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

Prepared in cooperation with the
PUERTO RICO ELECTRIC POWER AUTHORITY

Sedimentation Survey of Lago Lucchetti, Puerto Rico, March 2000

Water-Resources Investigations
Report 01-4105

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

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By Luis R. Soler-López

Water-Resources Investigations Report 01-4105

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San Juan, Puerto Rico: 2001

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[Plates are in pocket]

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CONVERSION FACTORS, DATUMS, ACRONYMS, and TRANSLATIONS

Multiply	By	To obtain
	Length	
centimeter	0.03281	foot
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 centimeter	0.06102	cubic inch
cubic meter	35.31	cubic foot
cubic meter	0.0008107	acre-foot
million cubic meters	810.7	acre-foot
	Volume per unit time (includes flow)	
cubic meter per second	35.31	cubic feet per second
cubic meter per second	15,850	gallon per minute
cubic meter per second	22.83	million gallons per day
	Mass per area (includes sediment yield)	
gram per cubic centimeter	62.43	pound per cubic foot
kilogram per square kilometer	0.002855	ton per square mile
megagram per square kilometer	2.855	ton per square mile
megagram per year	1.102	ton per year

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 the United States and Canada, formerly called "Seal 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
SWPRP	Southwestern Puerto Rico Project
TIN	Triangulated Irregular Network
USGS	U.S. Geological Survey

Translations

Spanish	English
Lago	Lake (in Puerto Rico, also reservoir)
Río	River

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By **Luis R. Soler-López**

Abstract

Lago Lucchetti, a reservoir of the Southwestern Puerto Rico Project, is filling with sediments at a long-term sedimentation rate of about 0.18 million cubic meters per year. The reservoir storage capacity has been reduced from 20.35 million cubic meters in 1952 to 15.84 million cubic meters in 1986 and to 11.88 million cubic meters in March 2000. This represents a total storage capacity loss of about 42 percent (8.47 million cubic meters) since construction in 1952 or an average long-term storage loss of 0.9 percent per year. The sedimentation rate was 0.13 million cubic meters per year in 1986, increasing to 0.18 million cubic meters per year in 2000. The trapping efficiency of Lago Lucchetti was about 97, 96, and 95 percent for 1952, 1986, and March 2000 respectively, resulting in an average of 96 percent. The sediment yield of the reservoir basin was 906 megagrams per square kilometer per year in 1986, increasing to 1,255 megagrams per square kilometer per year in March 2000, which represents a 38 percent increase. In 1986 the life expectancy of Lago Lucchetti was about 122 more years, however, at the current long-term sedimentation rate or storage capacity loss, the reservoir has a useful life of about 66 more years; Lago Lucchetti would fill with deposited material by the year 2066 if the rate remains constant.

Sumario

El Lago Lucchetti, uno de los embalses del Proyecto del Suroeste de Puerto Rico, se está llenando de sedimento a una tasa a largo plazo de un 0.18 millón de metros cúbicos al año. La capacidad de almacenamiento del embalse se ha reducido de 20.35 millones de metros cúbicos en 1952 a 15.84 millones de metros cúbicos en 1986 y a 11.88 millones de metros cúbicos para marzo de 2000. Esto representa una pérdida total de capacidad de almacenamiento de un 42 por ciento (8.47 millones de metros cúbicos) desde su construcción en 1952 o una pérdida promedio a largo plazo de 0.9 por ciento al año. La tasa de sedimentación en 1986 era de 0.13 millones de metros cúbicos al año, la cual aumentó a 0.18 millones de metros cúbicos al año en el año 2000. La eficiencia de Lago Lucchetti para atrapar sedimento era de un 97, 96, y 95 por ciento para 1952, 1986, y marzo de 2000 respectivamente, lo cual constituye un promedio de 96 por ciento. El rendimiento de sedimento de la cuenca del emblse era de 906 megagramos por kilómetro cuadrado al año en 1986, el cual aumentó a 1,255 megagramos por kilómetro cuadrado al año en marzo de 2000, lo cual constituye un aumento de 38 por ciento. En 1986, la expectativa de vida del Lago Lucchetti era de unos 122 años más, sin embargo, a partir de la tasa actual de sedimentación a largo plazo o de pérdida de capacidad de almacenamiento, la vida útil del embalse es de unos 66 años más; El Lago Lucchetti se llenaría de material depositado para el año 2066, si esta tasa de sedimentación permaneciera constante.

INTRODUCTION

The Puerto Rico Power Electric Authority (PREPA) operates the Southwestern Puerto Rico Project (SWPRP), which consists of a series of reservoirs connected by underground tunnels and is used for hydroelectric power generation and for crop irrigation in southwestern Puerto Rico. Among these reservoirs is Lago Lucchetti, which provided about 20.35 million cubic meters of water storage capacity when constructed in 1952. Lago Lucchetti, which has a drainage area of 44.81 square kilometers, also receives inflow from the upland Lago Guayo, Lago Prieto, Lago Toro, and Lago Yahuecas through underground tunnels. The effective drainage area of Lago Lucchetti varies, depending on the seasonal rainfall magnitudes and operation of the upper reservoir tunnels. In addition, Lago Lucchetti discharges water through an underground tunnel to Lago Loco.

Rapid sediment accumulation in Lago Lucchetti has reduced storage capacity, which has diminished the water resources available for power generation and irrigation. High average annual rainfall (2,032 millimeters, Calvesbert, 1970) combined with steep slopes and agricultural land practices in the reservoir basin promote erosion and transport of sediments into Lago Lucchetti.

To assess the extent of storage capacity loss through sediment accumulation, the U.S. Geological Survey (USGS) in cooperation with PREPA conducted a bathymetric survey of Lago Lucchetti during March 2000. Data on geographic position and water depths were acquired simultaneously by using a differential global positioning system (DGPS) interfaced to a depth sounder. The field-collected data were then transferred into a geographic information system (GIS), which was used to determine the existing storage capacity, sedimentation rates, sediment distribution, and to predict the useful life of the reservoir. This report provides PREPA officials with the necessary information to manage effectively the water resources available and to develop strategies to mitigate the storage capacity loss in Lago Lucchetti.

DAM, RESERVOIR, AND BASIN CHARACTERISTICS

The Lago Lucchetti dam structure was completed in 1952. It is located on the Río Yauco, in southwestern Puerto Rico, about 7 kilometers north of the town of Yauco (fig. 1). The dam was designed to provide about 20.35 million cubic meters of water storage for hydroelectric power generation and for irrigation of croplands in the Lajas Valley. The dam is a concrete gravity structure with a length of 174.04 meters, a maximum height of 54.25 meters and a maximum basal width of 45.72 meters (table 1).

Table 1. Principal characteristics of Lago Lucchetti and Lucchetti dam, Puerto Rico (modified from Sheda and Legas, 1968)

Total length of dam, in meters	174.04
Maximum height of dam, in meters	54.25
Total length of non-overflow sections, in meters	122.83
Crest elevation of non-overflow sections, in meters above mean sea level	179.83
Length of spillway section, in meters	52.12
Crown elevation of sluiceway structure, in meters above mean sea level	136.25
Crest elevation of spillway structure, in meters above mean sea level	173.74
Maximum discharge capacity at head of 6.10 meters, in cubic meters per second	1,778
Length of power tunnel, in meters	3,368
Drainage area at damsite, in square kilometers	44.81
Maximum depth during the March 2000 bathymetric survey, in meters	25.5

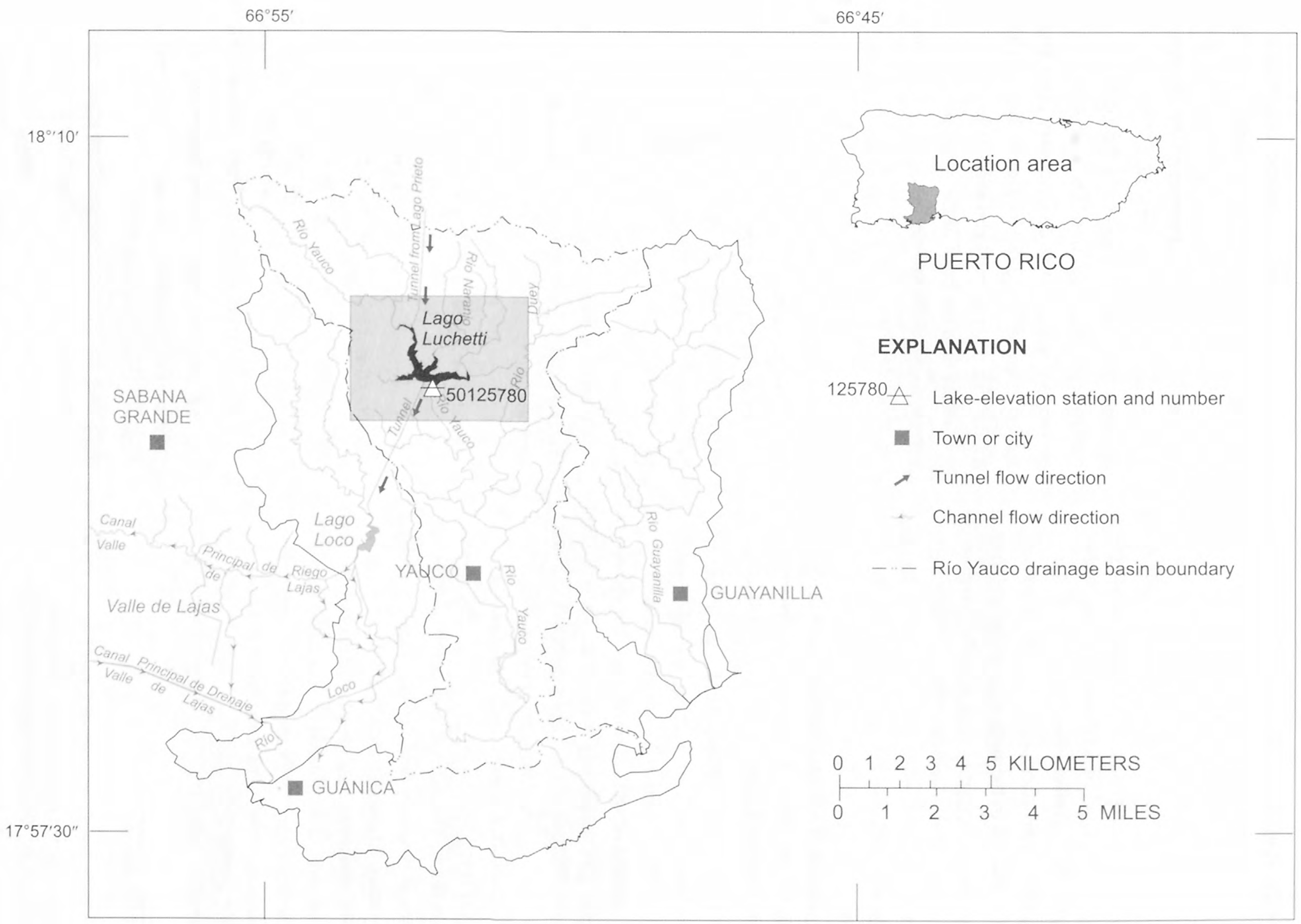


Figure 1. Location of Lago Lucchetti and the Río Guayanilla, Río Yauco, and Río Loco basins, Puerto Rico.

The non-overflow sections of the dam (left and right abutments) have a combined length of 122.83 meters and a crest elevation of 179.83 meters above mean sea level. An ungated, overflow-type spillway, with a clear length of 52.12 meters and a crest elevation of 173.74 meters above mean sea level, occupies the central portion of the dam. The spillway was designed for a maximum discharge of 1,778 cubic meters per second at a design head of 6.10 meters. Nine timber flash boards were installed after construction, but removed shortly thereafter. A 1.22-meter-diameter sluiceway is located in the right side of the spillway section and has a crown elevation of 136.25 meter above mean sea level. The intake for a 3,368-meter-long and 3.50-meter-diameter power tunnel is located on the right side of the reservoir (facing downstream), about 0.4 kilometers upstream from the dam. The tunnel terminates in a 2.44-meter-diameter penstock that conveys water to two 5,000-kilowatt generators in power plant number 2 (Sheda and Legas, 1968).

The Lago Lucchetti basin is located within the Consumo-Humatas soil association in southwestern Puerto Rico. The Consumo-Humatas association generally consists of well-drained soils that are very strongly acid and moderately permeable. These soils formed from weathered to highly weathered volcanic rock and tuffaceous mudstone. Hill slopes range from 12 to 60 percent. In a representative profile, the surface layer is reddish-brown, very acid clay about 15 centimeters thick. The subsoil, to a depth of 50 centimeters, is red, very acid, friable, slightly sticky and plastic clay. The substratum is thick, very acid, very friable, nonsticky slightly plastic clay loam. The depth to the semi-consolidated rock is more than 1.2 meters. The soils are mostly used for pasture, coffee, and subsistence crops, with some areas in brush (Gierbolini, 1975).

METHOD OF SURVEY

The bathymetric survey of Lago Lucchetti involved planning, data collection, and data processing and analysis. An Arc/Info GIS was used to plan the survey and to analyze collected data. Cross sections were planned at a spacing of 50 meters, starting at the dam and continuing upstream along the different branches of Lago Lucchetti (fig. 2). Bathymetric data were collected during March 2000 using a depth sounder coupled to a DGPS to control the horizontal position of the survey boat. A geo-referenced digital map of the reservoir shoreline and planned cross sections were loaded into the portable personal computer and served as the guide for bathymetric data collection. The reservoir pool elevation was monitored continuously at the lake-level station number 50125780 located at the damsite, near Yauco (fig. 1). The pool elevation of Lago Lucchetti was lower than the crest of the spillway during the survey, so the collected depth data were adjusted to represent depths at the spillway elevation by applying a time-elevation correction factor.

The adjusted depths along the cross sections were plotted, and using a computer mouse, contour lines of equal depth for the March 2000 bathymetric survey were drawn manually at variable intervals from the shoreline to the deepest parts of the reservoir. The procedure used to contour the reservoir bottom is explained later in this report. These contour lines were then converted into a triangulated irregular network (TIN) describing the surface model of the reservoir bottom. The GIS utilized the TIN to calculate the storage capacity, the amount, and the location of sediment accumulation. In addition, a 1986 bathymetric map of Lago Lucchetti (F. Quiñones, USGS, written commun., 1986) was scanned, geo-referenced and loaded into the GIS, from which a TIN model was developed and the storage capacity of Lago Lucchetti for 1986 was determined. The 1986 volume was then compared with the March 2000 volume to calculate sedimentation rates from 1986 to 2000.

A stage-storage curve for both years was generated by calculating the reservoir volume at 1-meter depth intervals. Selected cross sections depicting the reservoir bottom from shore to shore, as well as longitudinal profiles of the reservoir bottom along the thalweg of the different branches of the reservoir were constructed from the 1986 and March 2000 TIN surface models.

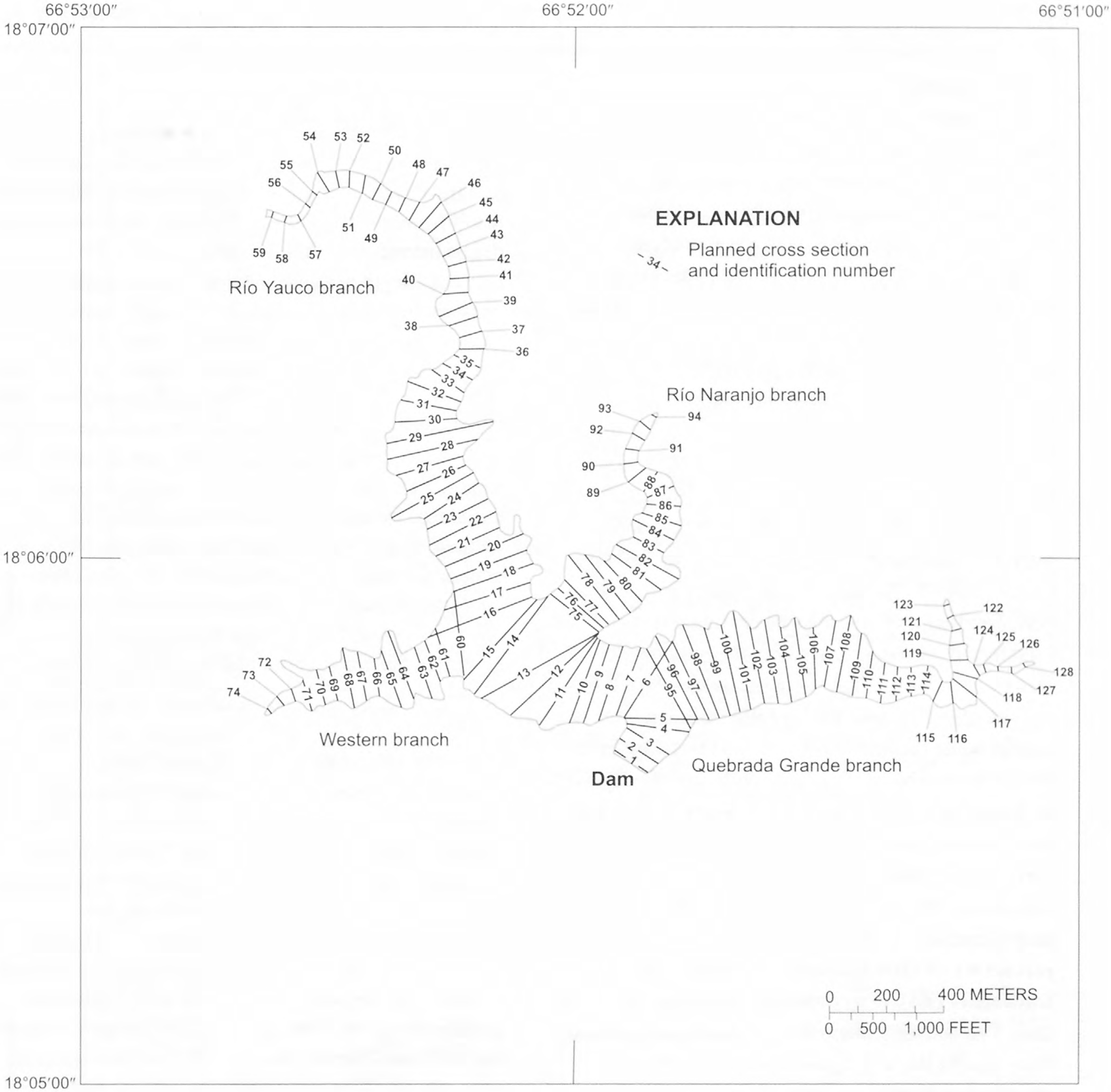


Figure 2. Planned cross-section locations for the March 2000 bathymetric survey of Lago Lucchetti, Puerto Rico.

Field Techniques

The bathymetric survey of Lago Lucchetti took place during March 8 to 9, 2000. Data were collected using the BLASS developed by Specialty Devices, Inc. The system consists of two Novatel global positioning system (GPS) receivers coupled to a Depth Sounder model SDI-IDS Intelligent. The GPS receivers monitor the horizontal position of the survey boat while the depth sounder collects water-depth data. The GPS units were first used in static mode to establish benchmarks at three sites overlooking the reservoir. Satellite information was recorded simultaneously at the Centro de Recaudación de Ingresos Municipales benchmark "Lajas 2" (latitude 18°04'26.3034"N., longitude 66°57'34.4487"W.) and at three sites overlooking the reservoir. Then, the benchmark coordinates for "Lucchetti 1" (latitude 18°05'35.9403"N., longitude 66°51'51.1122"W.), "Lucchetti 2" (latitude 18°05'38.6422"N., longitude 66°51'55.6031"W.), and "Lucchetti 3" (latitude 18°05'41.7417"N., longitude 66°52'00.6894"W.) were calculated using the post-processing software CENTIPOINT. These new benchmarks indicated a horizontal error of less than 10 centimeters. Once established, the benchmark with the best view of the area to be surveyed was occupied as the reference station. One GPS unit was installed at the reference station while the other GPS unit was installed in the survey boat to be used as the mobile station. The GPS on board the survey boat independently calculates a position every second while receiving a set of correction signals from the reference station, converting the system into a DGPS. This combination maintained the survey boat horizontal position precision to within 2 meters. The bathymetric survey software HYPACK was used to navigate and to collect data. The software integrates the depth and position data, storing the x, y, (geographic location) and z (depth) coordinates in a portable personal computer.

A total of 128 cross sections were planned in the office using the GIS (fig. 2); however, low reservoir pool elevation and sediment accumulation in riverine areas limited the data collection to 83 track lines (fig. 3).

Data Processing

Initial editing to verify the position and depth data was performed using the HYPACK software. Positions were corrected to eliminate anomalies that occur when the correction signal from the reference station is lost because of local topographic features or electromagnetic interference. Position errors were corrected by interpolating back to the middle point between the correct anterior and posterior positions. The depth readings were also corrected to eliminate incorrect depth readings. Incorrect depth readings can result from insufficient signal gain or because floating debris interferes with the transducer face. The incorrect depth readings were also interpolated between the correct anterior or posterior depth readings. Once corrected, the edited data were then transferred into the GIS database, where the rest of the data processing took place. The Arc/Info software was customized to color-code the depth values according to different depth ranges. Then, the data points of the March 2000 bathymetry with the same color were connected by adding a line between them, and a contour map of the reservoir bottom depth was generated (plate 1). Since contours from the 1986 bathymetric survey were already delineated (plate 2), the only adjustments were to digitize and geo-reference the map (assign real-world coordinates).

The bathymetric contour maps (plates 1 and 2) were used to create the TIN surface models of the reservoir bottom for March 2000 and 1986, respectively. Selected cross sections representing specific areas of the reservoir bottom are shown in figure 4. Sampling the TINs every 5 meters along selected cross sections generated profiles representing the reservoir bottom from shore to shore for September 1986 and March 2000 (fig. 5). The same procedure used in generating the selected cross-section profiles was employed to generate the longitudinal profiles along the different branches of Lago Lucchetti for 1986 and March 2000 (fig. 7). The selected cross sections (fig. 4) were located to represent flooded areas of reservoir whereas the longitudinal profiles (fig. 6) were located at the deepest part of the branches. By overlaying the 1986 and 2000 selected cross sections, it was possible to calculate the thickness of sediment layer in specific areas of the reservoir.

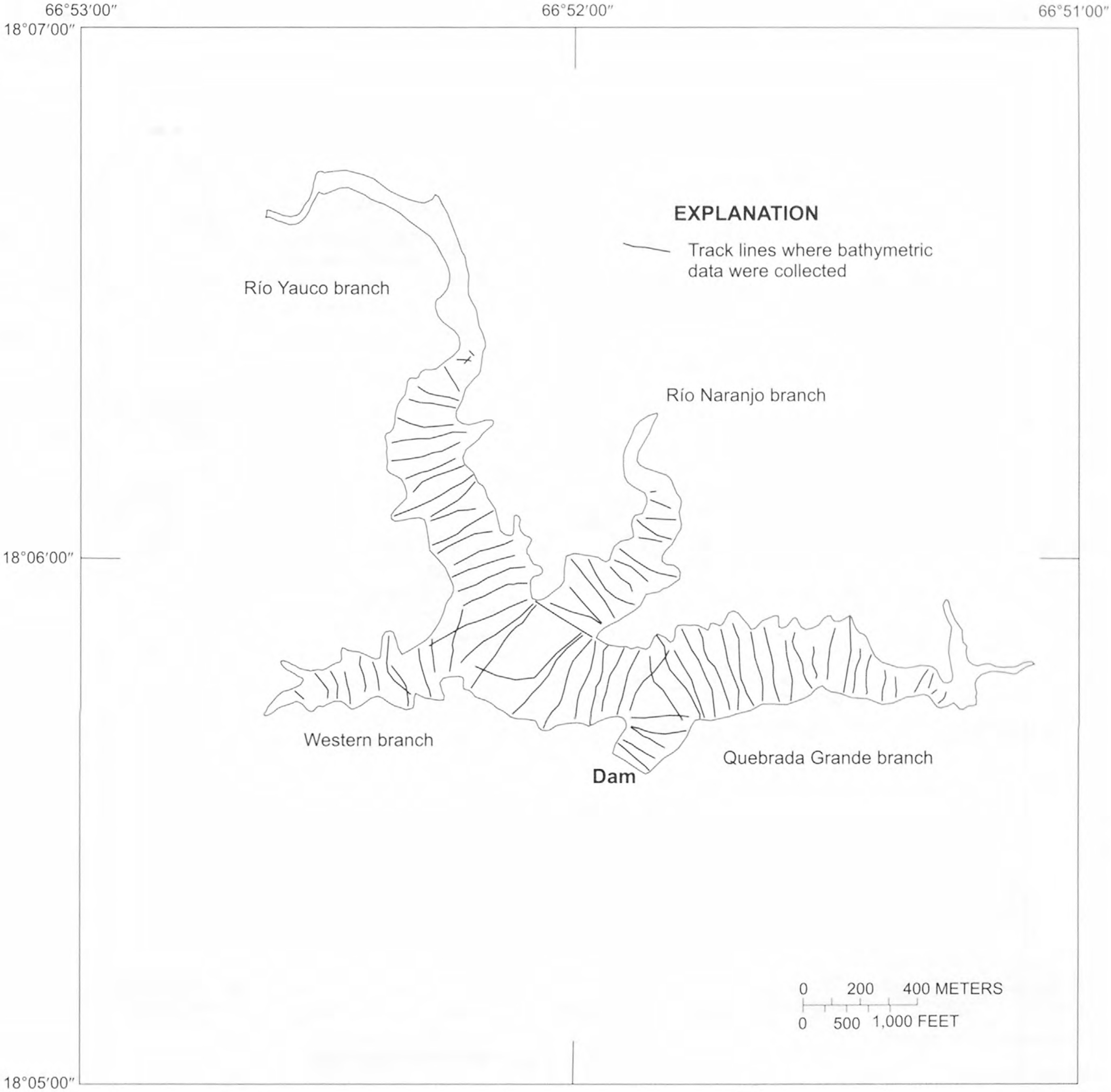


Figure 3. Actual track lines of the March 2000 bathymetric survey of Lago Luchetti, Puerto Rico.

Figure 4. Selected cross-section locations for the March 2000 bathymetric survey of Lago Lucchetti, Puerto Rico. Cross-section profiles are shown in figure 5.

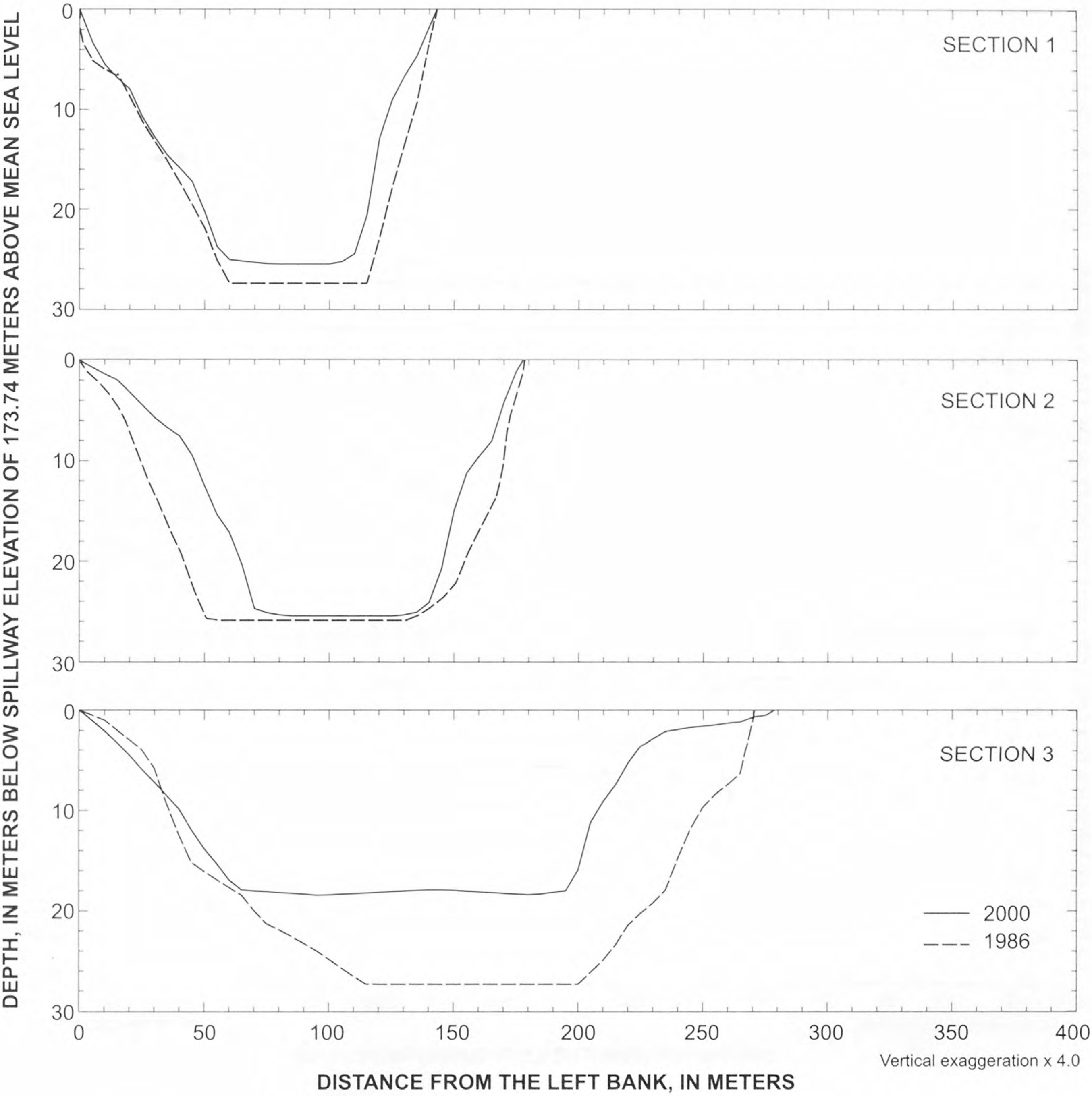


Figure 5. Selected cross sections generated from the TIN surface model of Lago Lucchetti, Puerto Rico, for September 1986 and March 2000. Refer to figure 4 for cross-section locations.

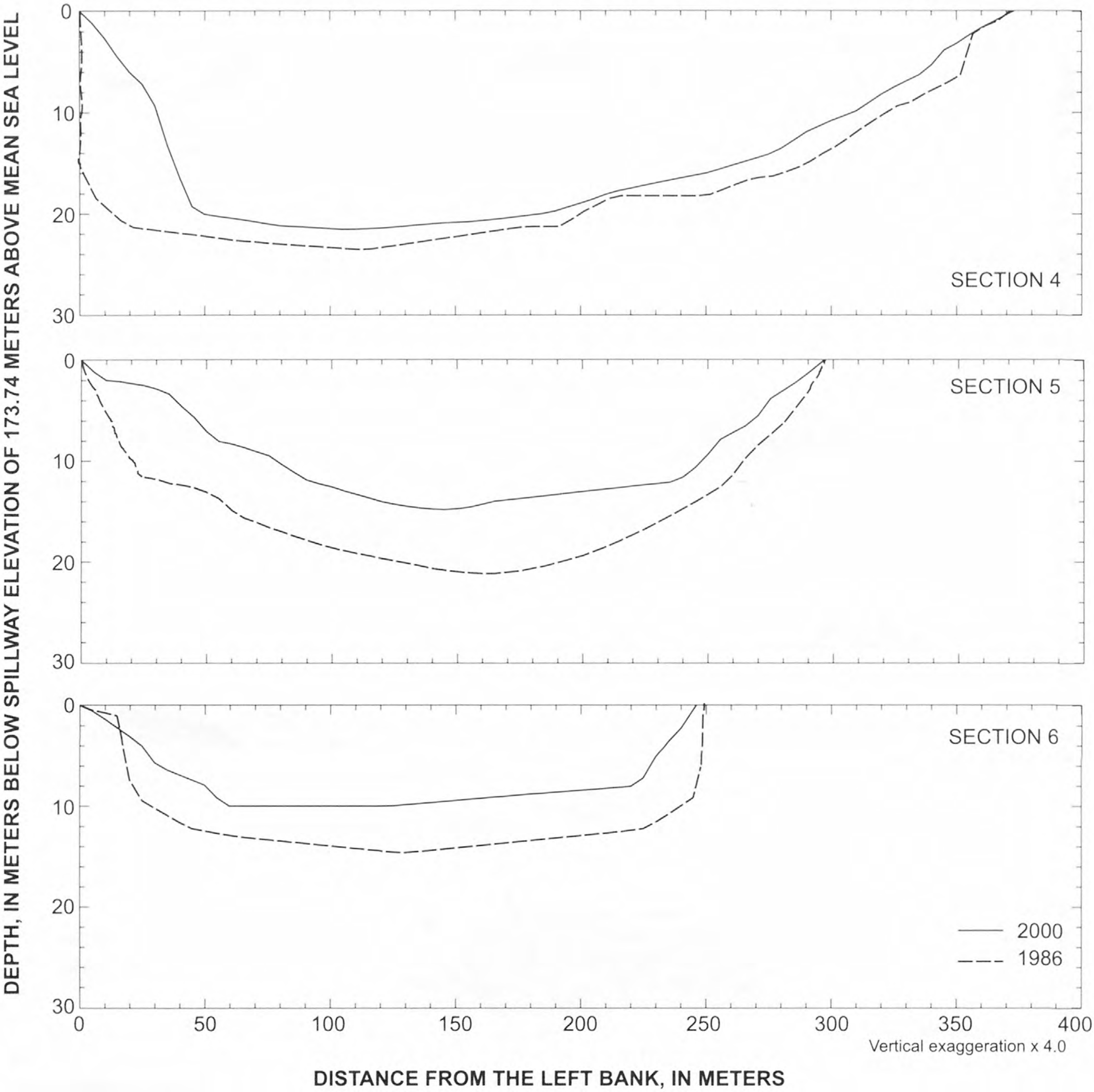
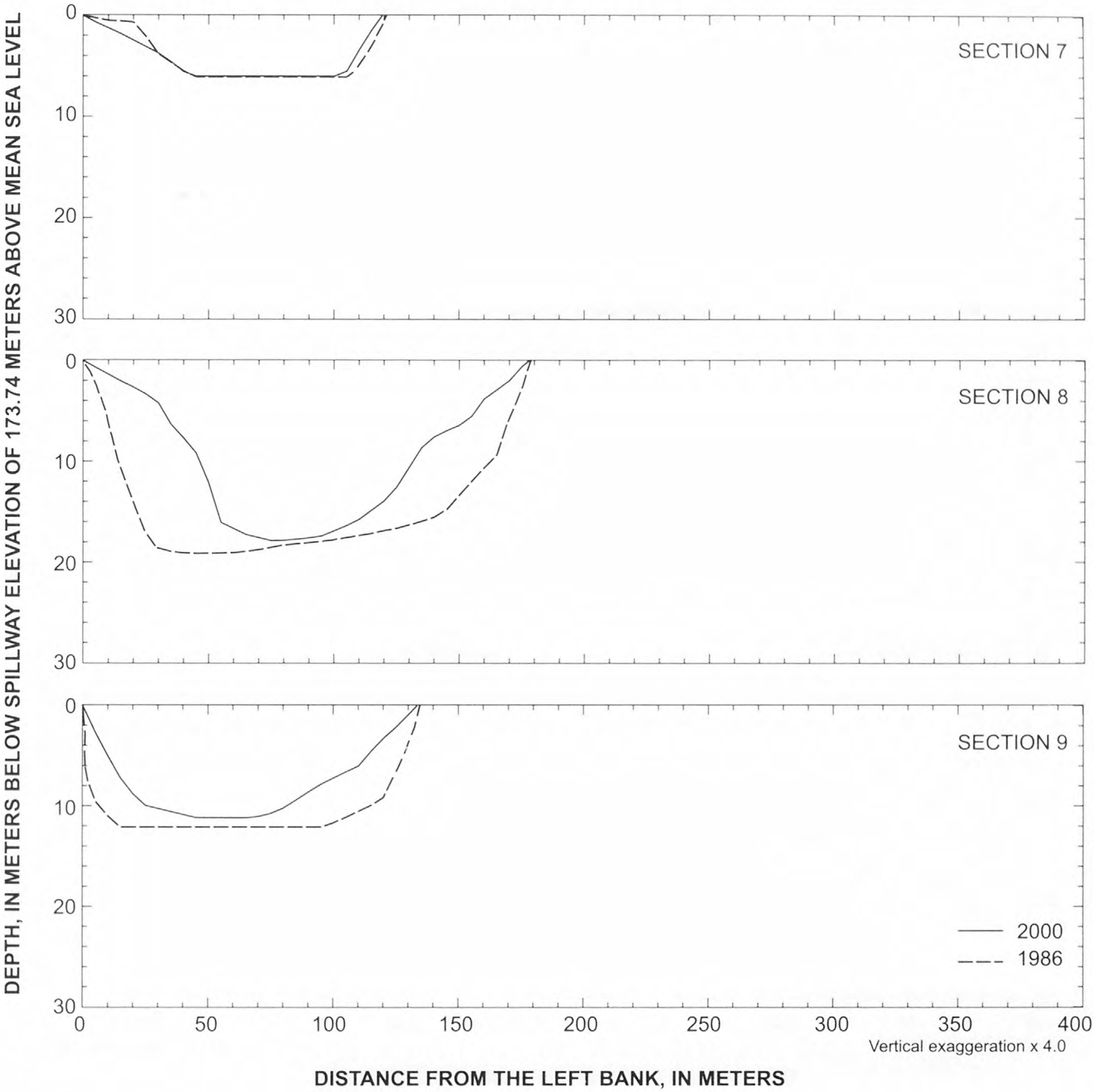


Figure 5. Selected cross sections generated from the TIN surface model of Lago Lucchetti, Puerto Rico, for September 1986 and March 2000. Refer to figure 4 for cross-section locations—Continued.



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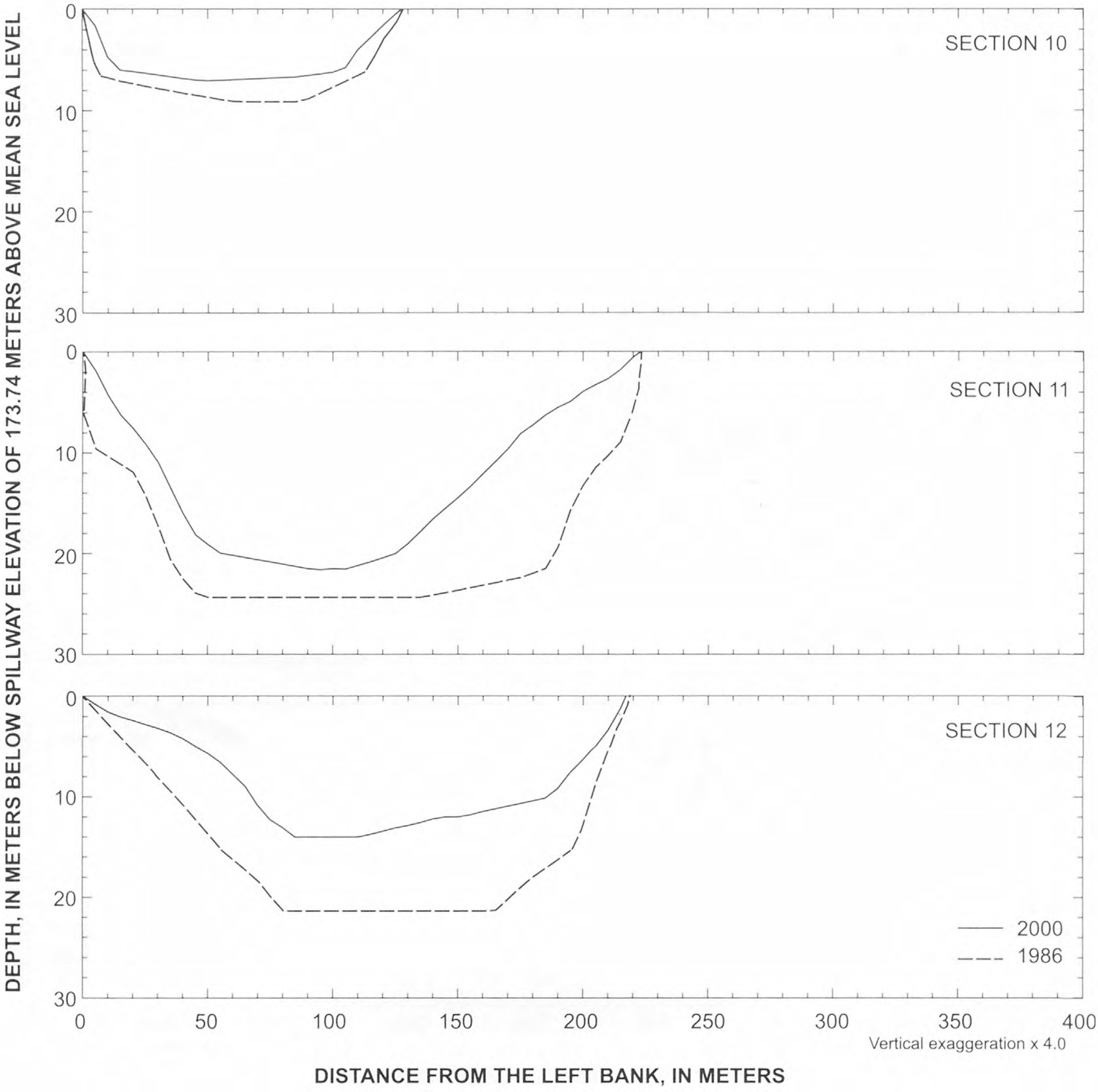

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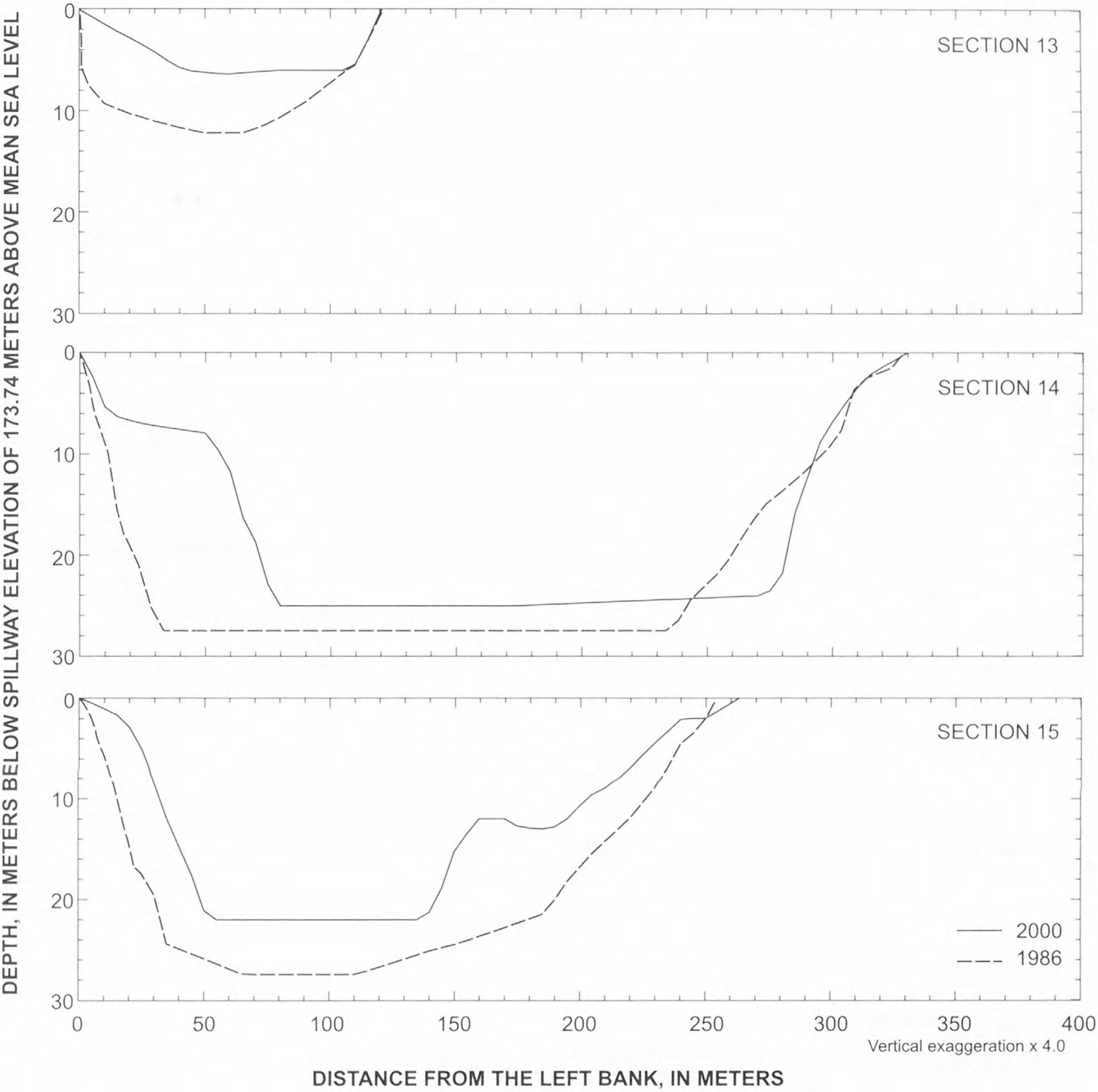

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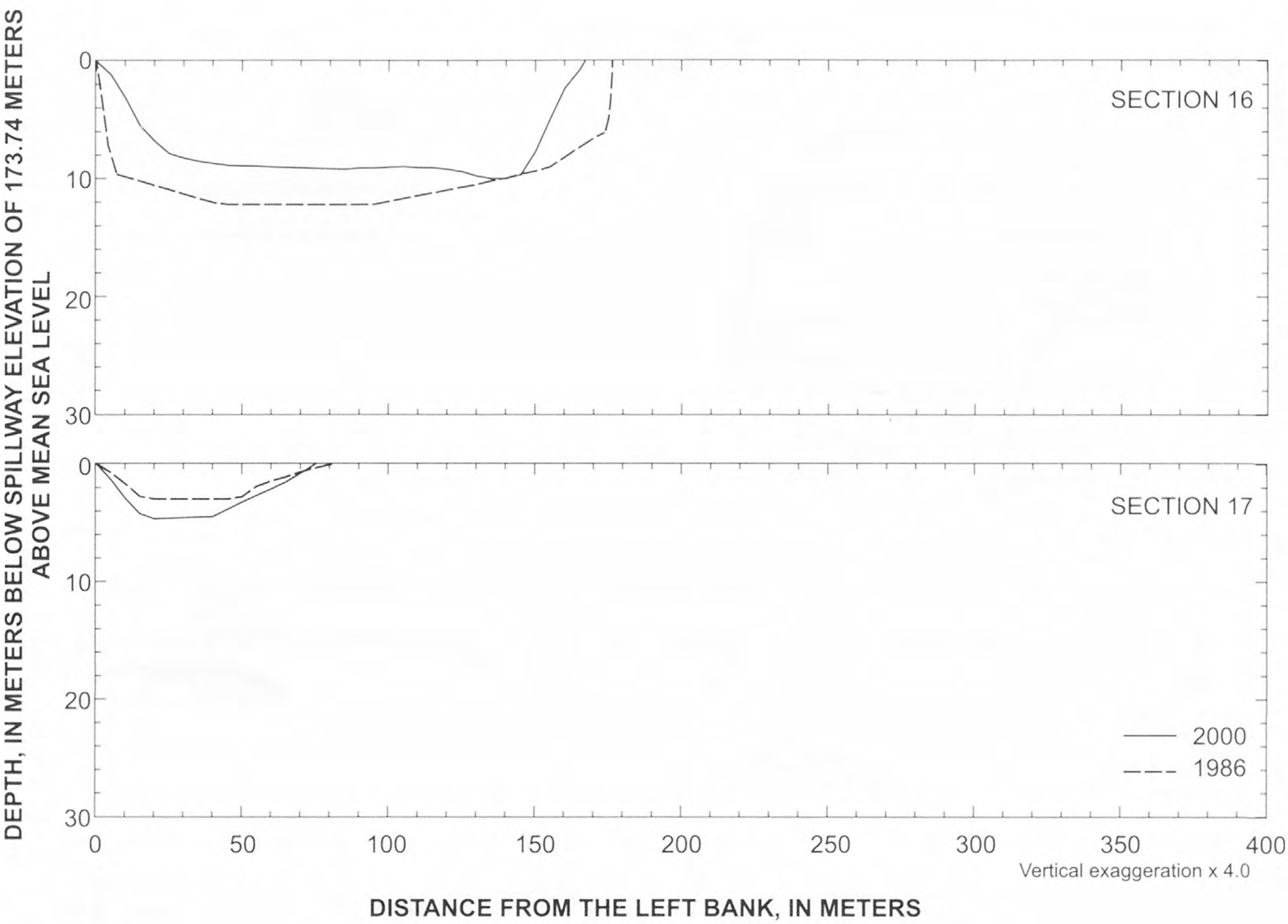

Figure 5. Selected cross sections generated from the TIN surface model of Lago Lucchetti, Puerto Rico, for September 1986 and March 2000. Refer to figure 4 for cross-section locations—Continued.

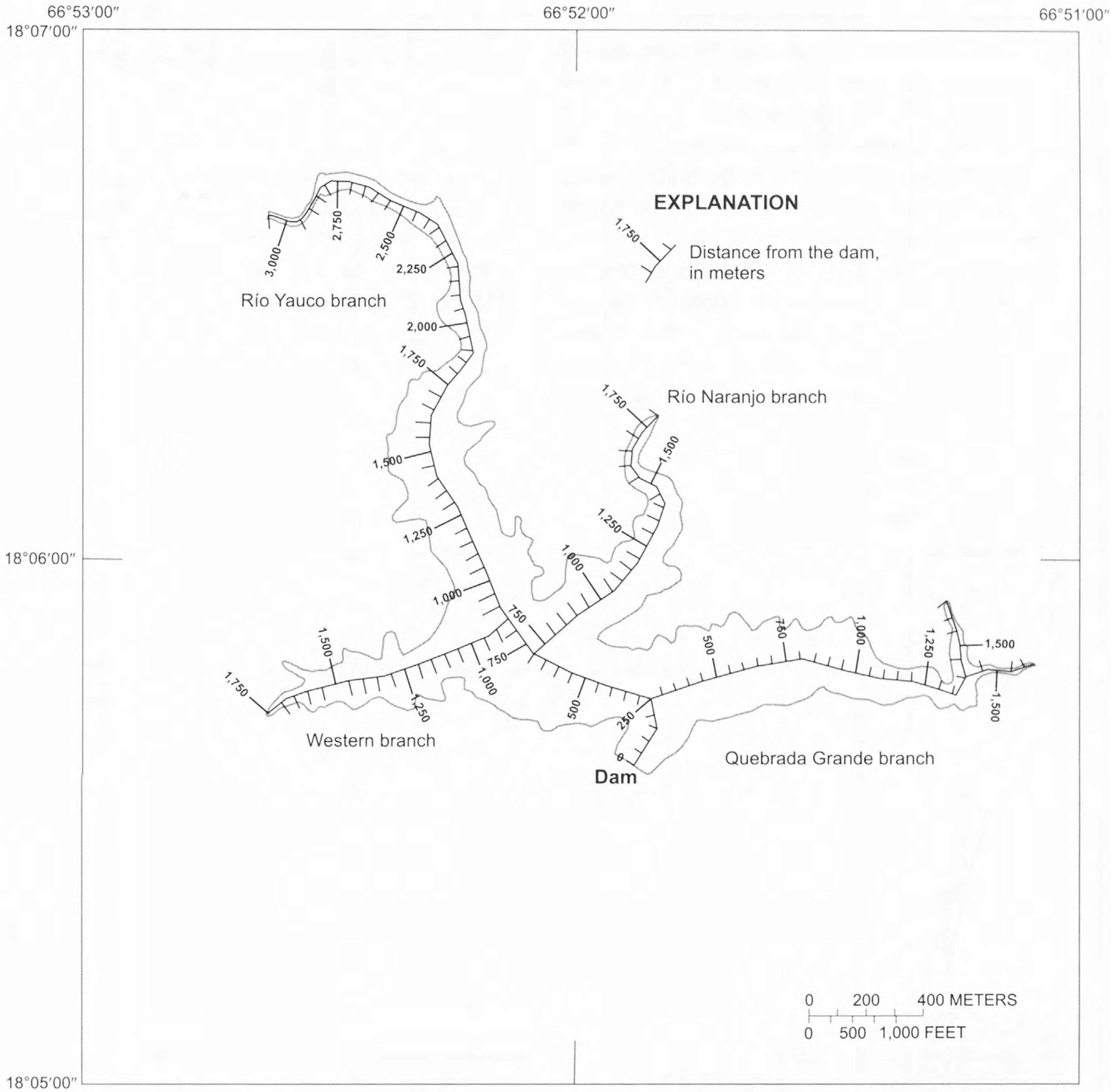

Figure 6. Reference distances for longitudinal profiles along the different branches of Lago Lucchetti, Puerto Rico.

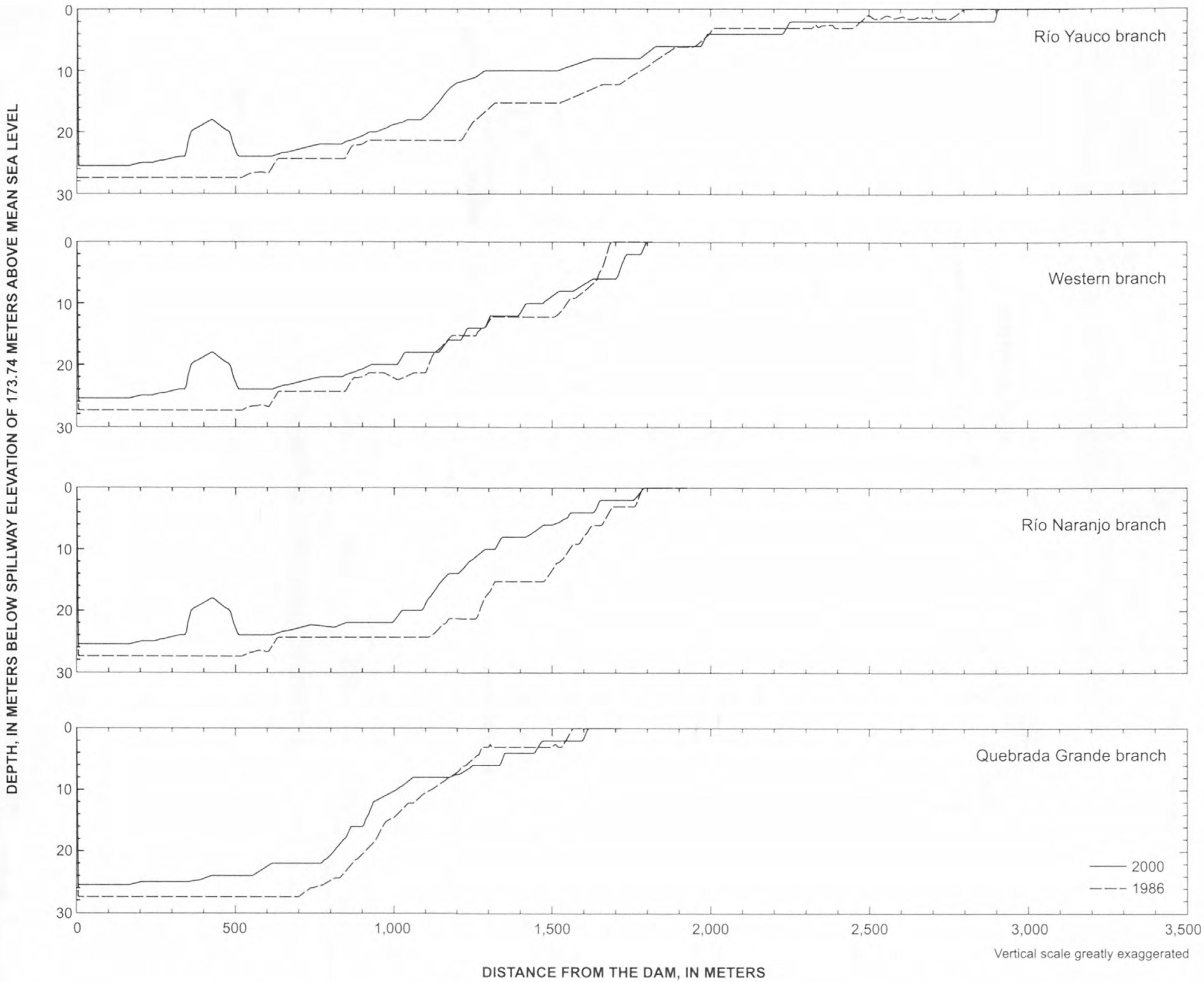

Figure 7. Longitudinal bathymetric profiles along the thalweg of the different branches of Lago Lucchetti, Puerto Rico. The profiles were generated from the September 1986 and March 2000 TIN surface models of the reservoir. Refer to figure 6 for location profiles.

ACTUAL CAPACITY AND SEDIMENT ACCUMULATION

The storage capacity of Lago Lucchetti has decreased from 20.35 million cubic meters in 1952 to 15.84 million cubic meters in 1986, and to 11.88 million cubic meters in March 2000 (table 2). This represents a storage loss of 4.51 million cubic meters by 1986 and 8.47 million cubic meters by March 2000, or a storage loss of 22 and 42 percent, respectively. The average annual capacity loss of Lago Lucchetti was 0.13 million cubic meters for the period 1952 to 1986 (or 0.6 percent per year), slightly increasing to 0.18 million cubic meters for the period 1986 to 2000 (or 0.9 percent per year).

The storage capacity as a function of pool elevation of Lago Lucchetti is listed in table 3 at 1-meter elevation intervals, and the graphical relation between pool elevation and storage capacity is shown in figure 8.

Sediment accumulation in the reservoir is not uniform. On the Río Yauco branch (cross sections 4 to 7, fig. 5) an average of about 4 meters of sediment has accumulated since 1986, giving a depositional rate of about 0.3 meters per year. On the Río Naranjo branch (cross sections 11 to 13, fig. 5) an average of about 5 meters of sediment has accumulated during the same period of time. This represents a depositional rate of about 0.4 meters per year. On the Quebrada Grande branch (cross sections 14 to 17, fig. 5), the average accumulation is about 3 meters, representing a depositional rate about 0.2 meters per year. On the Western branch (cross sections 8 to 10, fig. 5), an average of about 1 meter of sediment has accumulated, representing a depositional rate of less than 0.1 meter per year. The generally flat, central portion of the reservoir bottom, about 400 meters upstream northwest of the dam (plate 1) indicates that widespread deposition of sediment in this area may have occurred as high water velocities generated during floods transported bed-load material from the Río Yauco, Río Naranjo and Quebrada Grande branches of the reservoir to their confluence. As these waters mixed, water velocities slowed, and sediment was deposited.

Table 2. Comparison of the 1952 land survey with the 1986 and March 2000 sedimentation surveys of Lago Lucchetti, Puerto

[---, undetermined]

Year of survey	1952	1986	2000
Available storage capacity, in million cubic meters	20.35	15.84	11.88
Sediment accumulated, in million cubic meters	0	4.51	8.47
Years since construction	0	34	48
Storage capacity loss, in percent	0	22	42
Annual storage capacity loss, in percent	0	0.6	0.9
Long-term sedimentation rate, in million cubic meters per year	0	0.13	0.18
Trapping efficiency, in percent[1]	97	96	95
Drainage basin sediment yield, in megagrams per square kilometer per year[2]	---	906	1,255
Year that the reservoir will fill with sediments[3]	---	2108	2066

[1] Using the capacity-inflow ratio described by Brune (1953).

[2] Using the combined drainage areas of Lago Guayo, Lago Lucchetti, Lago Prieto, Lago Toro, and Lago Yahuecas, and assuming a sediment dry-bulk density of 1 gram per cubic centimeter.

[3] Assuming that the reservoir would continue to fill at the calculated long-term sedimentation rate.

Table 3. Storage capacity of Lago Lucchetti, Puerto Rico, March 2000

[All elevations, in meters above mean sea level; all capacities, in million cubic meters]

Pool elevation	Storage capacity
173.74	11.88
172.74	10.82
171.74	9.82
170.74	8.91
169.74	8.05
168.74	7.24
167.74	6.46
166.74	5.75
165.74	5.09
164.74	4.51
163.74	3.98
162.74	3.52
161.74	3.09
160.74	2.69
159.74	2.32
158.74	1.98
157.74	1.65
156.74	1.35
155.74	1.06
154.74	0.81
153.74	0.59
152.74	0.40
151.74	0.23
150.74	0.12
149.74	0.04
148.74	0.01
147.74	0.00

If the pool elevation of the reservoir lowers to less than 156 meters above mean sea level because of low runoff and/or water releases for power generation, two separate pools could form, further limiting the available water resources of the reservoir. Several meters from the dam, the reservoir bottom is at an elevation of 148.24 meters above mean sea level, according to the March 2000 bathymetric data. The sluiceway structure at the dam, at a crown elevation (upper part of the structure) of 136.25 meters above mean sea level, is currently under about 12 meters of sediment. The power generating tunnel intake is at a crown elevation of 146.30 meters above mean sea level. Since the reservoir bottom in the area adjacent to the structure is at about 152 meters above mean sea level, the intake is surrounded by about 6 meters of deposited material and could be disabled if not operated regularly.

As design and operation criteria, the water used for generating electricity at power plant no. 2 flows from Lago Lucchetti through the power tunnel into Lago Loco, a small reservoir located about 5 kilometers southwest of Lago Lucchetti. Because the intake tunnel is surrounded by about 6 meters of sediment, it is likely that large volumes of sediment are transported from Lago Lucchetti to Lago Loco, which accelerates the storage capacity loss in this small reservoir. This process was observed in Lago Guayo, another reservoir of the SWPRP, located upland in the mountainous reaches of the project (Soler-López, 1999).

TRAPPING EFFICIENCY

Heinemann (1981) considered trapping efficiency to be the most informative descriptor of a reservoir. This value is the proportion of the incoming sediment that is deposited or trapped in a pond, reservoir or lake. Trapping efficiency is dependent on several factors, including sediment size, distribution, the time and rate of water inflow to the reservoir, the reservoir size and shape, the location of the outlet structure, and location and discharge schedules (Verstraeten and Poesen, 2000).

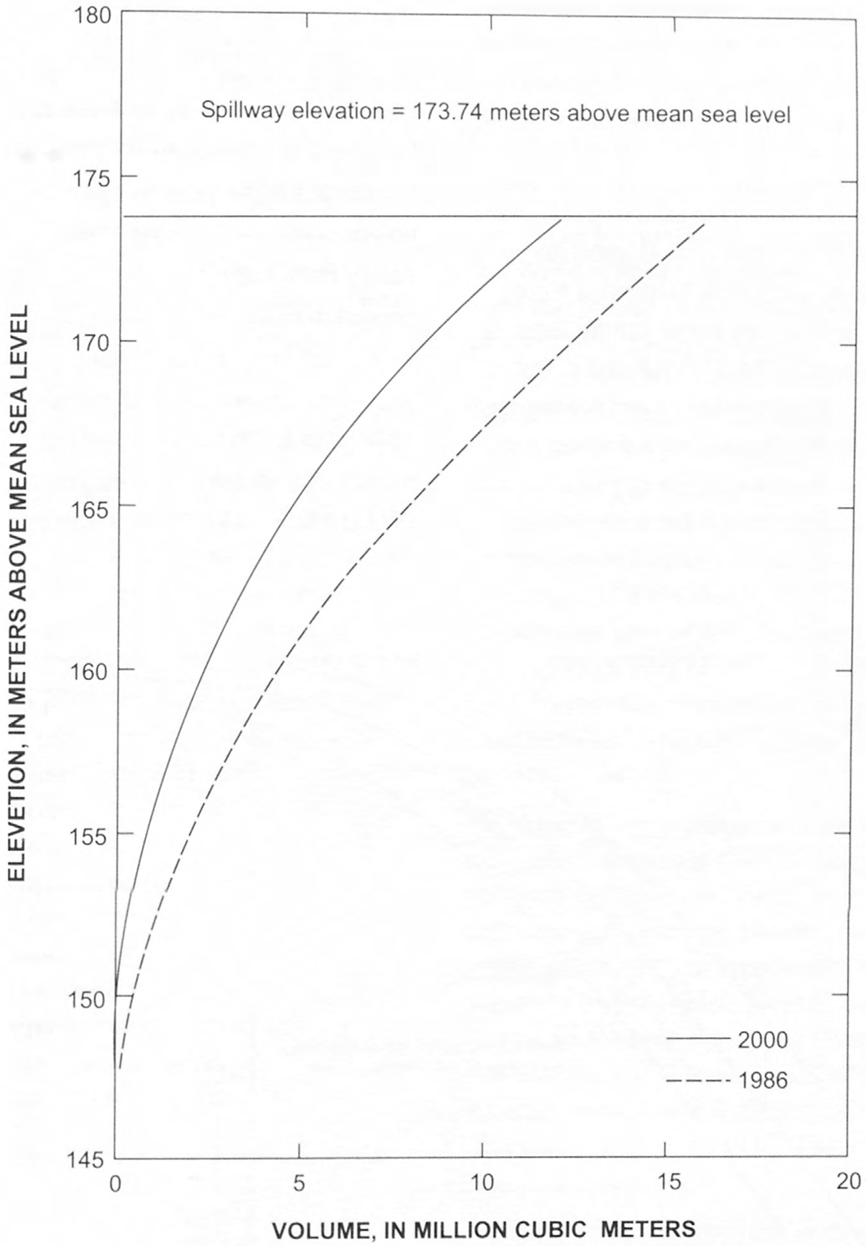

Figure 8. Relation between water-storage capacity and pool elevation for Lago Lucchetti, Puerto Rico, for September 1986 and March 2000.

Many empirical studies showing the relation between reservoir storage capacity, water inflow, and trapping efficiency have been conducted in the past, of which Brune's (1953) is the most widely used and accepted. Brune developed a curve (fig. 9) that estimates the trapping efficiency of a reservoir based on the ratio of storage capacity to annual water inflow volume. The trapping efficiency of Lago Lucchetti was estimated using the relation established by Brune (1953).

The Lago Lucchetti drainage area was increased artificially when four other reservoirs (Lago Guayo, Lago Prieto, Lago Toro, and Lago Yahuecas) were connected to Lago Lucchetti by underground tunnels. These reservoirs are part of the SWPRP and divert flow from the mountainous reaches of the project area into Lago Lucchetti, providing additional water for hydroelectric power generation at power plant no. 1. However, the water inflow from these reservoirs is seasonal, and depends on rainfall magnitude and frequency, and tunnel operation schedule. This means that not all the runoff generated inside the SWPRP flows into Lago Lucchetti. Therefore, the calculations of the basin runoff were made using the natural drainage area of Lago Lucchetti since there is no long-term, precise information on water diversion activities.

Water inflow from these reservoirs into Lago Lucchetti is subsequently released from Lago Lucchetti via the power outlet for power generation at power plant no. 2. The amount of water released yearly from Lago Lucchetti to power plant no. 2 is greater than the water influx from these reservoirs into Lago Lucchetti. For example, in 1995, the four reservoirs discharged 433 million cubic meters of water into Lago Lucchetti whereas 716 million cubic meters of water was discharged for power generation (W.L., Molina USGS, written commun., 2000).

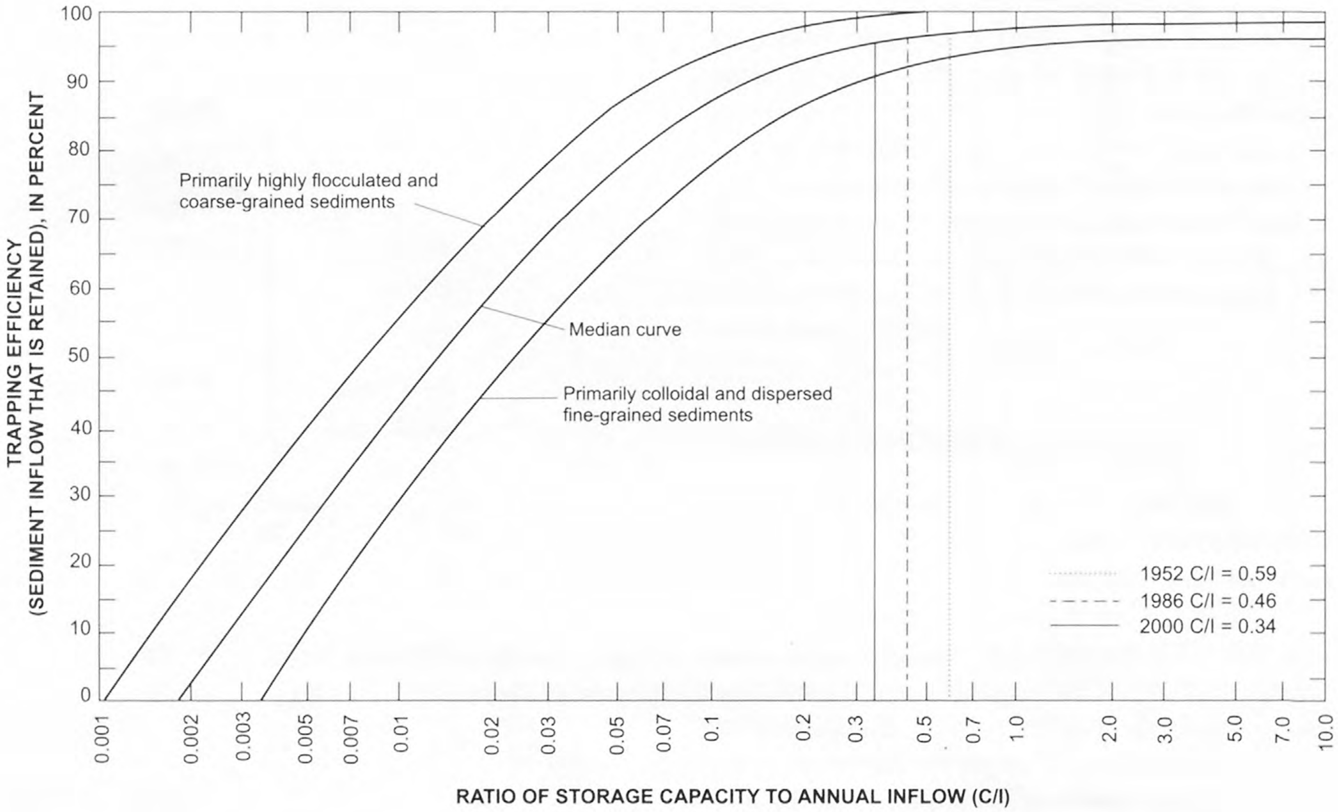

Figure 9. Storage capacity to inflow relation established by Brune (1953).

The Lago Lucchetti drainage area has no stream-gaging station to measure annual inflow to the reservoir. To estimate how much rainfall becomes runoff in the Lago Lucchetti drainage area, the neighboring basin of Río Guayanilla was used to estimate the rainfall/runoff ratio of the Lago Lucchetti drainage area. The Río Guayanilla drainage area has somewhat similar topography, land use, and slopes, and therefore, the rainfall/runoff ratio was expected to be similar to the Lago Lucchetti basin.

The long-term average rainfall in the Lago Lucchetti basin is 2,032 millimeters per year (Calvesbert, 1970). The Río Guayanilla basin has a runoff/rainfall ratio of 0.38 (Giusti and López, 1967). By multiplying the rainfall of 2,032 millimeters of the Lago Lucchetti basin by the runoff/rainfall ratio of 0.38, the estimated runoff for the Lago Lucchetti basin is calculated to be 772 millimeters (0.772 meters) per year. This number (0.772 meters) multiplied by the 44.81 square kilometer drainage area of Lago Lucchetti, gives an estimated inflow to the reservoir of 34.59 million cubic meters per year. With a present storage capacity of 11.88 million cubic meters, the storage capacity to inflow ratio is 0.34, which implies that the natural drainage basin supplies enough water to completely fill the reservoir three times per year. Using the median curve of Brune's relation (fig. 9), the storage capacity to inflow ratio was 0.59 in 1952 and 0.46 in 1986, resulting in a trapping efficiency of 97 percent and 96 percent, respectively, and 95 percent for March 2000. The long-term average trapping efficiency of Lago Lucchetti is 96 percent for the period 1952 to 2000. According to Brune's empirical relation (fig. 9), however, the trapping efficiency of Lago Lucchetti will decrease as sediments fill the reservoir and lower the storage capacity.

SEDIMENT YIELD

Sediment yield has been defined by the American Society of Civil Engineers as the total sediment outflow measurable at a point of reference, for a specified period of time, per unit of surface area (McManus and Duck, 1993).

The bathymetry of Lago Guayo, Lago Prieto, and Lago Yahuecas were surveyed in 1997 (Soler-López and others, 1998; Soler-López, 1999; Soler-López and Webb, 1999). Survey results show that sediments accumulating in these reservoirs have reached the elevation of the connecting tunnel intake structures, and so sediments pass through the power tunnels downstream into Lago Lucchetti during flood events. Hence, the sediment accumulating in Lago Lucchetti is not only being derived from the reservoir basin, but also, from the Lago Guayo, Lago Prieto, Lago Toro, and Lago Yahuecas basins. Therefore, to adequately estimate the sediment yield of the Lago Lucchetti basin, the combined drainage area of all reservoirs is needed in the calculations.

The total volume of sediment derived from the combined reservoir basins discharging water and sediment to Lago Lucchetti is 8.47 million cubic meters (table 2) divided by the long-term trapping efficiency (0.96) or 8.82 million cubic meters. The rate of sediment influx is 8.82 million cubic meters divided by the age of the reservoir (48 years), or 183,750 million cubic meters per year. The sediment yield volume of the combined drainage area of the SWPRP portion above Lago Lucchetti is 183,750 million cubic meters per year divided by the combined net sediment contributing area of 146.37 square kilometers, (the total drainage area of 147.47 square kilometers minus the 1.10 square kilometer surface area of Lago Lucchetti) or 1,255 million cubic meters per square kilometer per year.

Because the bottom of Lago Lucchetti was not sampled to determine the sediment dry-bulk density, the value of 1 gram per cubic centimeter obtained from a nearby reservoir (Soler-López and others, 1999) was used to estimate sediment yield mass of the combined basins, which gives about 1,255 megagrams per square kilometer per year. Using the same calculations, the sediment yield of the combined drainage areas was 906 megagrams per square kilometers per year in 1986. This represents a 38 percent increase since 1986.

However, the estimate does not account for the sediment eroded from the upper basins, which was being trapped in the upland reservoirs, or for the sediment temporarily stored in the river channels upstream from the dams. The upland reservoirs acted as sediment traps for Lago Lucchetti before their bottoms reached the intake structures elevations. Hence, the total amount of eroded material is somewhat higher than the calculated number reported herein.

The life expectancy of Lago Lucchetti, or any other reservoir can be estimated by dividing the remaining storage capacity by the annual storage capacity loss. Although the life expectancy of Lago Lucchetti was about 122 more years in 1986, the life expectancy will be reduced considerably (to about half; 66 more years) if the long-term sedimentation rate recorded in March 2000 remains constant. This life expectancy reduction probably was the effect of floods associated with the passage of Hurricanes Hortense in 1996, and Georges in 1998, as demonstrated at two other upland reservoirs, Lago Caonillas and Lago Dos Bocas, studied in 1999 and 2000, respectively (Soler-López, 2000 and 2001). In reality, the most likely life expectancy of Lago Lucchetti should be somewhat between the 1986 and March 2000 time frame depending on the magnitude and frequency of flood events, as well as the decrease in trapping efficiency of the reservoir.

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