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

Rec'd
12/10/9

Prepared in cooperation with the
PUERTO RICO ELECTRIC POWER AUTHORITY

Sedimentation Survey of Lago Prieto, Puerto Rico, October 1997

Water-Resources Investigations
Report 99-4169

USGS
science for a changing world

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

Sedimentation Survey of Lago Prieto, Puerto Rico, October 1997

By Luis R. Soler-López and Richard M.T. Webb

Water-Resources Investigations Report 99-4169

In cooperation with the
PUERTO RICO ELECTRIC POWER AUTHORITY

San Juan, Puerto Rico: 1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

Use of trade names in this report is for identification purposes only and does not imply endorsement by the U.S. Government.

For additional information write to:

District Chief
U.S. Geological Survey
GSA Center, Suite 400-15
651 Federal Drive
Guaynabo, Puerto Rico 00965-5703

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

PLATES

[Plates are in pocket]

FIGURES

TABLES

CONVERSION FACTORS, DATUMS, and ACRONYMS

Multiply	By	To obtain
	Length	
millimeter	0.03937	inch
meter	3.281	foot
kilometer	0.6214	mile
	Area	
square meter	10.76	square foot
square kilometer	0.3861	square mile
	Volume	
cubic meter	35.31	cubic 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)	
gram per cubic centimeter	62.43	pound per cubic foot
megagram per square kilometer	2.855	ton per square mile

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:

BLASS	Bathymetric/Land Survey System
DGPS	Differential Global Positioning System
GIS	Geographic Information System
PREPA	Puerto Rico Electric Power Authority
TIN	Triangulated Irregular Network
USGS	U.S. Geological Survey

Sedimentation Survey of Lago Prieto, Puerto Rico, October 1997

By **Luis R. Soler-López and Richard M.T. Webb**

Abstract

Lago Prieto, a reservoir built to divert water to the Southwestern Puerto Rico Project, is filling with sediment at a long-term rate of about 12,900 cubic meters per year. Only 29 percent of the original storage capacity remains in the reservoir. The storage capacity has decreased from 766,000 cubic meters in 1955 to 223,000 cubic meters in 1997. At this sedimentation rate the reservoir has a useful life of about 17 more years.

The sediment yield of the 24.8-square-kilometer drainage area is about 900 megagrams per square kilometer per year. Only 45 percent of the sediment entering the reservoir remains in it; the rest of the sediment is either spilled over the overflow structure or transported through the tunnel connection into the power generation plant above Lago Lucchetti.

INTRODUCTION

Lago Prieto is a reservoir that is part of the Southwestern Puerto Rico Project, operated by the Puerto Rico Electric Power Authority (PREPA). The system consists of a series of reservoirs connected by underground tunnels and it is used to produce hydroelectric power for the south and western parts of Puerto Rico. Agricultural practices, combined with soil erosion caused by runoff, is depleting the storage capacity of Lago Prieto, endangering the continued utility of the reservoir to produce energy.

The U.S. Geological Survey (USGS), in cooperation with PREPA, conducted a bathymetric survey of Lago Prieto to calculate the existing water storage capacity, the volume of sediment accumulated, and the sedimentation rate of the reservoir and to locate the areas of major sediment deposition within the reservoir. The results of this study will help PREPA in managing effectively the water resources available in the reservoir. On October 28, 1997, bathymetric data were collected by using a depth sounder coupled to a Differential Global Positioning System (DGPS) and the data were stored both in digital and written form. The data were transferred and analyzed by using a Geographic Information System (GIS). This analysis revealed the actual storage capacity of the reservoir and the rate at which the sediments are filling the reservoir.

DAM AND RESERVOIR CHARACTERISTICS

The Lago Prieto dam structure was completed in 1955. It is located on the Río Prieto in the west-central part of Puerto Rico, about 13 kilometers west of the town of Adjuntas (fig. 1). Lago Prieto is part of the Southwestern Puerto Rico Project and was built to provide about 863,500 cubic meters (700 acre-feet) of water storage for power generation and cropland irrigation. Although this is the reported original storage capacity, to standardize the analysis of the data the re-computed value of 766,000 cubic meters is used in this report as the original capacity. The methodology used to re-compute the original storage capacity is explained later in this report.

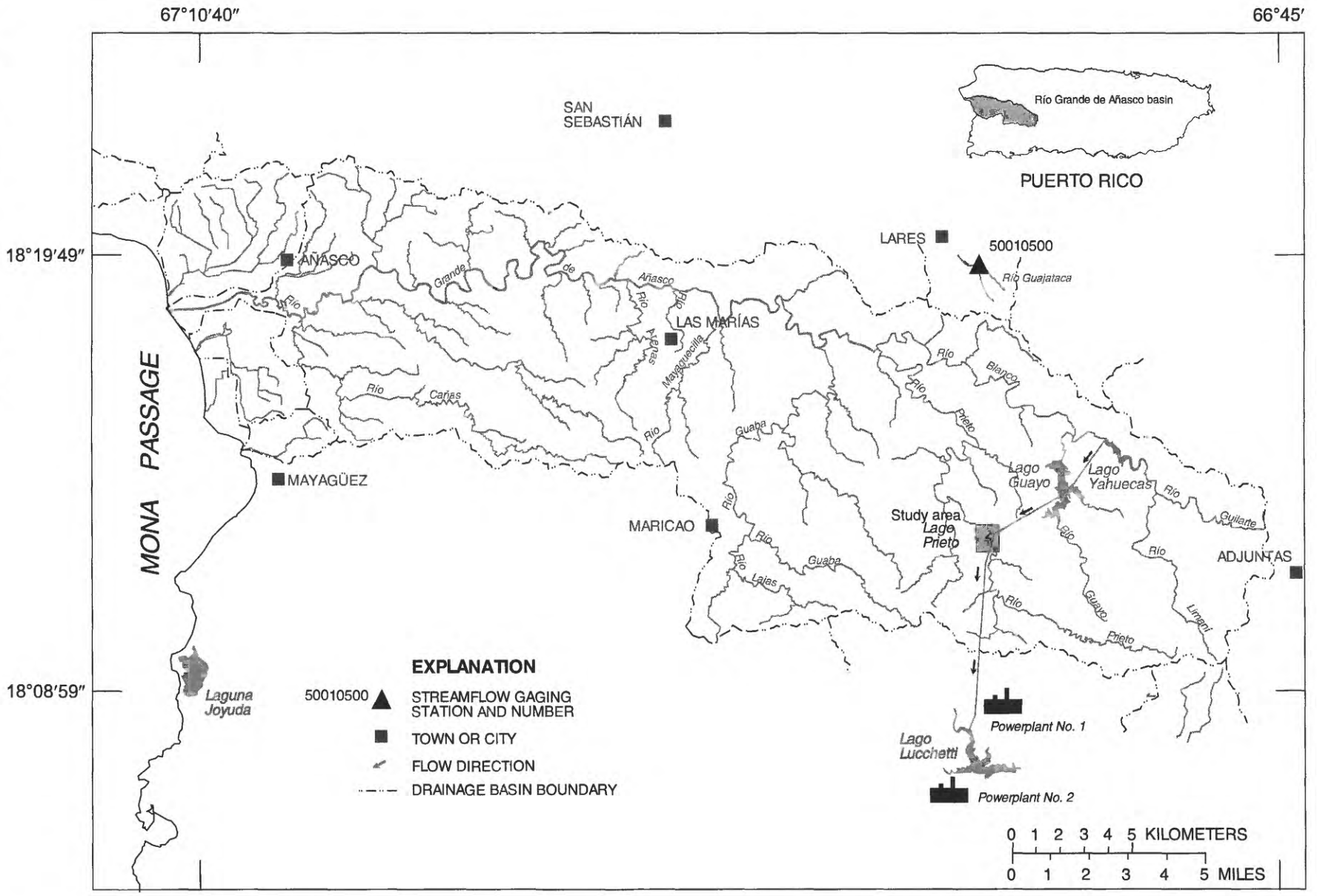

Figure 1. Location of Lago Prieto in the Río Grande de Añasco basin, Puerto Rico.

The dam is a concrete gravity structure with a length of 75.25 meters, a structural height of 29.87 meters and a base width of 19.81 meters. An ungated overflow spillway is centrally located and has an elevation of 452.63 meters above mean sea level. The spillway section has a length of 51.82 meters and is capable of managing a maximum design discharge of 906 cubic meters per second (Sheda and Legas, 1968). Water is diverted to the Lago Guayo tunnel through a diversion tunnel located at the east side of the reservoir, about 325 meters upstream of the dam. The water diverted through the Lago Guayo tunnel is used to produce electric power at Powerplant No. 1 (fig. 1). Turbine releases are then collected in the Lago Lucchetti, where power is generated at Powerplant No. 2. The principal characteristics of the Lago Prieto dam are described in table 1.

METHOD OF SURVEY

The bathymetric survey of Lago Prieto involved planning, data collection, processing, and analysis. A Geographic Information System, Arc/Info, was used to plan the cross-section locations and for the analysis of bathymetric data. Cross sections were located at a 50-meter spacing starting at the upstream face of the dam and continuing to the river mouth. Data were collected with a DGPS combined with a depth sounder. The soundings were subsequently adjusted to represent depths below the spillway elevation of 452.63 meters above mean sea level. A bathymetric map of the reservoir bottom was then developed. The original pre-impoundment storage capacity was re-calculated by digitizing a 1:20,000 topographic map and creating a surface triangulated irregular network (TIN) model using a GIS. The pool elevation of Lago Prieto during the October 1997 bathymetric survey varied. To monitor the pool elevation during the survey, a reference point was established at the left side of the nonoverflow structure of the reservoir and tape down readings were made at the beginning, several times during the data collection process, and at the end of the survey. To convert the depth soundings to depths at the spillway elevation of 452.63 meters above mean sea level, a time-elevation correction factor was applied.

Table 1. Principal characteristics of Lago Prieto and dam as of 1955 (Sheda and Legas, 1968)

[All elevations are in meters above mean sea level]

Total length of dam at top (spillway and nonoverflow section)	75.25 meters
Length of spillway section	51.82 meters
Elevation of spillway crest	452.63 meters
Maximum length at base	19.81 meters
Normal volume at spillway elevation[1]	863,500 cubic meters
Original recomputed volume at spillway elevation[2]	766,000 cubic meters
Maximum design discharge at spillway elevation	906 cubic meters per second
Maximum structural height	29.87 meters
Drainage area at dam site	24.8 square kilometers
Maximum depth during the 1997 survey	9.80 meters
Maximum depth of the original normal pool	22.6 meters
Elevation of sluiceway structure	433.43 meters
Elevation of tunnel intake structure	441.66 meters

[1] Original reported capacity.
[2] Original volume recomputed by using the TIN surface model of the 1955 preimpoundment topography.

Field Techniques

Data were collected on October 28, 1997, by using the bathymetric/land survey system (BLASS), developed by Specialty Devices, Inc. The system uses two Motorola SixGun DGPS receivers for horizontal positioning of the survey boat. The DGPS receivers were first used in static mode to establish a reference mark at a site overlooking the reservoir. Satellite information was simultaneously recorded at a previously established control station GUAYO-1 (lat 18°11'50.534" N., long 66°50'02.404" W.) and at a new reference station PRIDAM-97 (lat 18°11'16.179" N., long 66°51'51.961" W.). Once the reference station PRIDAM-97 was established, a DGPS receiver was installed there as the base station and the other 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 pseudorange corrections from the base station every 5 seconds to maintain a positional accuracy within 2 meters. Depths were measured by using a RAYTHEON DE-719 depth recorder coupled to an ODOM DIGITRACE that converts the depth data into digital form. The depth recorder measures depth to the nearest 0.1 meter and was calibrated in water depths of 2 and 6 meters. The bathymetric survey software HYPACK (Coastal Oceanographics, Inc.) received and recorded the geographic positions and depths once every second while in survey mode. HYPACK runs on a portable personal computer and is used to record depth data and to navigate.

At the beginning of the project, a total of 23 cross sections at a 50-meter spacing were planned. Since Lago Prieto is not shown on the USGS Monte Guilarte topographic quadrangle (revised on 1960), the exact location of the dam was not available for cross-sectional planning, and two of the planned cross sections were located on the downstream side of the dam. To obtain a more accurate location of the dam, the dam was then surveyed by using the DGPS. Once the dam was located in the topographic quadrangle, a total of 21 cross sections at a 50-meter spacing were planned (fig. 2). The reference longitudinal distances measured in Lago Prieto are shown in figure 3.

Because of sediment accumulation in the upper reach of the reservoir and a low-pool elevation during the survey, only the first eight cross sections were surveyed (fig. 4). Also, a random survey along a route extending from the existing reservoir tail down to the dam was conducted.

Data Processing

Initial editing and verification of the positional and depth data was performed within the HYPACK program. Sounding positions were corrected to eliminate anomalous spikes. Spikes or jumps in the positional data may occur when the reception of the satellite signal is obstructed by local topographic features or is disrupted by electromagnetic interference. In such instances, the locations of the soundings were interpolated from the midpoints between the correct antecedent and posterior positions.

Depth contours were drawn at variable intervals, from the deepest part of the reservoir up to the shoreline (plate 1). Data points were color coded so each depth range had different colors. The bathymetric contour lines were then converted into a surface model by creating a TIN. The TIN models the lake bottom as thousands of adjoining triangles with x, y, and z coordinates assigned to each vertex. The reservoir volume was then calculated at incremental pool elevations of 1 meter to develop a stage-storage curve. A contour map (plate 2) and TIN surface model of the original 1955 preimpoundment topography was also produced by using a 1:20,000 scale topographic map. Then, the original 1955 storage capacity was calculated.

Selected cross sections describing the 1955 and 1997 TIN generated lake bottom are plotted in figure 5 to show the amount of sediment that has been deposited since the reservoir was impounded. Longitudinal profiles for 1955 (generated from the 1955 TIN) and 1997 along the thalweg of Lago Prieto are shown in figure 6.

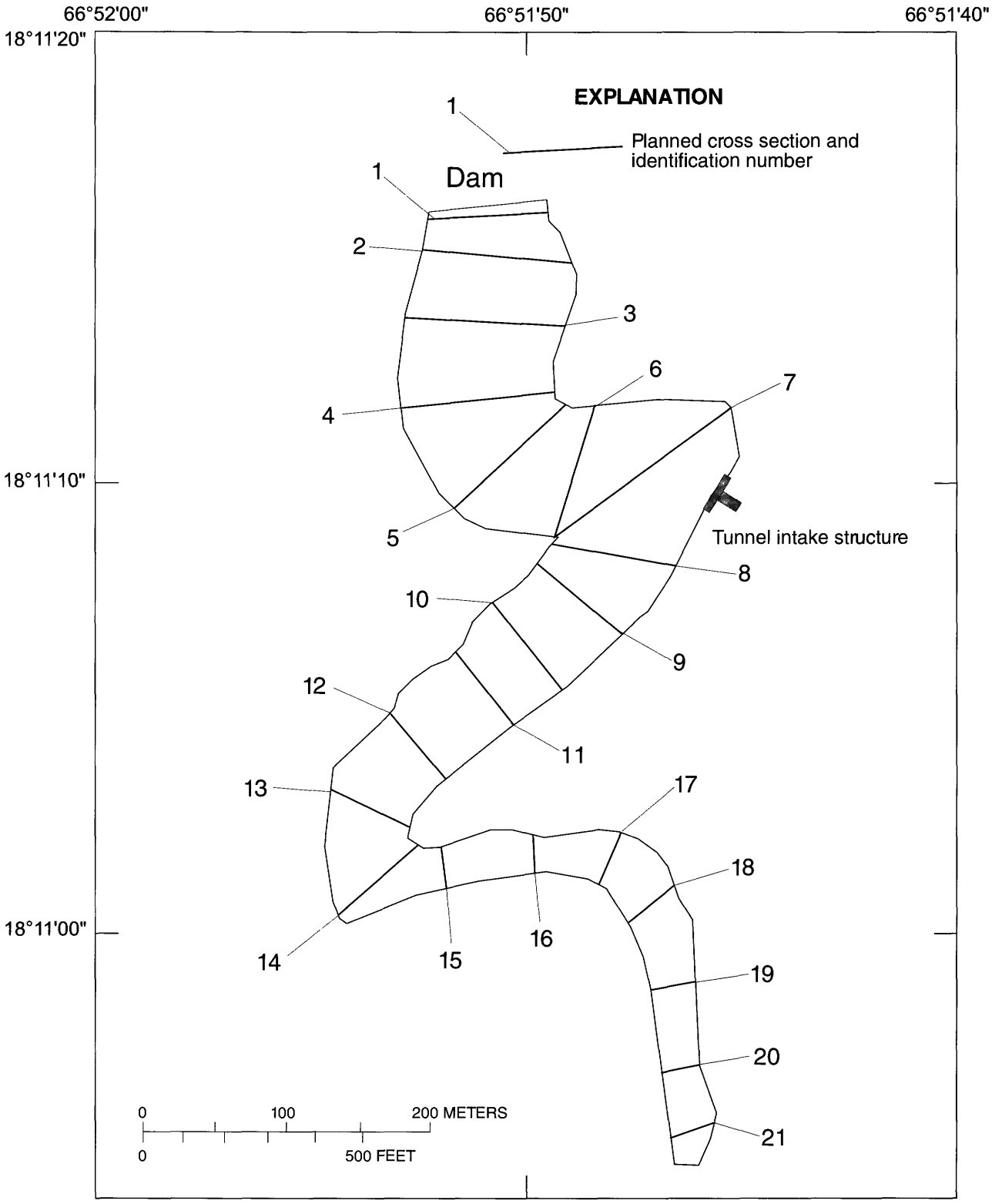

Figure 2. Planned cross-section locations for the October 1997 bathymetric survey of Lago Prieto, Puerto Rico.

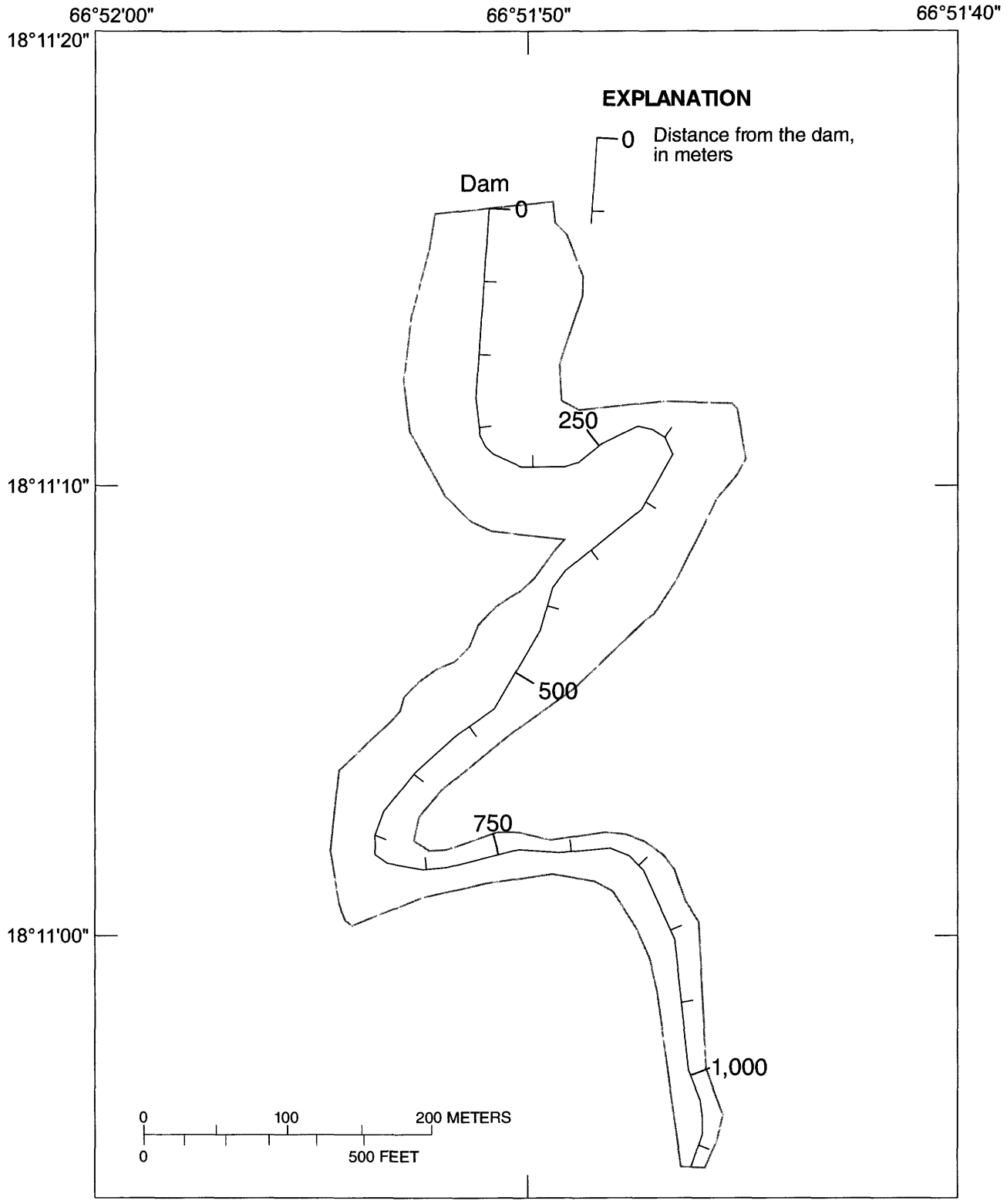

Figure 3. Reference distances for longitudinal profiles measured in Lago Prieto, Puerto Rico, during the October 1997 bathymetric survey.

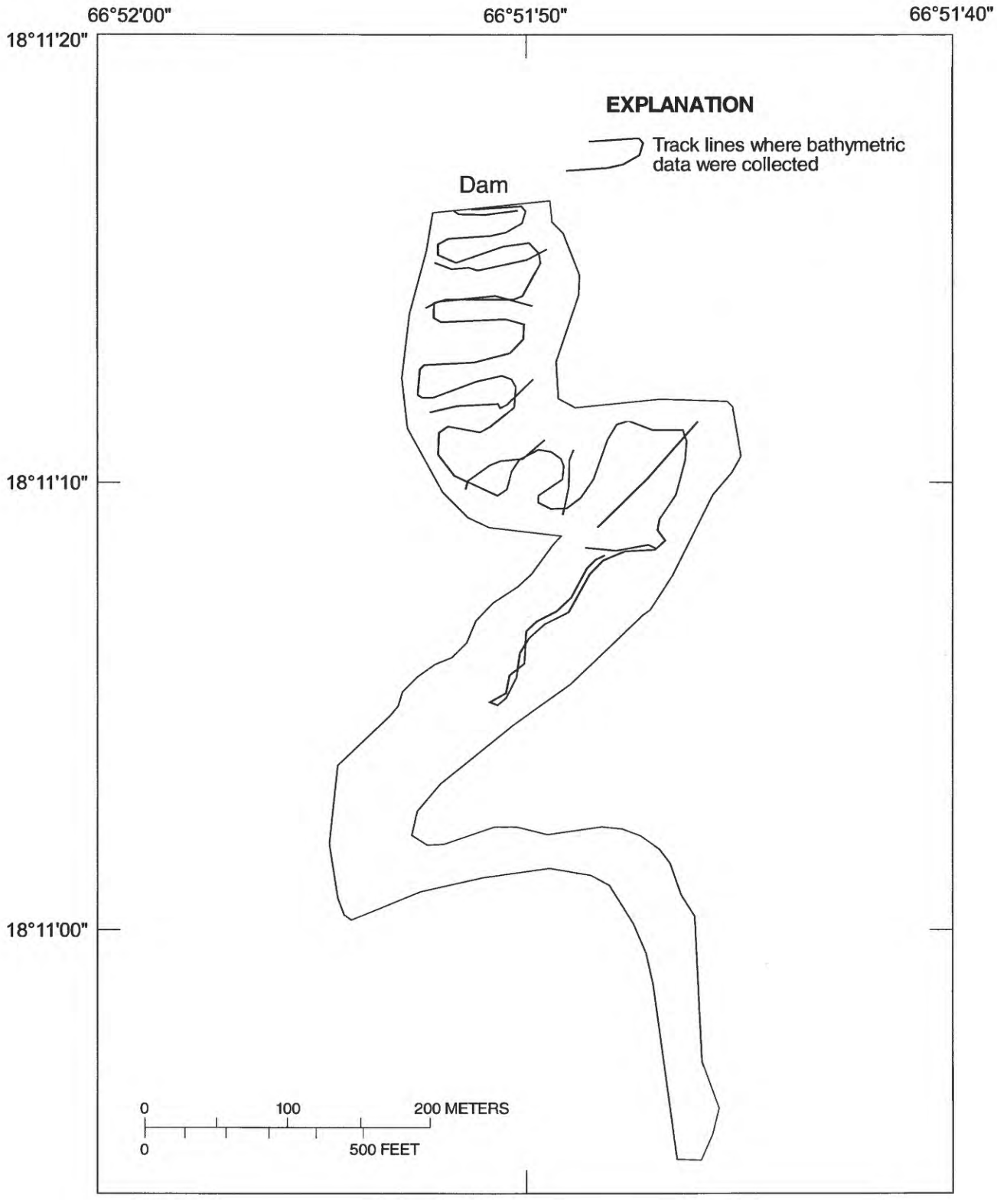

Figure 4. Actual track lines of the October 1997 bathymetric survey of Lago Prieto, Puerto Rico.

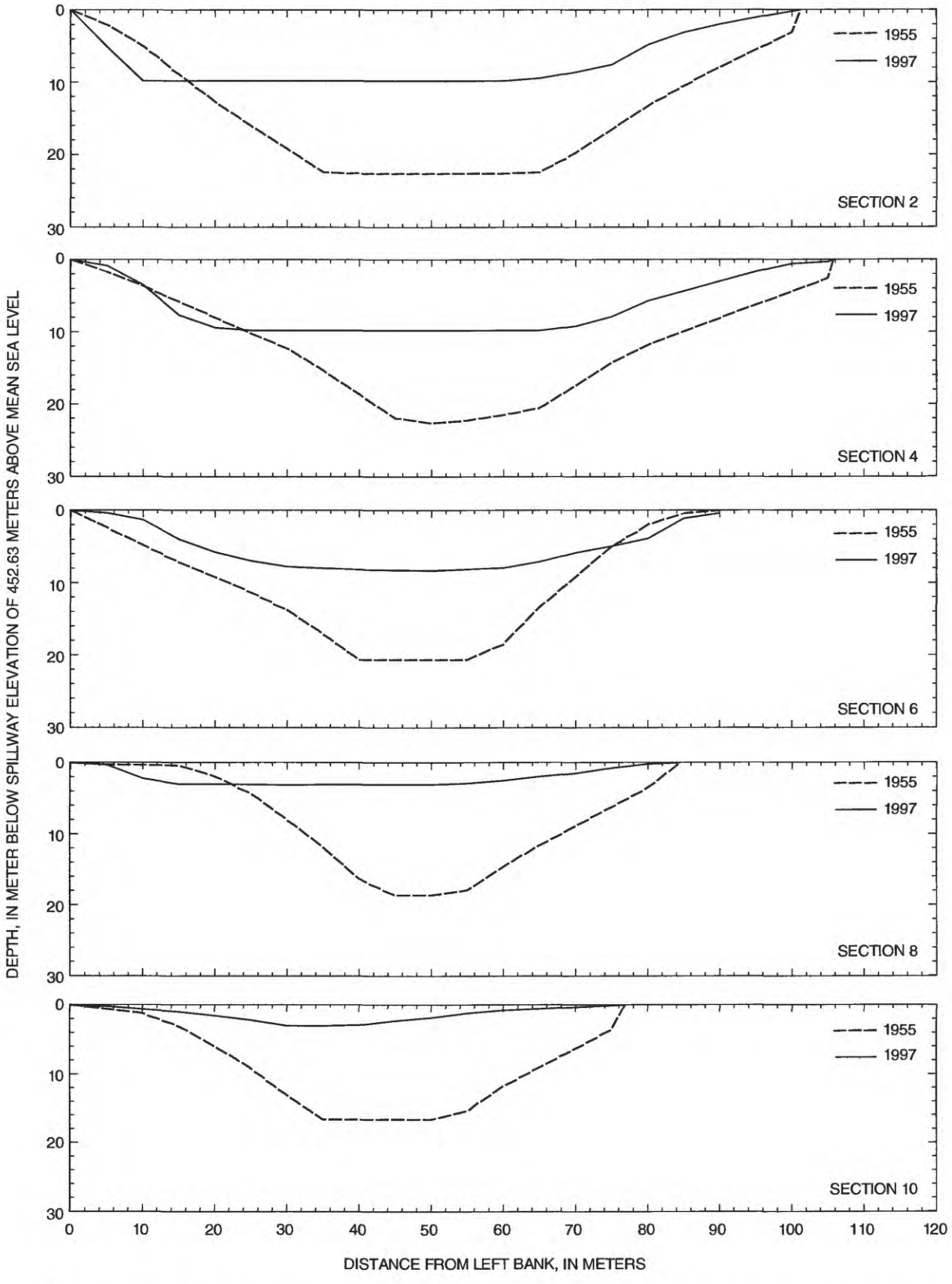

Figure 5. Selected 1955 TIN-generated cross sections and the 1997 TIN-generated cross sections. [Cross sections are oriented with the observer looking in the downstream direction. Refer to figure 2 for the location of each cross section.]

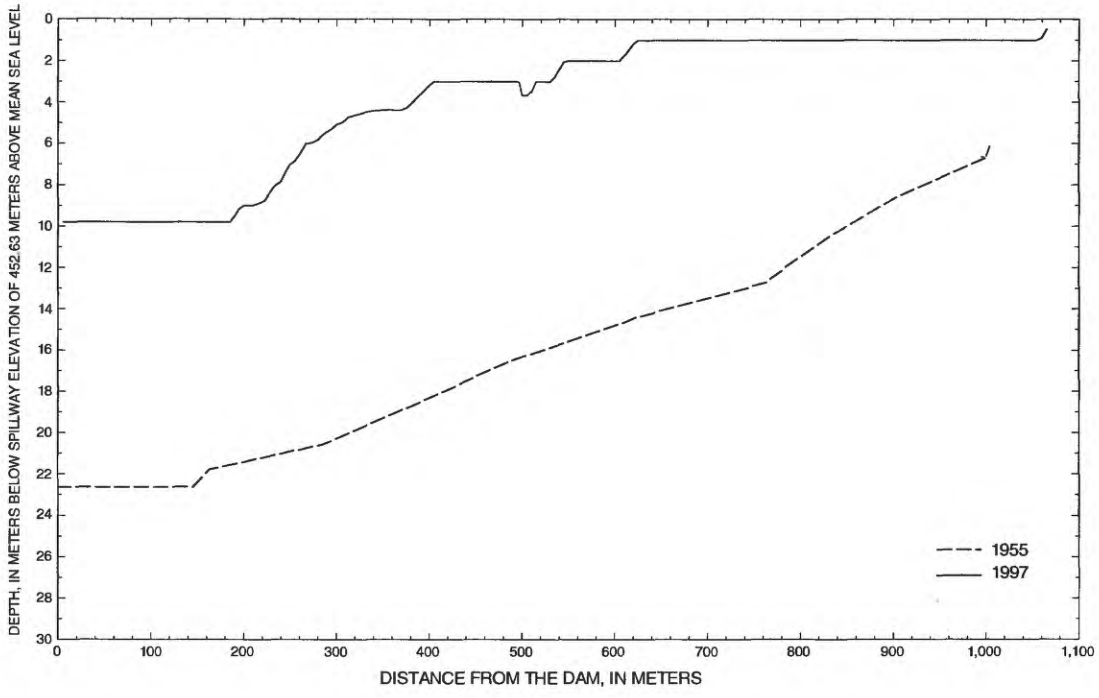

Figure 6. Longitudinal profiles for 1955 and 1997, along the thalweg Lago Prieto, Puerto Rico.

ACTUAL CAPACITY AND SEDIMENT ACCUMULATION

The Lago Prieto storage capacity decreased from 766,000 cubic meters in 1955 to 223,000 cubic meters in 1997, which represents a reduction of 71 percent. The relation between the pool elevation and the storage capacity for 1955 and 1997 is shown in figure 7. Since impoundment, the reservoir has been losing storage capacity at a long-term average rate of about 12,900 cubic meters per year (10.46 acre-feet per year). This represents a loss of capacity of 1.7 percent per year. Although at this sedimentation rate the reservoir has a life expectancy of about 17 years before it is completely filled with sediment, this estimation is made assuming that the trapping efficiency of the reservoir remains constant. However, this life expectancy is very likely to be greater since the trapping efficiency decreases as the reservoir becomes shallower as a result of sediment accumulation.

In 1990, a bathymetric survey was conducted by the USGS at a water elevation of 448.05 meters above mean sea level. The unpublished data were adjusted to reflect the volume at spillway elevation of 452.63 meters above mean sea level. The results of the 1955 recomputed capacity and the 1990 and 1997 sedimentation surveys are compared in table 2.

A layer about 12-meter thick has been deposited in the vicinity of the dam in 42 years (fig. 5). Because the reservoir bottom has reached an elevation of 443.0 meters above mean sea level in this area, the sluiceway structure, which is at an elevation of 433.43 meters above mean sea level, is under a 10-meter thick layer of deposited material. The reservoir has the tunnel intake structure at the right bank, about 325 meters upstream from the dam. It is located at a meander that serves as a natural sediment trap (fig. 2). In this area, sediment accumulation has been so extensive that the intake opening is hampered by 4 meters of sediment leaving open about 0.5 meter of the intake. Deposition in this area is about 15 meters thick. At the current sedimentation rate, it is very possible that the tunnel intake structure is on the verge of becoming completely inoperative.

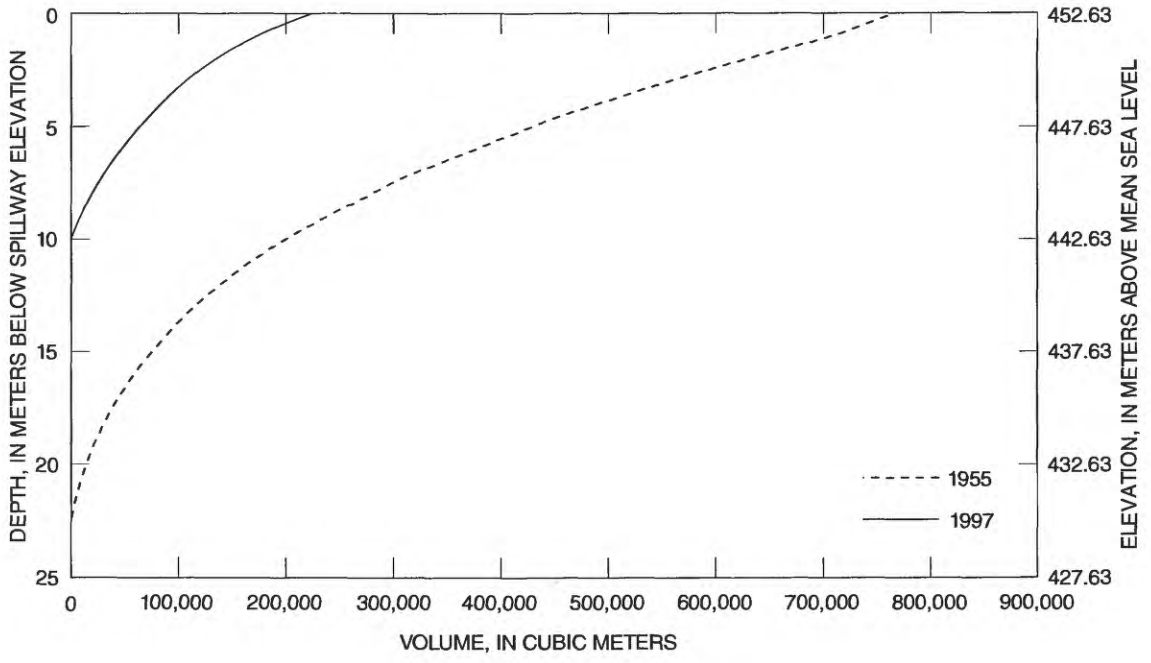

Figure 7. Relation between pool elevation and volume derived from the 1955 and 1997 TIN surface models of Lago Prieto, Puerto Rico.

Table 2. Comparison of the 1955, 1990, and 1997 sedimentation surveys of Lago Prieto, Puerto Rico

[---, not available or undetermined]

	Year of survey		
	1955	1990	1997
Capacity at spillway elevation of 452.63 meters above mean sea level (cubic meters)	766,000	308,000	223,000
Years since construction	0	35	42
Sediment accumulated (cubic meters)	0	458,000	543,000
Storage loss (percent)	0	59.8	71
Long-term annual loss of capacity (cubic meters)	0	13,100	12,900
Annual loss of capacity (percent)	0	1.7	1.7
Sediment yield (megagrams per square kilometer per year)	---	775	900
Surface area (square meters)	92,650	---	59,500
Intersurvey sedimentation rate (cubic meters per year)	0	13,100	12,100
Years until reservoir is completely filled with sediment (at current rate)	---	24	17

TRAPPING EFFICIENCY AND SEDIMENT YIELD

The trapping efficiency of the reservoir was estimated by using the capacity/inflow ratio described by Brune (1953). Since there is no stream gaging station on the Río Prieto to measure the inflow entering the reservoir, the neighboring Río Guajataca at Lares gaging station (USGS station number 50010500) was used to estimate the runoff of the Lago Prieto basin. Average annual rainfall at this gaging station is 2,290 millimeters (Calvesbert, 1970) and average runoff for the 27 years of record is 713 millimeters per year (Díaz and others, 1996). This gives a runoff/rainfall ratio of 0.31. The basin of Río Prieto upstream of Lago Prieto has the same average annual rainfall of 2,290 millimeters (Calvesbert, 1970). Based on the 24.8-square kilometer drainage area of Lago Prieto, the average annual runoff entering the reservoir is 22.7 million cubic meters. By using Brune's curve, the trapping efficiency of Lago Prieto is estimated to be about 45 percent.

The sediment yield of the reservoir catchment was estimated by averaging the trapping efficiency of the reservoir when it was constructed and the 1997 trapping efficiency. By using the capacity/inflow ratio relation, the 1955 trapping efficiency was estimated to be 70 percent and averaged 58 percent for the period 1955-97. Dividing the sediment accumulated until 1997 (543,000 cubic meters) by the average trapping efficiency (0.58) results in a volume of 936,000 cubic meters of sediment in 42 years or 22,300 cubic meters per year. Based on the 24.8 square kilometers and using an estimated dry-bulk density of 1 gm/cm^3, the sediment yield of the Lago Prieto basin was estimated to be about 900 megagrams per square kilometer per year.

REFERENCES

Brune, G.M., 1953, Trap efficiency of reservoirs: Transactions of the American Geophysical Union, v. 34, no. 3, p. 407-418.

Calvesbert, R.J., 1970, Climate of Puerto Rico and the U.S. Virgin Islands: U.S. Department of Commerce, Environmental Science Services Administration, 29 p.

Díaz, P.L, Aquino, Zaida, Figueroa-Álamo, Carlos, Vachier, R.J., and Sánchez, A.V., 1997: Water Resources Data Puerto Rico and the U.S. Virgin Islands Water Year 1996: U.S. Geological Survey Water-Data Report PR-96-1, p. 548.

Sheda, H.E., and Legas, James, 1968, Condition of concrete dams in Puerto Rico, *in* Section 7, Condition of Prieto Dam, Puerto Rico: Prepared for Puerto Rico Water Resources Authority, Puerto Rico Aqueduct and Sewer Authority by the U.S. Department of Interior, Bureau of Reclamation, 10 p., 3 pls.