedimentation rate of the reservoir will require a closer

monitoring; sedimentation surveys every 4 to 5 years would yield adequate information. A sediment-transport investigation in the basin and the reservoir would help to better define sedimentation rate. Stations to measure the inflow and outflow of sediment at the reservoir on a continuous basis would aid in sediment management of the reservoir.

SUMMARY

The 1985 survey of the sedimentation of Lago Dos Bocas shows that the actual capacity of the reservoir is about 19,620 acre-ft. Sediment is accumulating in the reservoir at a rate of about 251 acre-ft/yr. Comparisons with a survey conducted in 1979 show that the sedimentation rate of the reservoir has increased from about 0.62 to 0.82 percent per year of the original capacity. The trap efficiency of the reservoir is about 80 percent. The average basin sediment yield is about 1.5 acre-ft/mi²/yr. The usable life of the reservoir based on the long-term sedimentation rate is about 78 years. However, if the rate of the last 6 years is used, the usable life would be about 32 years.

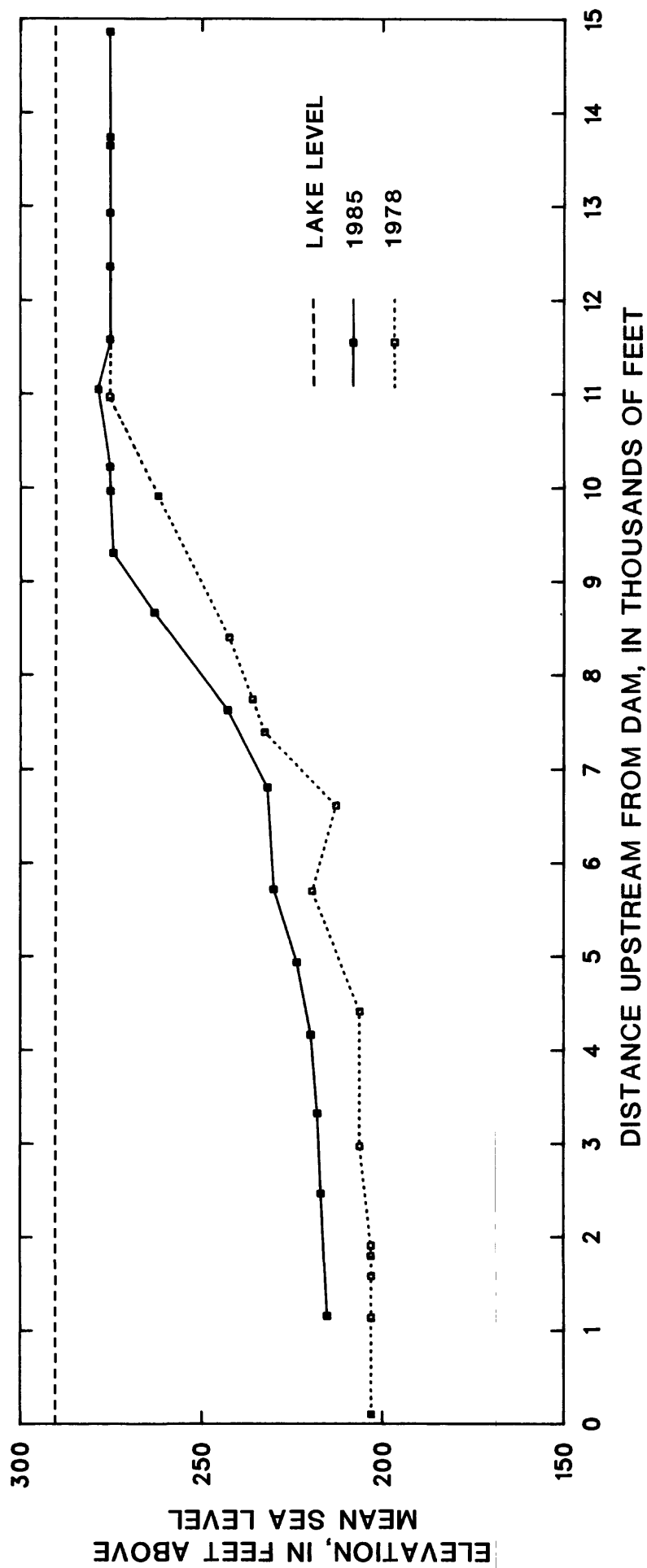


Figure 6a.--Bottom profiles, western section of Lago Dos Bocas.

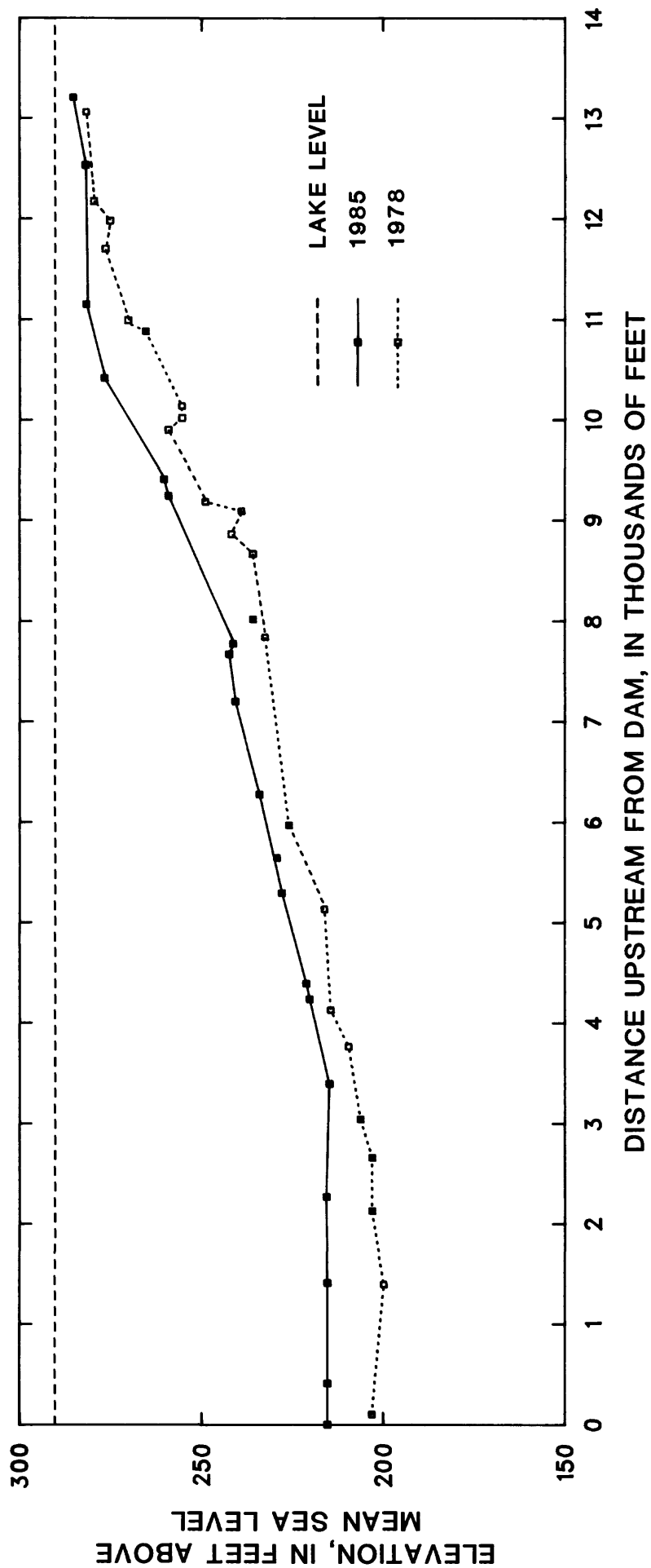


Figure 6b.--Bottom profiles, eastern section of Lago Dos Bocas.

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