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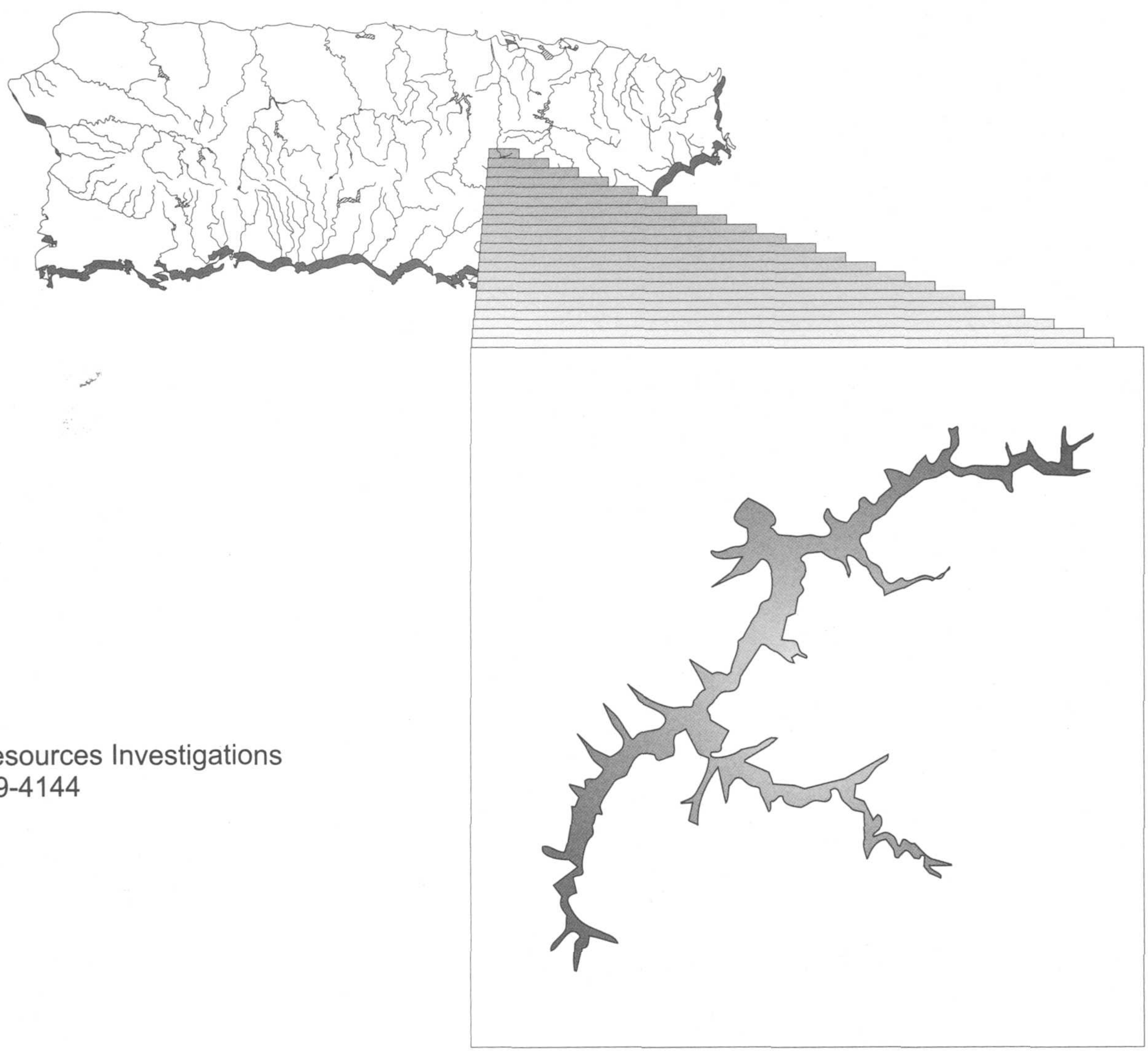
PUERTO RICO AQUEDUCT AND SEWER AUTHORITY

Sedimentation Survey of Lago de Cidra, Puerto Rico, November 1997



Water-Resources Investigations
Report 99-4144

U.S. Department of the Interior
U.S. Geological Survey

Sedimentation Survey of Lago de Cidra, Puerto Rico, November 1997

By Luis R. Soler-López

Water-Resources Investigations Report 99-4144

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San Juan, Puerto Rico: 1999

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CONVERSION FACTORS, DATUMS, and ACRONYMS

Multiply	By	To obtain
	Length	
centimeter	0.03937	inch
meter	3.281	foot
kilometer	0.6214	mile
	Area	
square meter	10.76	square foot
square kilometer	0.3861	square mile
square kilometer	247.1	acre
	Volume	
cubic meter	35.31	cubic foot
million cubic meters	810.7	acre-foot
cubic meter	0.0008107	acre-foot
	Volume per unit time (includes flow)	
cubic meter per second	35.31	cubic foot per second
cubic meter per second	15,850	gallon per minute
	Mass per area (includes sediment yield)	
kilogram per square kilometer	0.002855	ton per square mile
megagram per square kilometer	2.855	ton per square mile
megagram per square kilometer	0.004461	ton per acre

Datums

Horizontal Datum - Puerto Rico Datum, 1940 Adjustment

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

Acronyms used in this report:

AMSL	Above Mean Sea Level
BLASS	Bathymetric/Land Survey System
DGPS	Differential Global Positioning System
GIS	Geographic Information System
PRASA	Puerto Rico Aqueduct and Sewer Authority
TIN	Triangulated Irregular Network
USGS	U.S. Geological Survey

Sedimentation Survey of Lago de Cidra, Puerto Rico, November 1997

By **Luis R. Soler-López**

Abstract

Lago de Cidra reservoir (drainage area 21.39 square kilometers) was built to provide supplemental water supply to the San Juan metropolitan area. Sediment accumulation has reduced the reservoir storage capacity by about 12 percent over the last 51 years. In 1946, the storage capacity of the reservoir was approximately 6.54 million cubic meters. According to the 1997 survey, the storage capacity has decreased to about 5.76 million cubic meters. A total of about 0.78 million cubic meters of deposited material has accumulated in the past 51 years, giving a long-term average sedimentation rate of about 15,200 cubic meters of sediment per year. This represents a long-term average storage capacity loss of about 0.2 percent per year. At this sedimentation rate, the reservoir is projected to fill in approximately 380 years or by the year 2377. Assuming a dry bulk density of 1.0 grams per cubic centimeter and based on a sediment-contributing area of 20.32 square kilometers, the sediment yield of the Lago de Cidra basin was estimated to be approximately 768 megagrams per square kilometer per year.

INTRODUCTION

Water supply for the San Juan metropolitan area has become a major priority for the Puerto Rico Aqueduct and Sewer Authority (PRASA). The Lago de Cidra reservoir is a supplemental water-supply system for the region and sediment accumulation is depleting the storage capacity and threatens to render intake structures inoperable. During November 13-14, 1997, the U.S. Geological Survey (USGS), in cooperation with PRASA, conducted a bathymetric survey of Lago de Cidra to calculate the existing storage capacity and estimate the rate at which sediment is being deposited. This data will be useful in the effective management of the water resources and the operation of the dam structures.

Data on position and water depths were collected by using a differential global positioning system (DGPS) coupled with a depth sounder, allowing the collected data to be stored in analog and digital form. The digital data were transferred into a geographic information system (GIS) for analysis and interpretation. The existing storage capacity was computed from the processed data. The loss in capacity since the time of reservoir construction was used to calculate the average annual sedimentation rates.

The pool elevation of the reservoir was monitored during the data collection process at the USGS lake-level station, Lago de Cidra at Damsite near Cidra (50047550), located at the left abutment of the dam.

DAM AND RESERVOIR CHARACTERISTICS

Lago de Cidra is located in the municipality of Cidra in east-central Puerto Rico, about 3.0 kilometers northeast of the town of Cidra (fig. 1). The reservoir is operated by the Puerto Rico Aqueduct and Sewer Authority. The reservoir was built in 1946 as a 6.54-million cubic meter supplemental water supply for the San Juan metropolitan area.

The dam is a concrete gravity and earthfill structure with a length of approximately 165 meters between abutments and a structural height of 24 meters. The spillway portion of the dam is an ungated ogee crest about 40 meters long and a crest elevation of 403.00 meters above mean sea level (AMSL) (NGVD 1929). It is located 40 meters from the right abutment. Concrete nonoverflow sections with lengths of 40 and 30 meters, left and right abutments respectively, adjoin either side of the spillway. The crest lengths of the embankments and cutoff walls are 45 meters on the left side and 10 meters on the right side (looking in the downstream direction). Earth and rockfill embankments with concrete cutoff walls connect each nonoverflow section to the canyon walls. Table 1 summarizes the structures and reservoir characteristics of the Lago de Cidra dam.

METHOD OF SURVEY

The bathymetric survey of Lago de Cidra included planning, data collection, data processing and analysis. GIS and Arc/Info were used to plan the survey lines and for analysis of the bathymetric data. Cross-section locations were planned at a spacing of 50 meters, starting at the dam and continuing upstream along the different branches of the reservoir. Location and depth data were collected by using a DGPS interfaced to a depth sounder. The soundings were subsequently adjusted to represent depths below the spillway elevation. Depth contours were drawn at variable intervals from the deepest part of the reservoir up to the shoreline. The contour lines were then converted into a triangulated irregular network (TIN). The TIN represents the lake bottom as thousands of adjoining triangles, with x, y, and z coordinates assigned to all vertices. The volume of the reservoir was then calculated at incremental pool elevations. Cross sections and longitudinal profiles were generated from the TIN surface model.

Field Techniques

The bathymetric survey was performed during November 13-14, 1997. The bathymetric survey used the Bathymetric Survey Land Survey System (BLASS) developed by Specialty Devices, Inc. This system uses two Motorola SixGun DGPS units for horizontal positioning of the survey boat. The DGPS units were first used in a static survey mode to establish two reference points at sites overlooking the reservoir. Satellite information was recorded simultaneously at the USGS benchmark MESAS (lat 18°19'40.798"N., long 66°00'58.106"W.) and the desired reference station. An approximate 45-minute static DGPS observation session was used to establish reference point Cidra-1 at the left abutment of the dam (lat 18°11'56.261"N., long 66°08'27.709"W.).

Table 1. Principal characteristics of Lago de Cidra and dam, Puerto Rico (modified from Sheda and Legas, 1968)
[AMSL, above mean sea level]

Length of dam (between abutments)	165 meters
Maximum structural height of dam	24 meters
Length of spillway section	40 meters
Elevation of spillway crest AMSL	403.00 meters
Original normal capacity at top of spillway elevation	6.54 million cubic meters
Maximum volume at elevation of 406.91 meters AMSL	10.36 million cubic meters
Drainage area	21.39 square kilometer
Surface area	1.07 square kilometer
Maximum depth during the 1997 survey	18.5 meters

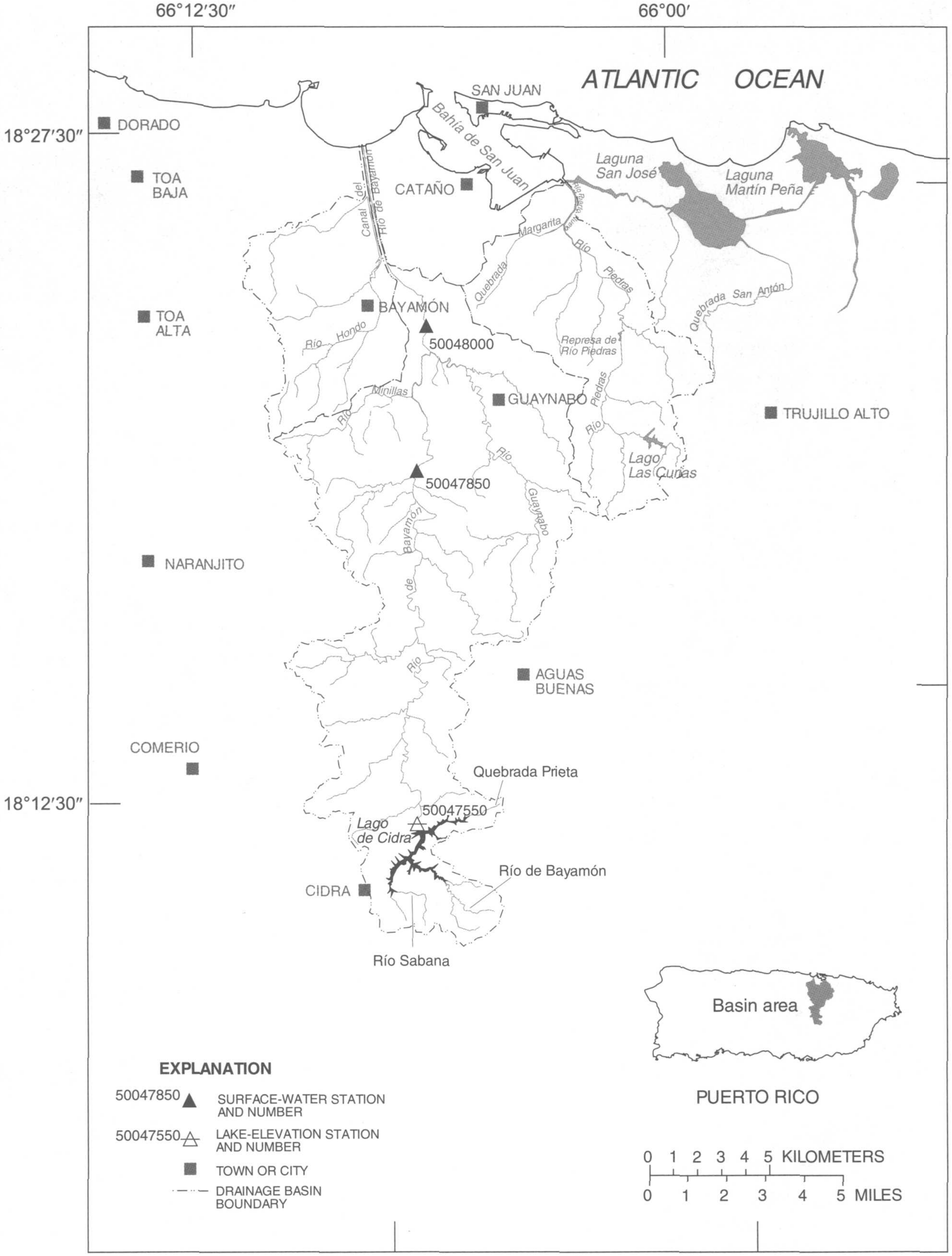


Figure 1. Location of Lago de Cidra in the Río de Bayamón basin, Puerto Rico.

Another reference station was established using the same procedure at Cidra-2 Toro (lat 18°11'18.709"N., long 66°08'38.744"W.) on the left edge of water, at a small hill, at the confluence of the Río Sabana and Río de Bayamón branches of the reservoir. Post-processing, using the software CentiPoint, indicated an error of less than 10 centimeters for these reference stations. Once established, Cidra-1 was occupied as the master station and the other DGPS was installed in the survey boat as the mobile unit. The DGPS on board the survey boat independently calculated a position every second while receiving a set of pseudo-range corrections from the master station to maintain positional precision within 2 meters. The master station was used to send differential corrections to the survey boat until the signal was lost because of topographic interference. When this happened, the master station was relocated to an alternate benchmark and communication was reestablished. Since the reservoir is sinuous, the master station was again relocated to another benchmark after the correction signal diminished. A signal repeater was also used to relay pseudo-range corrections into isolated branches of the reservoir.

Reservoir depths were measured by using a Raytheon model DE-719B echo sounder coupled to an Odom Digitrace, which converts depth readings into digital data. The digital data were then stored in a portable computer. The echo sounder measured the depth to within a 5-centimeter accuracy and was calibrated at a water depth of 10 meters each day of the survey. The bathymetric survey software HYPACK received and recorded the positions and depths once every second while in survey mode. HYPACK runs on a portable personal computer and was used both to record data and to navigate. The helmsman of the survey boat was provided with a graphical display showing the lake shore, the planned lines, the actual position of the boat while underway, and indicators of speed and the amount of deviation from the planned lines. Although 177 lines were planned (fig. 2), shallow water and sediment accumulation in some areas of the reservoir limited data collection to 140 lines (fig. 3).

Data Reduction

Initial editing and verification of the positional and depth data were performed by using the HYPACK software. Data were corrected to eliminate erroneous positions that could appear when the differential correction signal is lost for a significant amount of time, and when depth readings were erroneously collected because of insufficient signal gain.

The pool elevation during the two days of the bathymetric survey ranged from 402.42 meters AMSL on November 13 to 402.39 meters AMSL on November 14, 1997. Pool levels were recorded at the USGS lake-level station, Lago de Cidra at Damsite near Cidra (50047550) in order to adjust the depth data to the spillway elevation datum (403.00 meters AMSL). Pool levels were recorded at the beginning and end of each survey day.

Contour lines were drawn at variable intervals to adequately represent the lake bottom in areas with different relief. The contour map (plate 1) was used to create a TIN surface model of the November 1997 reservoir bottom. Locations and reference distances for longitudinal profiles are shown in figure 4. Selected cross sections and longitudinal profiles along the different branches of the reservoir were calculated from the TIN surface model by using GIS. The locations of the model cross sections are shown in figure 5, and the generated plots are shown in figure 6. Also, longitudinal profiles along the Río Sabana, Río de Bayamón and Quebrada Prieta branches of the reservoir are presented in figure 7.

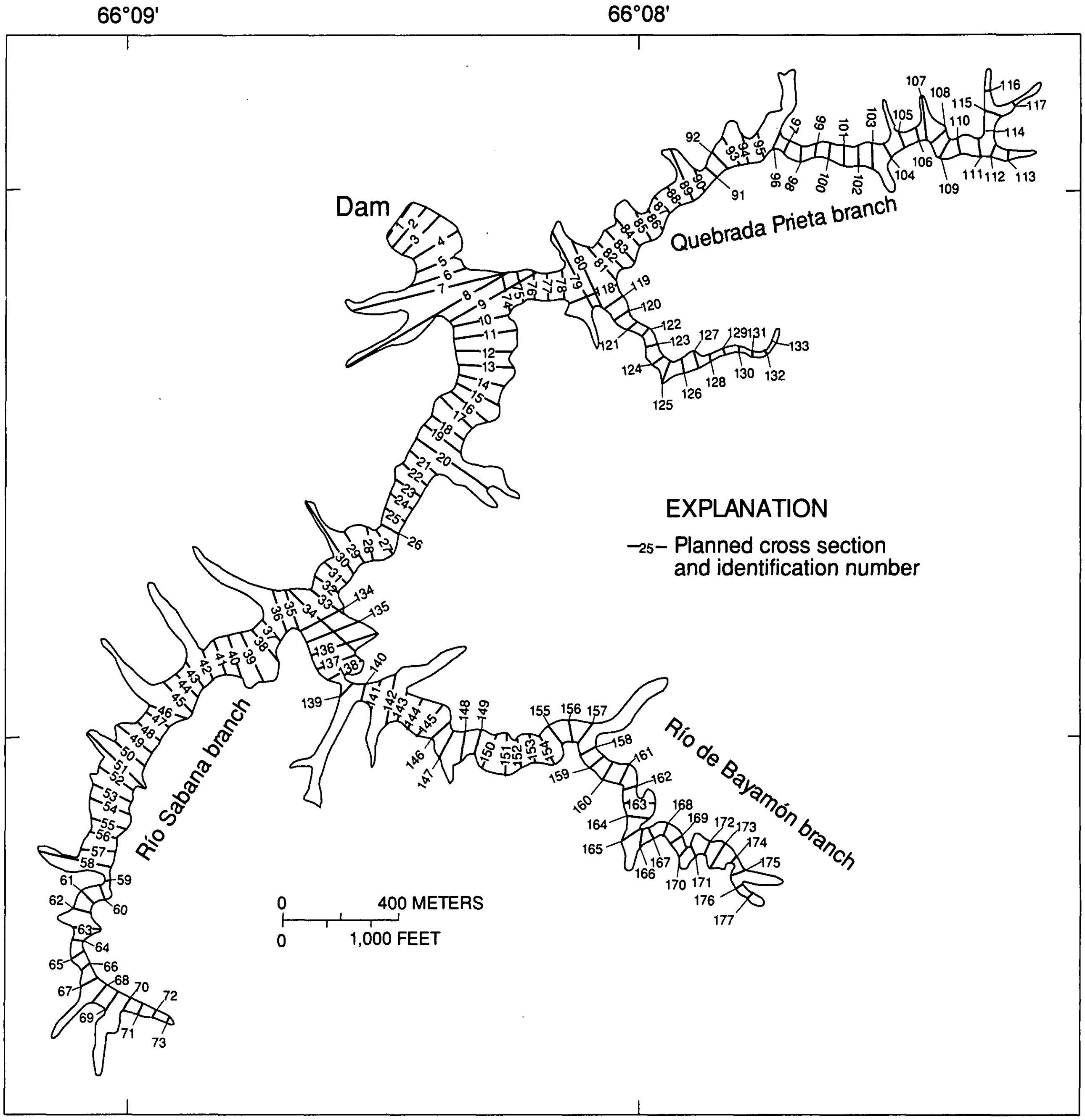


Figure 2. Planned cross-section locations for the November 1997 bathymetric survey of Lago de Cidra, Puerto Rico.

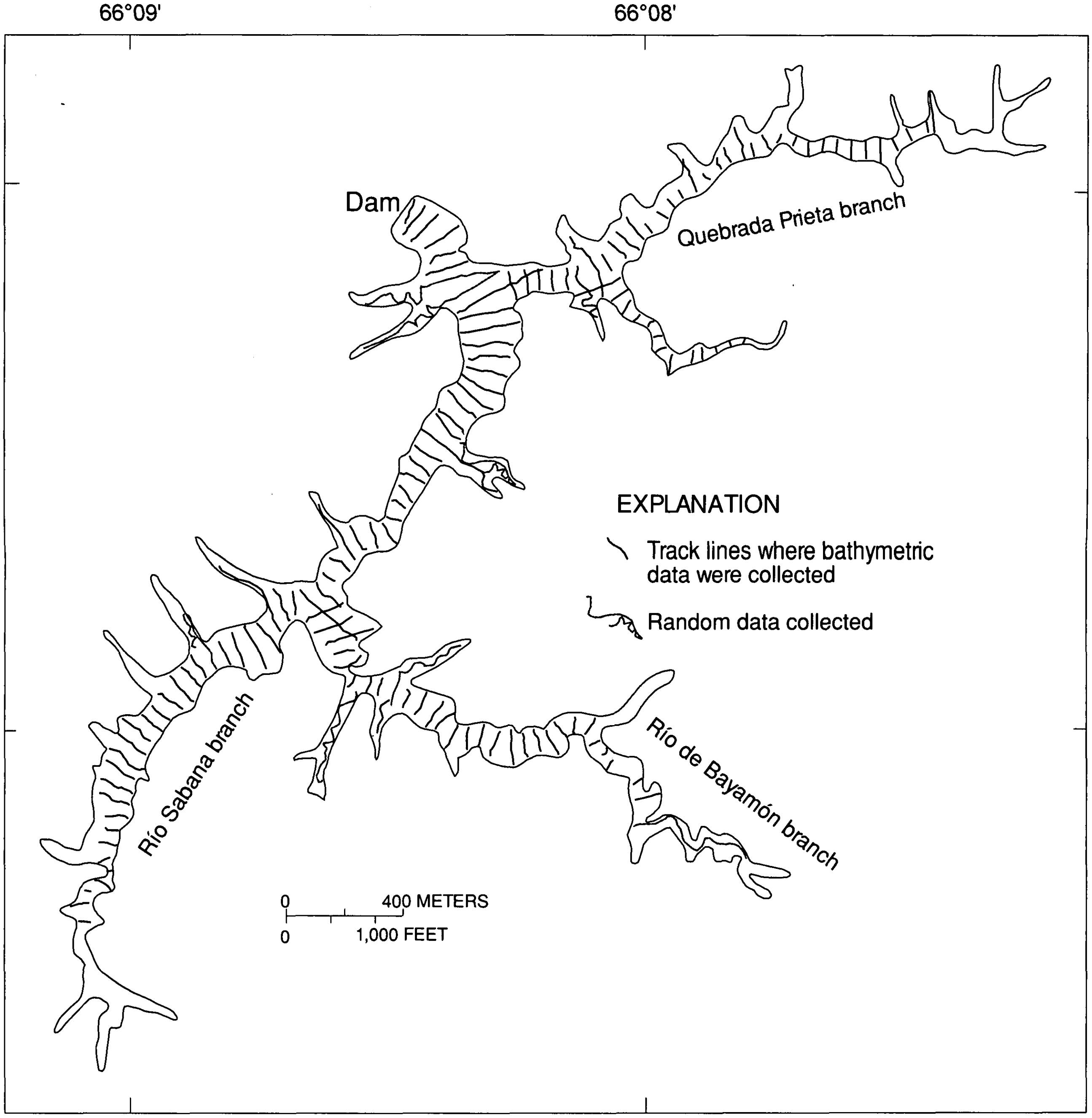


Figure 3. Actual track lines of the November 1997 bathymetric survey of Lago de Cidra, Puerto Rico.

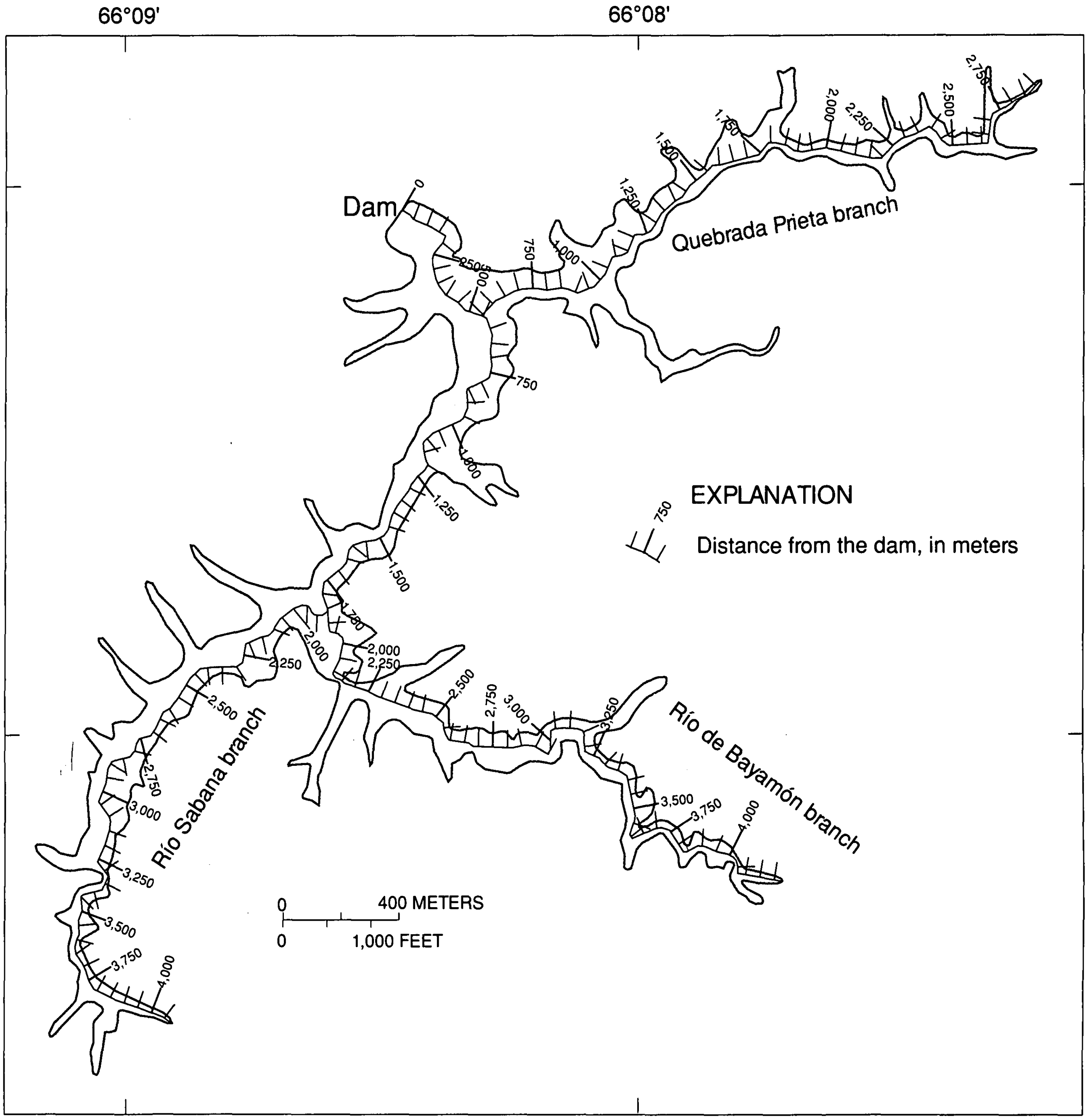


Figure 4. Reference distances for longitudinal profiles measured in Lago de Cidra, Puerto Rico, during the 1997 bathymetric survey.

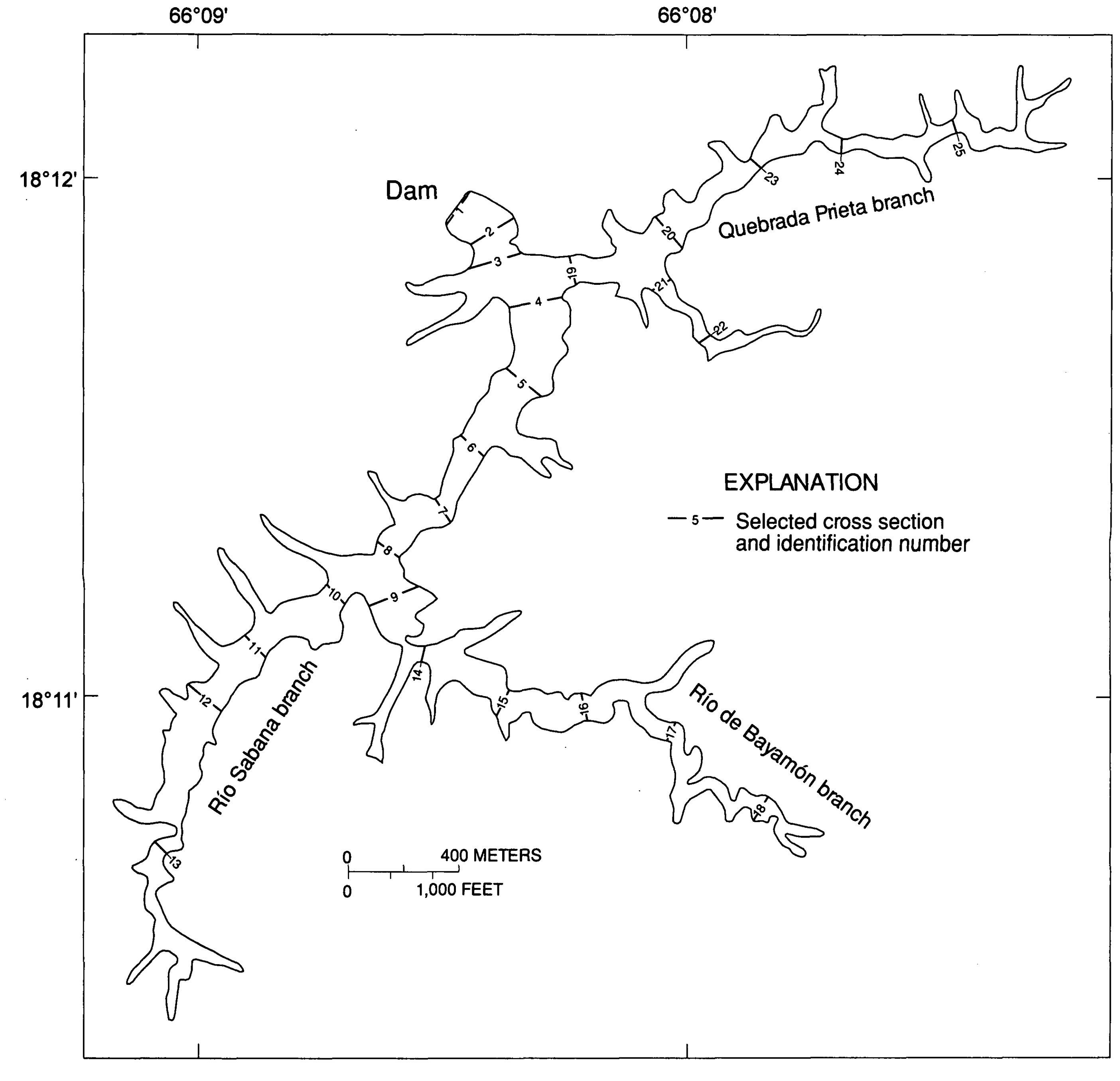


Figure 5. Model cross-section locations for the November 1997 bathymetric survey of Lago de Cidra, Puerto Rico.

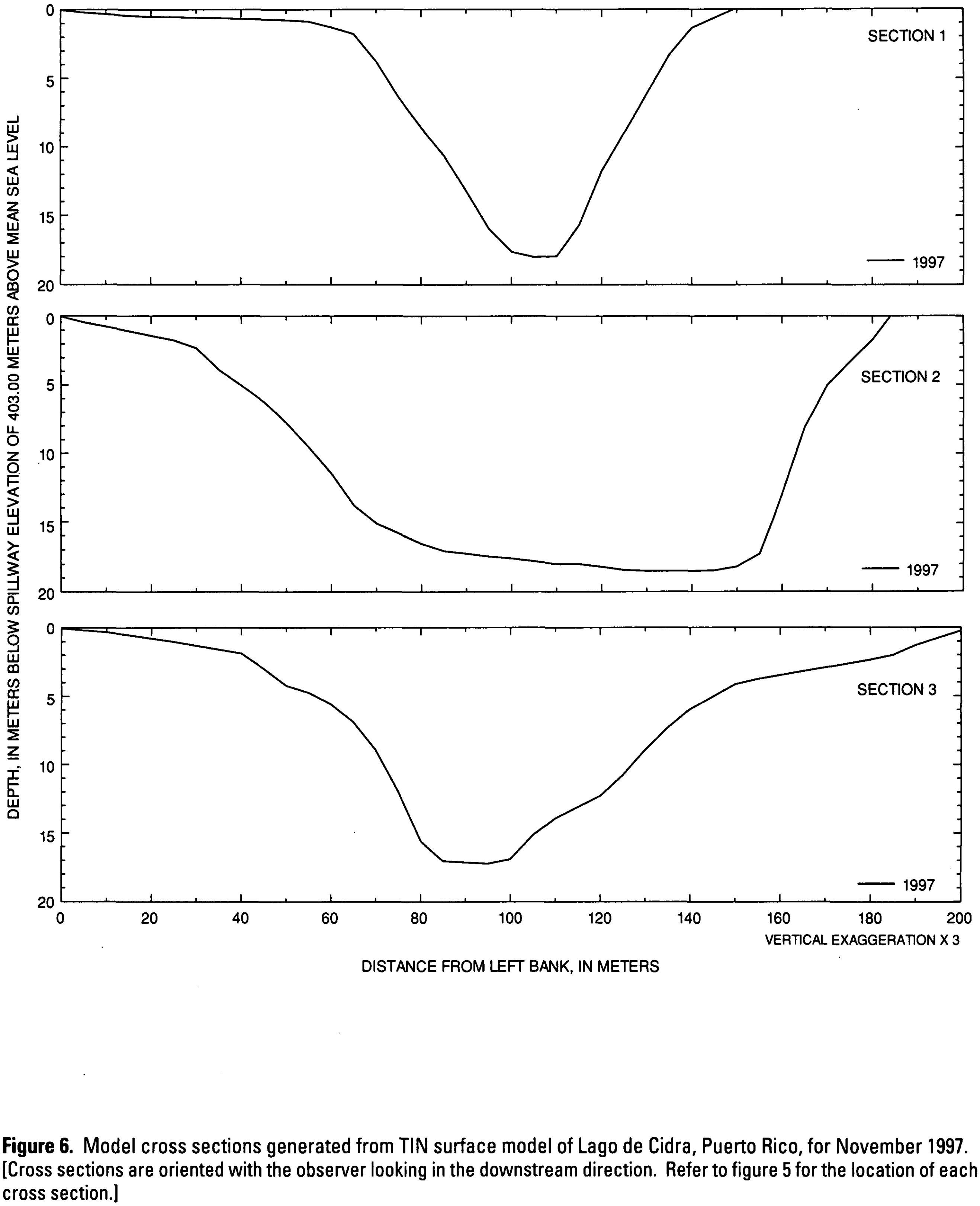


Figure 6. Model cross sections generated from TIN surface model of Lago de Cidra, Puerto Rico, for November 1997. [Cross sections are oriented with the observer looking in the downstream direction. Refer to figure 5 for the location of each cross section.]

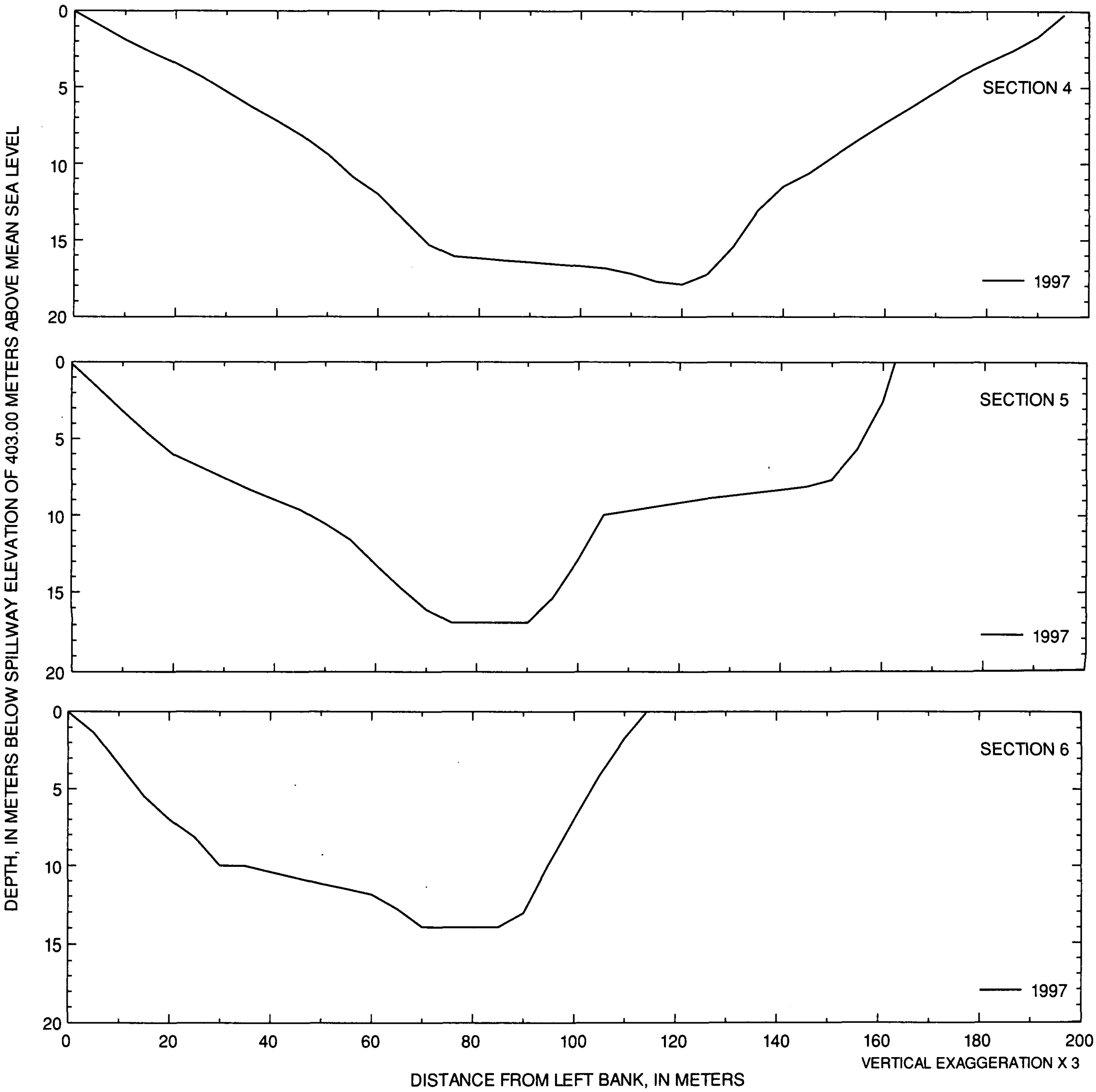


Figure 6. Model cross sections generated from TIN surface model of Lago de Cidra, Puerto Rico, for November 1997—Continued. [Cross sections are oriented with the observer looking in the downstream direction. Refer to figure 5 for the location of each cross section.]

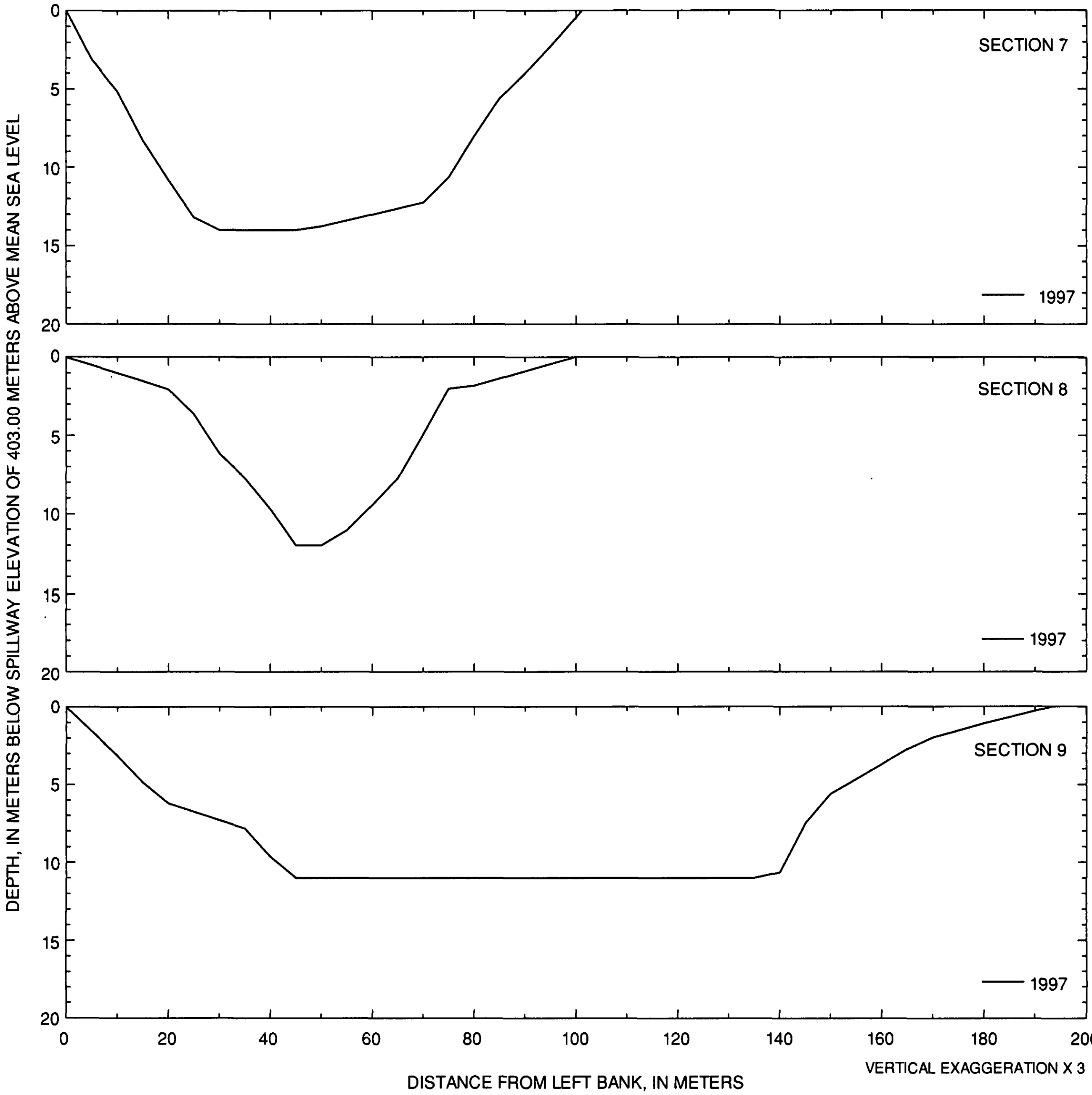


Figure 6. Model cross sections generated from TIN surface model of Lago de Cidra, Puerto Rico, for November 1997—Continued. [Cross sections are oriented with the observer looking in the downstream direction. Refer to figure 5 for the location of each cross section.]

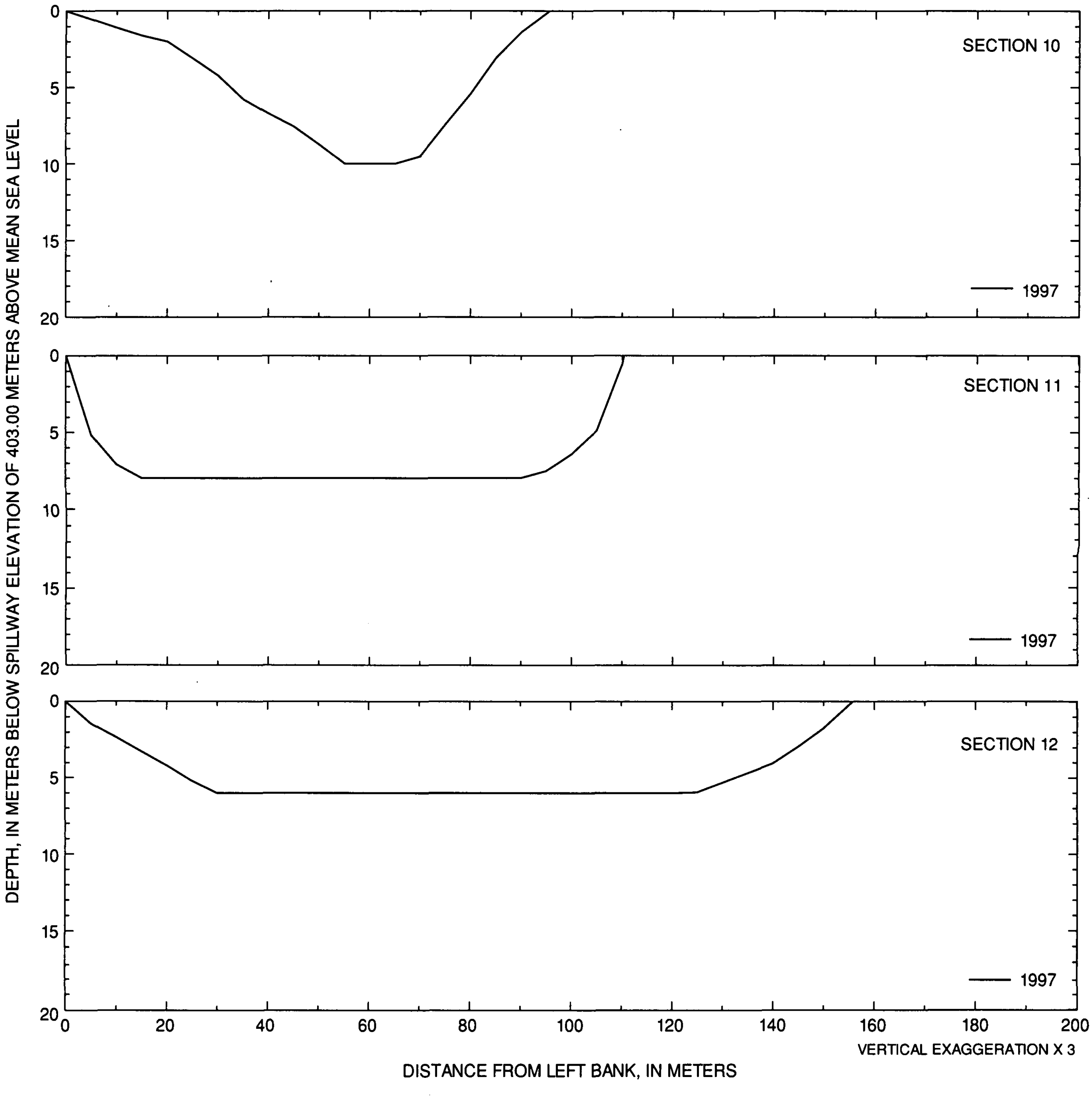


Figure 6. Model cross sections generated from TIN surface model of Lago de Cidra, Puerto Rico, for November 1997—Continued. [Cross sections are oriented with the observer looking in the downstream direction. Refer to figure 5 for the location of each cross section.]

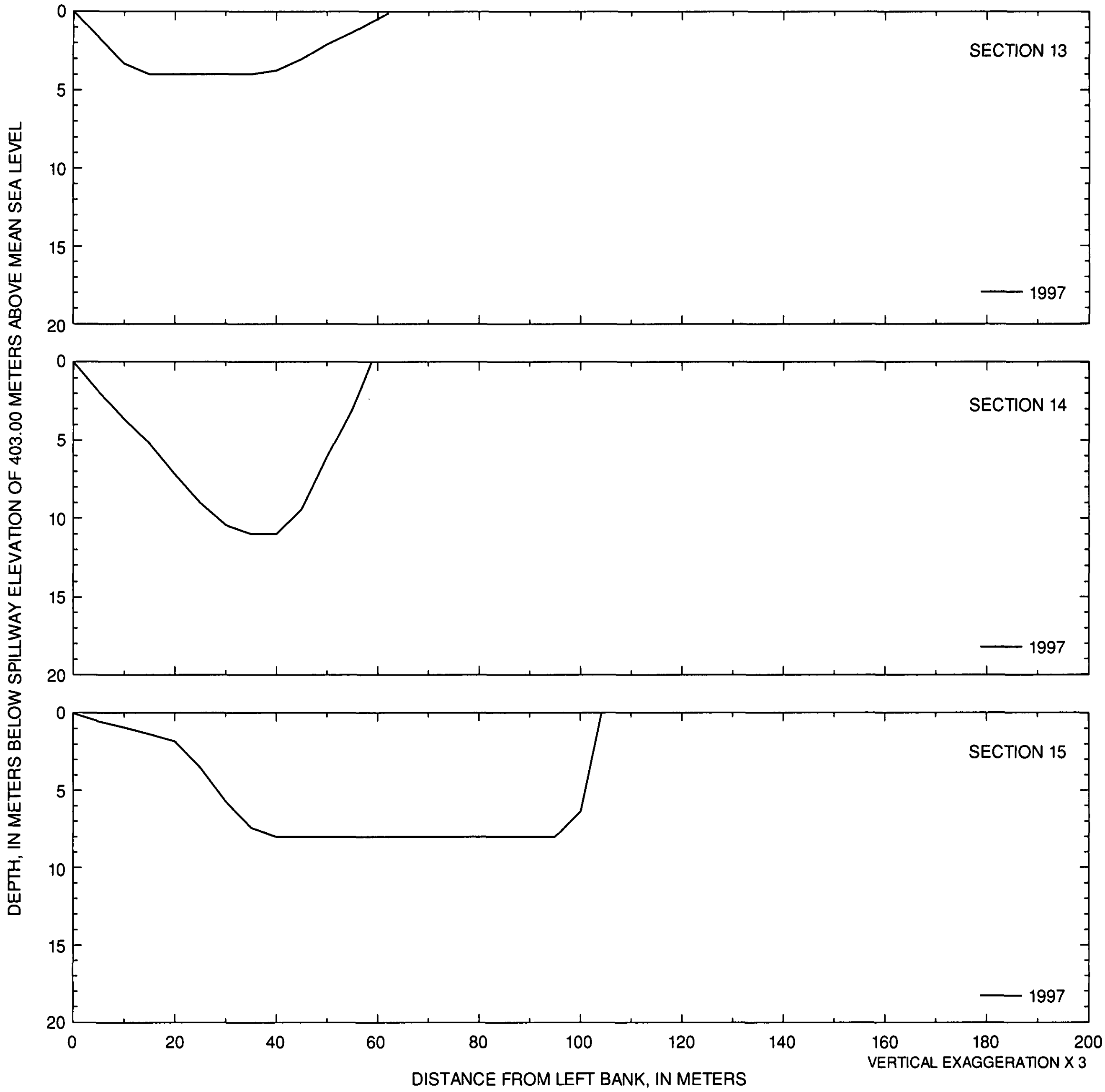


Figure 6. Model cross sections generated from TIN surface model of Lago de Cidra, Puerto Rico, for November 1997—Continued. [Cross sections are oriented with the observer looking in the downstream direction. Refer to figure 5 for the location of each cross section.]

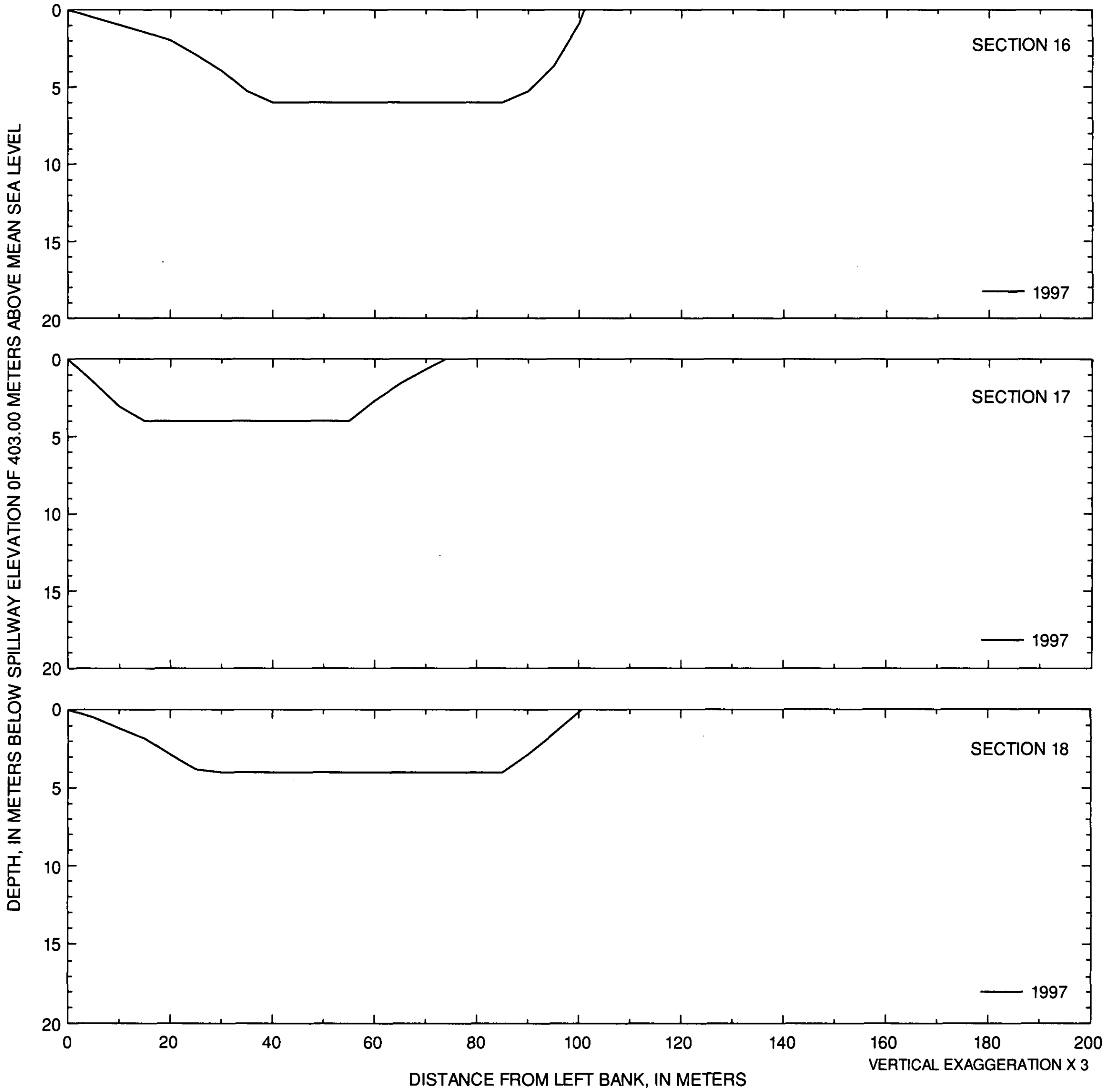
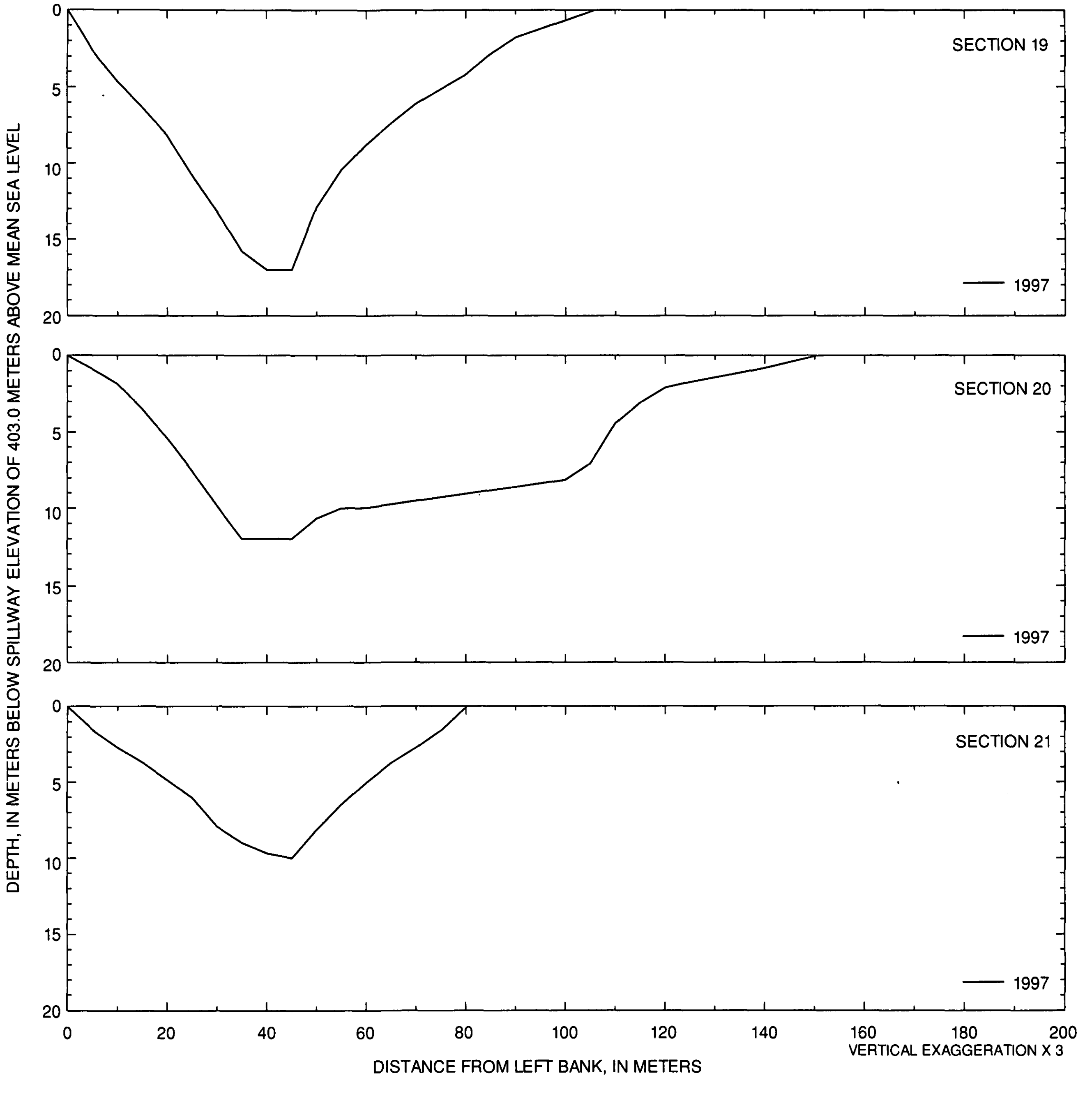


Figure 6. Model cross sections generated from TIN surface model of Lago de Cidra, Puerto Rico, for November 1997—Continued. [Cross sections are oriented with the observer looking in the downstream direction. Refer to figure 5 for the location of each cross section.]



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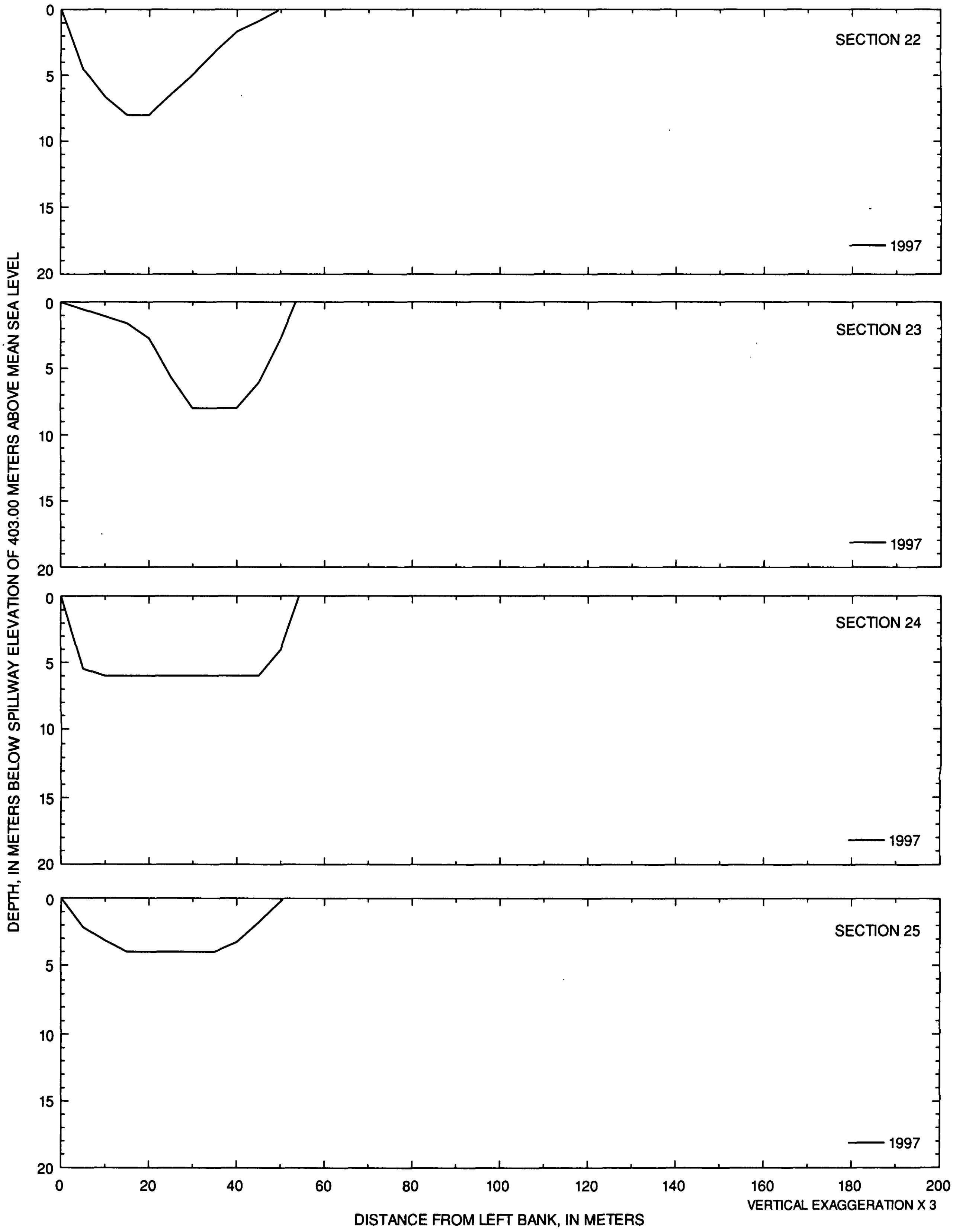

Figure 6. Model cross sections generated from TIN surface model of Lago de Cidra, Puerto Rico, for November 1997—Continued. [Cross sections are oriented with the observer looking in the downstream direction. Refer to figure 5 for the location of each cross section.]

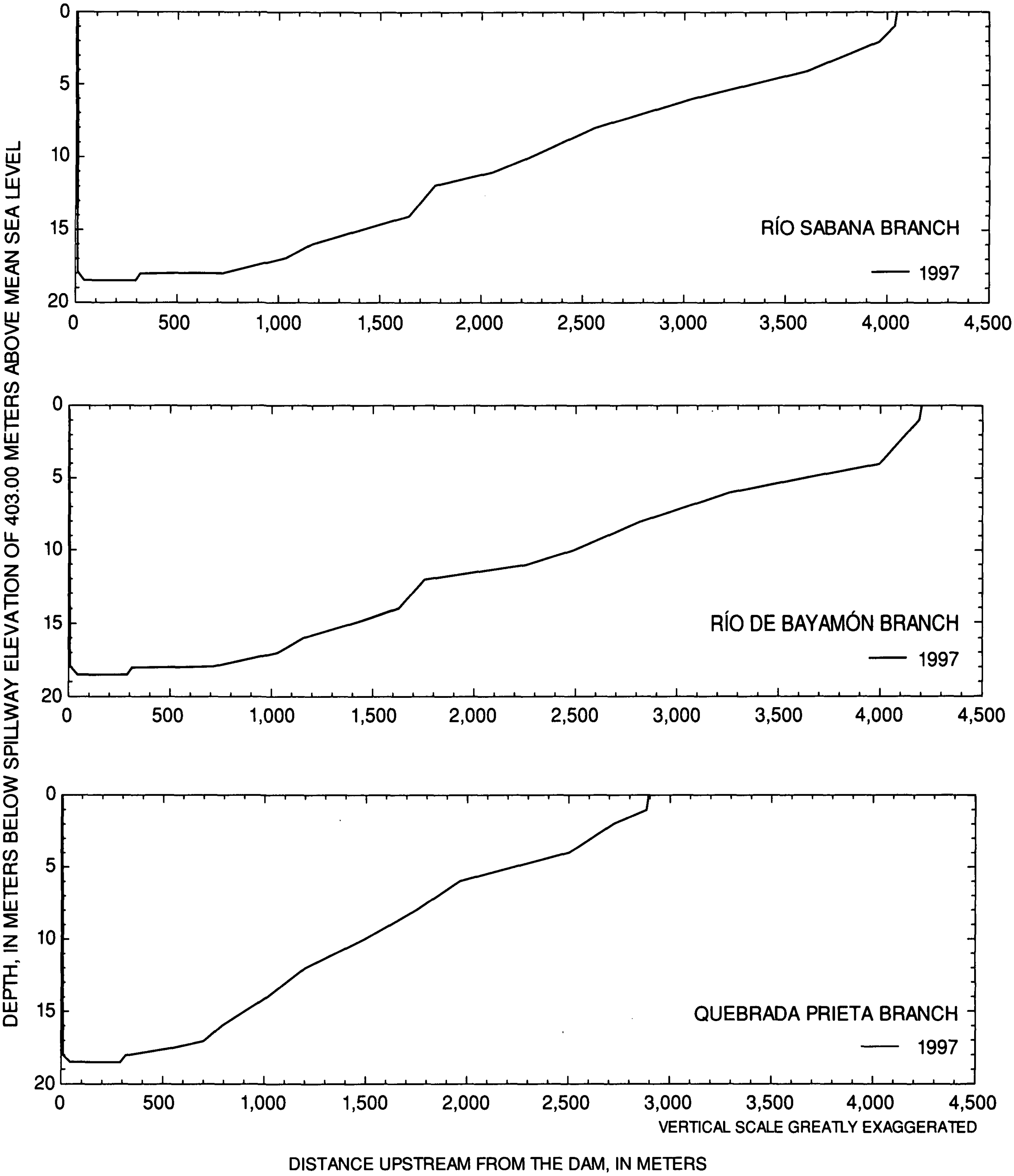

Figure 7. Longitudinal profiles for the November 1997 bathymetric survey of Lago de Cidra, Puerto Rico, along the Río Sabana, Río de Bayamón, and Quebrada Prieta branches.

ACTUAL CAPACITY AND SEDIMENT ACCUMULATION

The storage capacity of Lago de Cidra was computed to be 5.76 million cubic meters in 1997. This represents a storage capacity reduction of 0.78 million cubic meters since 1946. About 12 percent of the original capacity has been lost because of sediment deposition. The long-term average sedimentation rate of the reservoir is approximately 15,200 cubic meters per year or about 0.2 percent of capacity loss per year. A capacity curve for the November 1997 survey was produced by computing the reservoir volume at 1-meter intervals (fig. 8). Results of the November 1997 bathymetric survey of Lago de Cidra, Puerto Rico are summarized in table 2.

The reservoir has two intake openings at different elevations located at the dam (Sheda and Legas, 1968). The lower intake has an invert elevation of 381.97 meters AMSL. According to the 1997 data, the reservoir bottom in the dam area has reached an elevation of 384.50 meters AMSL, likely burying the lower intake.

The upper intake has an invert elevation of 394.97 meters AMSL. Although this structure is not in danger of being disabled by sediment accumulation in the near future, it can be left inoperable if the pool level lowers dramatically either by severe droughts, by excessive withdrawals of water, or both. A 1.06-meter diameter drain outlet in the dam has an invert elevation of 381.89 meters AMSL. Since the reservoir bottom has reached an elevation higher than the structure it is possible that the drain outlet is disabled by deposited material.

TRAPPING EFFICIENCY AND SEDIMENT YIELD

The trapping efficiency of Lago de Cidra was estimated by using the capacity/inflow ratio described by Brune (1953). The storage capacity of Lago de Cidra was 5,764,000 cubic meters in 1997. The runoff entering Lago de Cidra was reported to be 14,500,000 cubic meters in 1993 (Ramos-Ginés, 1997). The runoff reported in 1993 is considered to be a normal year in terms of rainfall and the value reported is considered to be representative of the average annual runoff per year. By using the capacity/inflow ratio and Brune's curve, the estimated trapping efficiency of Lago de Cidra is approximately 96 percent.

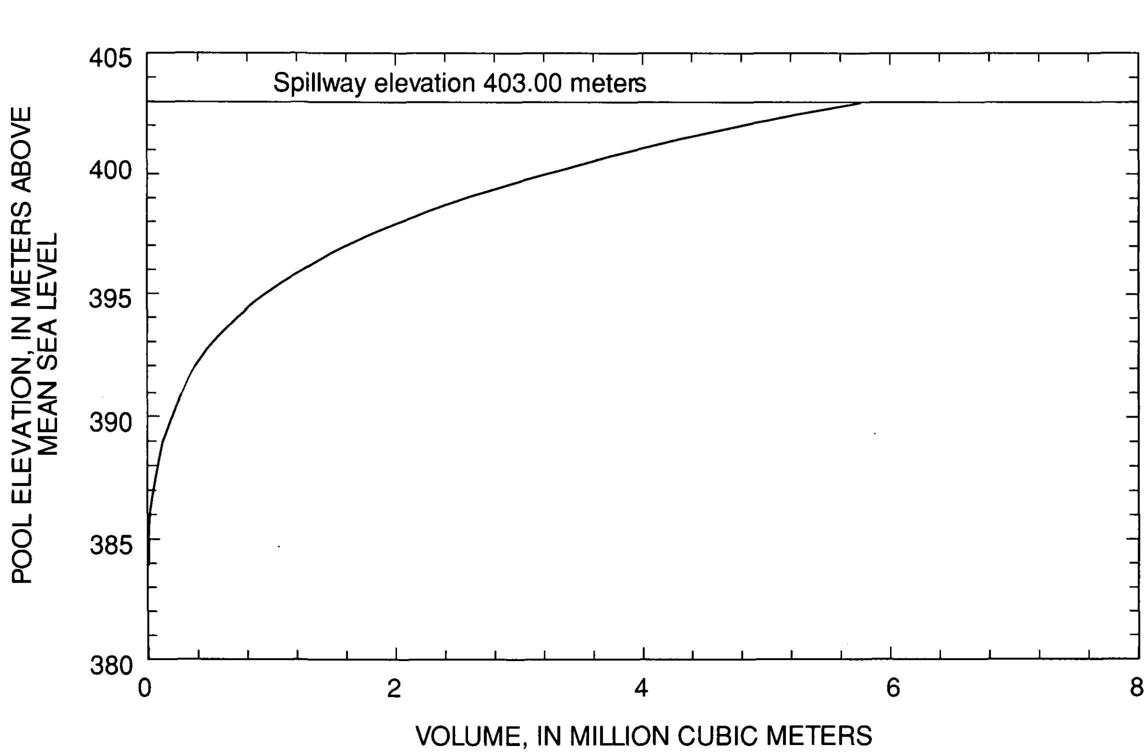

Figure 8. Capacity curve for Lago de Cidra, Puerto Rico, 1997.

Table 2. Comparison of the original 1946 and the November 1997 bathymetric surveys of Lago de Cidra, Puerto Rico

[---, not available or undetermined]

	1946	1997
Total capacity, in million cubic meters	6.54	5.76
Years since construction	0	51
Sediment accumulated, in million cubic meters	0	0.78
Storage loss, in percent	0	12
Average annual capacity loss, in cubic meters per year	---	15,200
Average annual capacity loss, in percent	---	0.2
Year reservoir is projected to fill with sediment [1]	---	2377
Live storage, in million cubic meters [2]	---	0.87
Dead storage, in million cubic meters [3]	---	4.90
Estimated sediment yield, in megagrams per square kilometer per year [4]	---	768

[1] Assuming the sedimentation rate remains constant and a trapping efficiency of 100 percent.

[2] Using the elevation of the upper intake structure (394.97 meters AMSL) of the wet well.

[3] Using the elevation of the upper intake structure (394.97 meters AMSL); the lower intake is currently under deposited material, according to the November 1997 data.

[4] Using a 98 percent trapping efficiency and a sediment dry bulk density of 1.0 gram per cubic centimeter.

The sediment yield of the Lago de Cidra basin was estimated by dividing the amount of sediment deposited in the reservoir since impoundment by the average trapping efficiency of the reservoir along its life. At the beginning the trapping efficiency of the reservoir is assumed to be 100 percent and the estimated trapping efficiency in 1997 was 96 percent. This gives an average trapping efficiency of 98 percent. The quantity of deposited material divided by the average trapping efficiency gives the net amount of material that the basin has contributed. The drainage area of the reservoir is 21.39 square kilometers. To estimate the sediment yield of the basin, the flooded area of the reservoir (1.07 square kilometer) was substracted since it does not contribute with eroded material. Based on the 20.32-square-kilometer contributing area and assuming a dry-bulk density of 1.0 gram per cubic centimeter, the sediment yield of the Lago de Cidra watershed was estimated to be 768 megagrams per square kilometer per year.

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*U.S. GOVERNMENT PRINTING OFFICE 1999-0-785-217

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Soler-López—SEDIMENTATION SURVEY OF LAGO DE CIDRA, PUERTO RICO, NOVEMBER 1997—WRIR 99-4144