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Sedimentation Survey of Lago El Guineo, Puerto Rico, October 2001

By Luis R. Soler-López

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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
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
square kilometer	247.1	acre
	Volume	
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)	
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 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
DOQ Digital Orthophoto Quadrangle
GIS Geographic Information System
PREPA Puerto Rico Energy Power Authority
TIN Triangulated Irregular Network
USGS U.S. Geological Survey

Translations

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

Sedimentation Survey of El Lago Guineo, Puerto Rico, October 2001

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Abstract

Lago El Guineo has lost about 17.5 percent of its original storage capacity in 70 years because of sediment accumulation. The water volume has been reduced from 2.29 million cubic meters in 1931, to 2.03 million cubic meters in 1986, and to 1.89 million cubic meters in 2001. The average annual storage-capacity loss (equal to the sedimentation rate) of Lago El Guineo was 4,727 cubic meters for the period of 1931 to July 1986 (or 0.21 percent per year), increasing to 5,714 cubic meters for the period of 1931 to October 2001 (or 0.25 percent per year). Discrepancies that could lead to substantial errors in volume calculations in a small reservoir like Lago El Guineo, were found when transferring the field-collected data into the geographic information system data base 1:20,000 U.S. Geological Survey Jayuya, Puerto Rico quadrangle. After verification and validation of field data, the Lago El Guineo shoreline was rectified using digital aerial photographs and differential global positioning data.

INTRODUCTION

Lago El Guineo, located in the Río Grande de Manatí Basin in the municipio of Villalba in central Puerto Rico (fig. 1), is owned by the Puerto Rico Electric Power Authority (PREPA). The reservoir was originally designed to provide 2.29 million cubic meters of water for irrigation of croplands in southern Puerto Rico and for hydroelectric power generation. Since completion in 1931, the reservoir has been losing water storage capacity because of sediment accumulation. Although agricultural practices within the reservoir basin are limited, the high average annual rainfall of 2,540 millimeters (Calvesbert, 1970) and steep slopes promote erosion and transport of sediment into Lago El Guineo.

The U.S. Geological Survey (USGS), in cooperation with PREPA, conducted a bathymetric survey of Lago El Guineo in October 2001 to assess the extent of sediment accumulation in the reservoir. Data on geographic position and water depths were acquired using a differential global positioning system (DGPS) interfaced to a depth sounder. The field-collected data were then loaded into a geographic information system (GIS), which was used to determine the existing water storage capacity, sedimentation rates, and sediment distribution, and to predict the useful life of the reservoir. This report provides PREPA with the necessary information to effectively manage the available water resources and to develop strategies to mitigate the storage-capacity loss in Lago El Guineo.

DAM, RESERVOIR, AND BASIN CHARACTERISTICS

The Lago Guineo dam construction started in 1928 and was completed in 1931. The dam is located about 4.8 kilometers north of the town of Villalba in central Puerto Rico on the Río Toro Negro. The Lago Guineo dam is a rockfill embankment 172.2 meters in length with a vertical concrete corewall continuous from abutment to abutment. The height of the dam at the top of the corewall is 906.78 meters above mean sea level. The dam is part of the Toro Negro Hydroelectric System, which was developed for electric generation and for irrigation of croplands in the southern part of Puerto Rico.

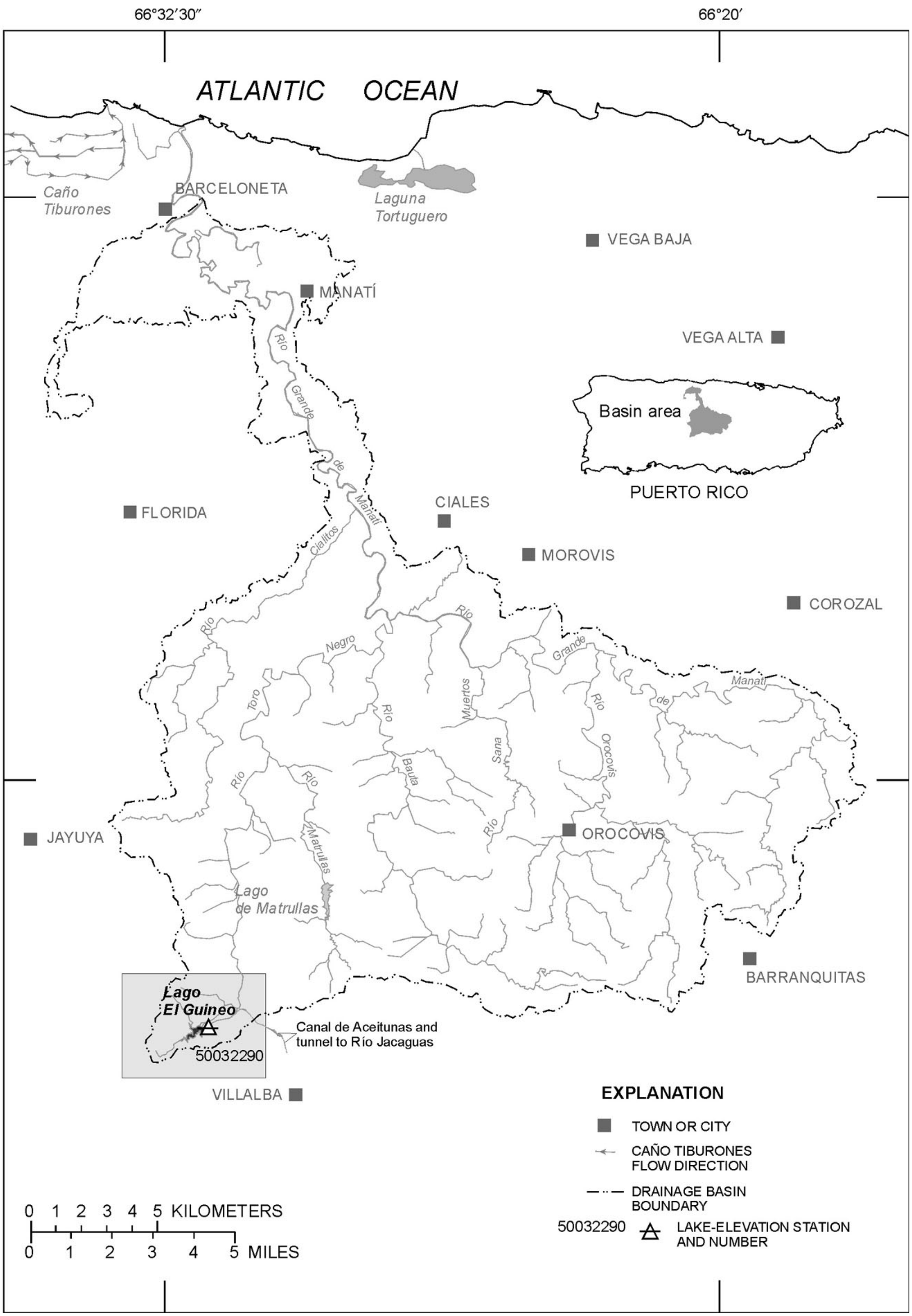


Figure 1. Location of Lago El Guineo in the Río Grande de Manatí Basin, Puerto Rico.

An uncontrolled morning glory-type spillway is located at the left abutment of the dam at an elevation of 902.21 meters above mean sea level. The spillway has a design discharge capacity of 198.24 cubic meters per second at a maximum reservoir water-surface elevation of 904.13 meters above mean sea level. The power outlet is located in a former stream diversion tunnel through the right abutment of the dam. The principal components of the outlet works are an entrance trashrack at the upstream end of the horseshoe conduit leading from the upstream toe of the dam to a gate tower located at the diversion tunnel portal, a horseshoe tunnel from the gate tower to the corewall, and a horseshoe tunnel from the corewall to the outlet portal. The gate tower consists of a double shaft structure. Two slide gates admit flow into the downstream shaft of the gate tower, which eventually flow out of the dam (Puerto Rico Electric Power Authority, 1988). Additional information about the dam structures and the reservoir is listed in table 1.

Lago Guineo Basin is located in the Humatas-Los Guineos-Alonso soil series association. This association, found mainly on the slopes and ridgetops in the mountainous north-central part of Puerto Rico, ranges from moderate to well drained clayey soils. The Humatas soils make up about 55 percent of the association, the Los Guineos soils make up about 25 percent, and the Alonso soils make about 20 percent (Acevido, 1982). In general, these types of clayey soils tend to be more plastic, cohesive, and are more difficult to erode than non-compacted sandy-type soils.

METHOD OF SURVEY

The bathymetric survey of Lago El Guineo involved planning, data collection, data processing, and analysis. An Arc/Info GIS was used to plan the survey and to analyze the 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 El Guineo (fig. 2). The longitudinal distance along the thalweg of Lago El Guineo is shown in figure 3.

Table 1. Principal characteristics of Lago El Guineo and Guineo dam, Puerto Rico (modified from the Puerto Rico Electric Power Authority, 1988)

[GIS, Geographic Information System]

Drainage area at dam, in square kilometers	4.07
Drainage area at dam from GIS calculations, in square kilometers	4.27
Reservoir surface area, in square kilometers	0.19
Discharge capacity at flood elevation of 904.13 meters above mean sea level, in cubic meters per second	198.24
Elevation of top of corewall, in meters above mean sea level	906.78
Elevation of top of dam, in meters above mean sea level	905.56
Elevation of spillway crest, in meters above mean sea level	902.21
Elevation of invert power tunnel intake, in meters above mean sea level	874.17
Elevation of top of power tunnel intake, in meters above mean sea level	876.30
Original storage capacity, in million cubic meters	2.29

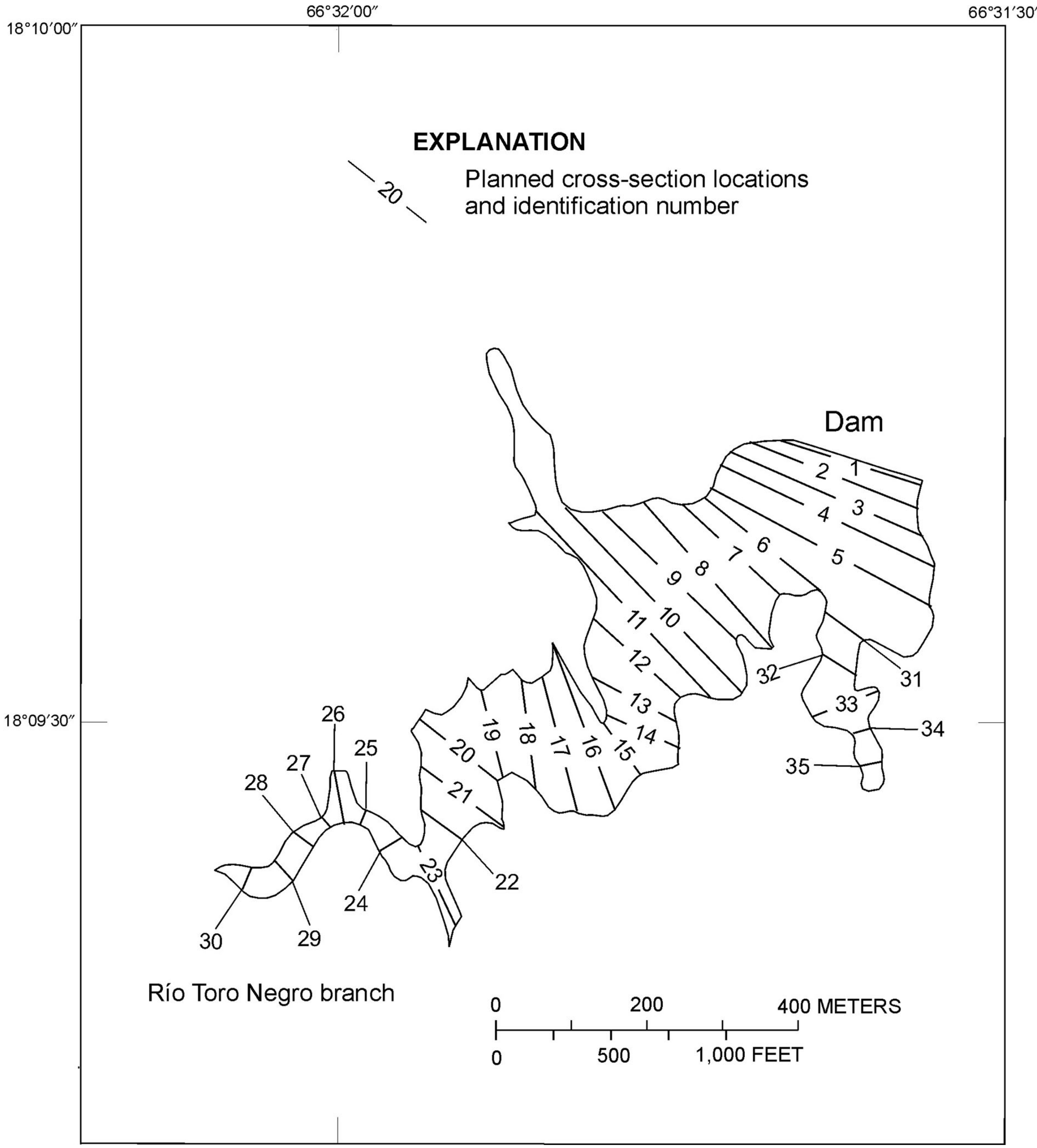


Figure 2. Planned cross-section locations for the October 2001 sedimentation survey of Lago El Guineo, Puerto Rico. Shoreline from the 1960 U.S. Geological Survey, Jayuya topographic map quadrangle.

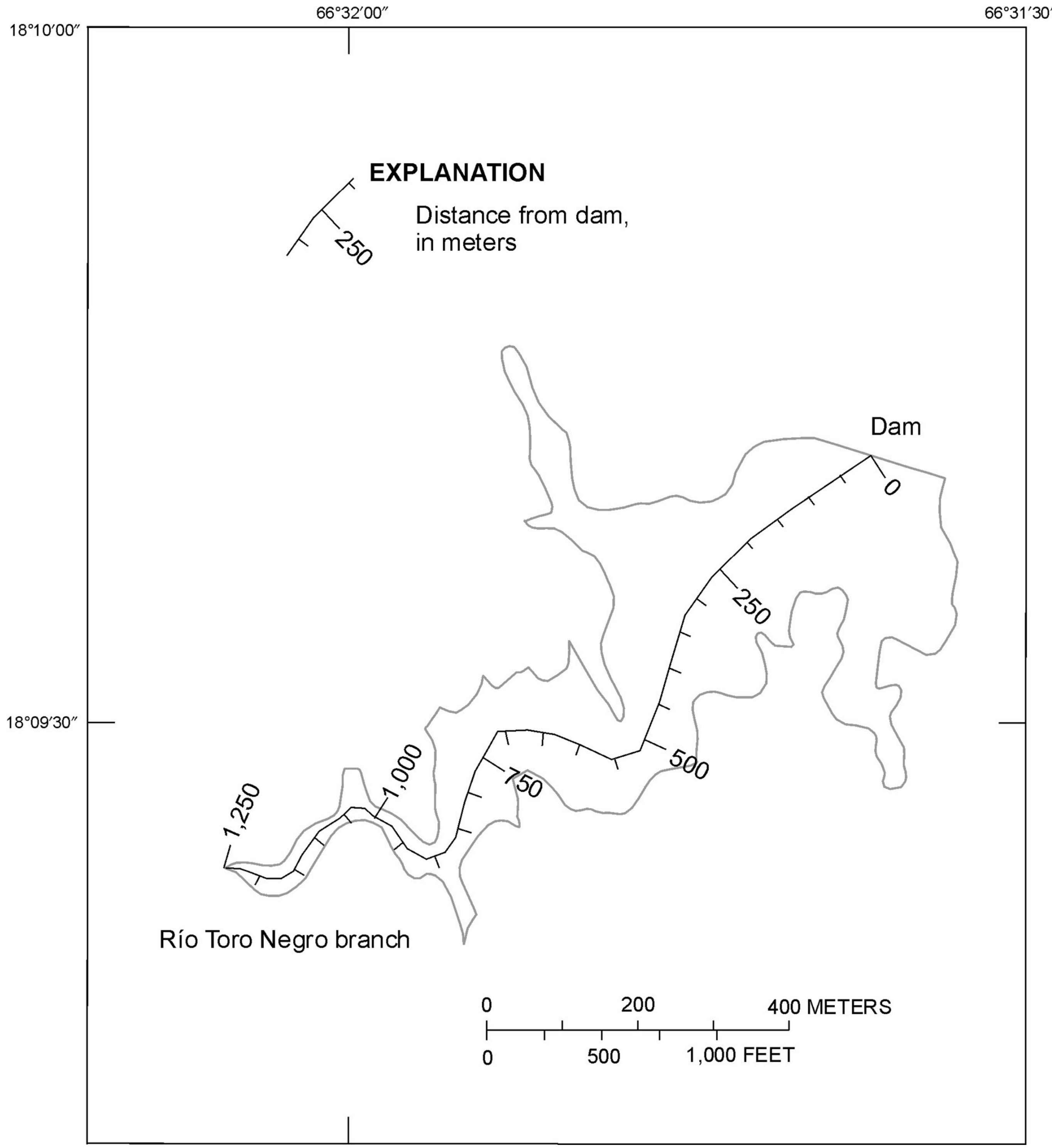


Figure 3. Longitudinal distance from the dam, along the thalweg of Lago El Guineo, Puerto Rico. Shoreline from the 1960 U.S. Geological Survey, Jayuya topographic map quadrangle.

A digital map of the Lago El Guineo shoreline, extracted from the 1960 USGS Jayuya quadrangle, Puerto Rico, was loaded into a portable computer to serve as guideline for the reservoir navigation and field data collection. However, some inconsistencies were found between the field data and the GIS-generated shoreline map. The DGPS field data did not conform adequately with the shoreline extracted from the 1:20,000 USGS topographic map of Jayuya, Puerto Rico, suggesting that one of the two datasets was inaccurate. To verify if the field data were accurate, an aerial 1:5,000 digital orthophoto quadrangle (DOQ) of the reservoir shoreline was overlaid with the GIS topographic map shoreline and with the DGPS data. The DOQ and DGPS data matched appropriately (fig. 4). However, the topographic map did not match with the other two sets, indicating that the 1:20,000 map did not have the same accuracy as the DGPS and the DOQ data.

After eliminating the uncertainty of the field data, the Lago El Guineo shoreline was rectified using the DOQ and the DGPS data, which have a horizontal positional accuracy of less than 2 meters. The use of an inaccurate reservoir shoreline for contouring and volume calculations can yield substantial errors, particularly in a small reservoir like Lago El Guineo.

Bathymetric data were collected using a depth sounder coupled to a DGPS, to control the horizontal position of the survey boat. The reservoir pool elevation was continuously monitored at the USGS lake-level station 50032290, Lago El Guineo at Damsite near Villalba (fig. 1). The pool elevation of Lago El Guineo was lower than the crest of the spillway during the survey; therefore, the collected depth data were adjusted to the spillway elevation by applying a time-elevation correction factor.

The adjusted depths along the cross sections were plotted in the rectified shoreline, and contour lines of equal depths were drawn manually at 1-meter 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) to create a model of the reservoir bottom. In addition, a bathymetric map from a July 1986 sedimentation survey was analyzed and compared with the current survey (October 2001) to establish historical sedimentation trends.

Field Techniques

The bathymetric survey of Lago El Guineo was conducted on October 16, 2001. Data were collected using the bathymetric/land survey system (BLASS) developed by Specialty Devices, Inc. The system consists of two Novatel global positioning systems (GPS) interfaced to a digital 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 used first in static mode to establish a benchmark at a site overlooking the reservoir. Satellite data were recorded simultaneously at the known benchmark, the USGS District office roof (latitude 18°25'N., longitude 66°06'W), and at the new benchmark, "Guineo dam" (latitude 18°09'N., longitude 66°31'W). The new benchmark coordinates were calculated using the GPS post-processing software CENTIPOINT. This new benchmark indicated a horizontal error of less than 10 centimeters. One GPS unit was deployed at the "Guineo dam" benchmark to serve as the reference station, while the other unit was mounted on the survey boat to serve as the mobile station. The GPS unit in the survey boat was used to independently calculate a position every second while it received a set of radio signal corrections from the reference unit, which converted the system into a DGPS maintaining the horizontal precision of the boat within 2 meters. The bathymetric survey software HYPACK was used to navigate and collect data. The software integrates the depth and position data, storing the x, y (geographic locations), and z (depth) coordinates in a portable personal computer.

A total of 35 cross sections were planned using the GIS. However, vegetation growth inside the reservoir at a shallow area in the northern reach impeded navigation and limited data collection to 33 transects, for a total of 3,221 data points over the entire reservoir (fig. 5).

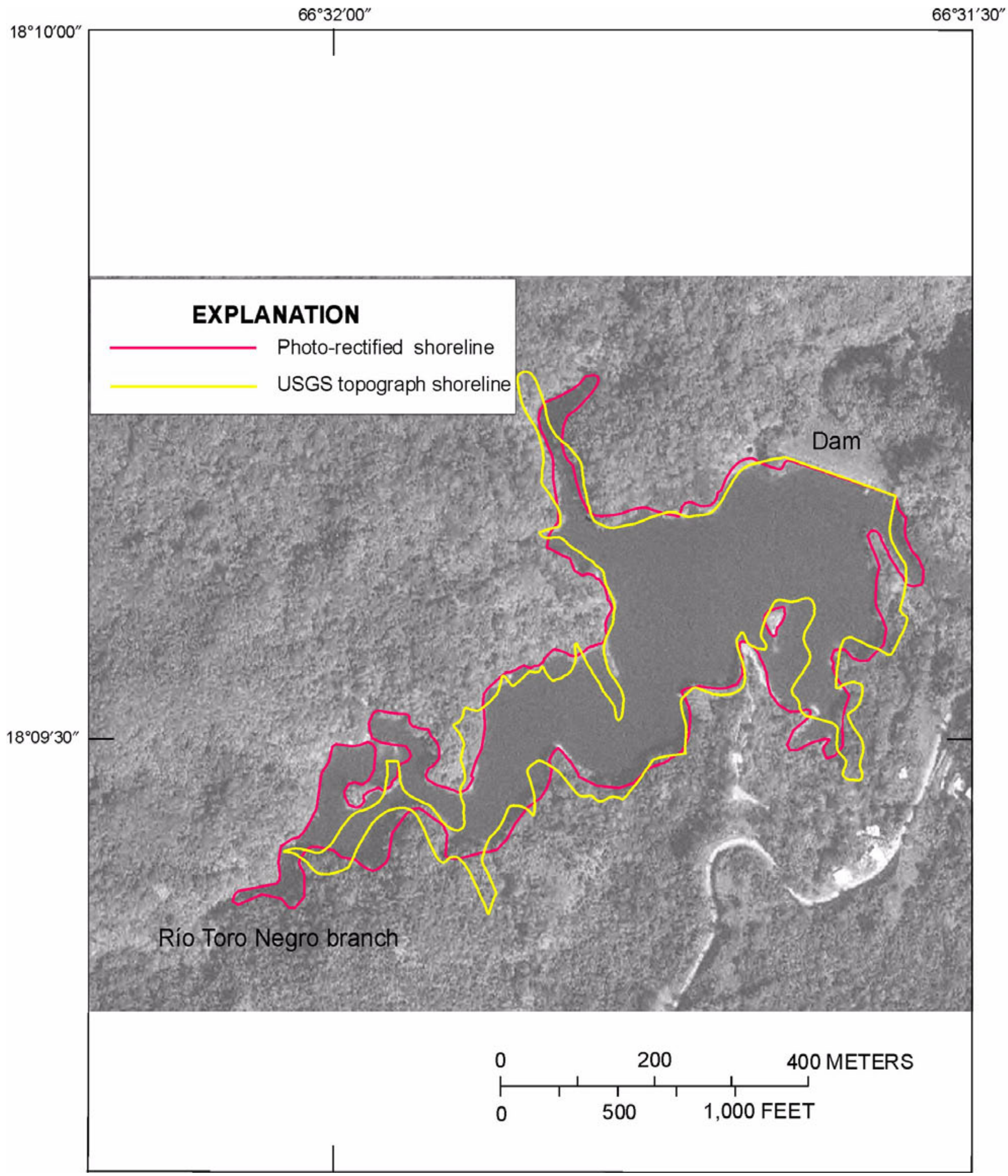


Figure 4. Comparison between the 1960 U.S. Geological Survey (USGS) Jayuya quadrangle shoreline, the 1:5,000 USGS digital orthophoto quadrangle data, and the photo-rectified shoreline of Lago El Guineo, Puerto Rico.

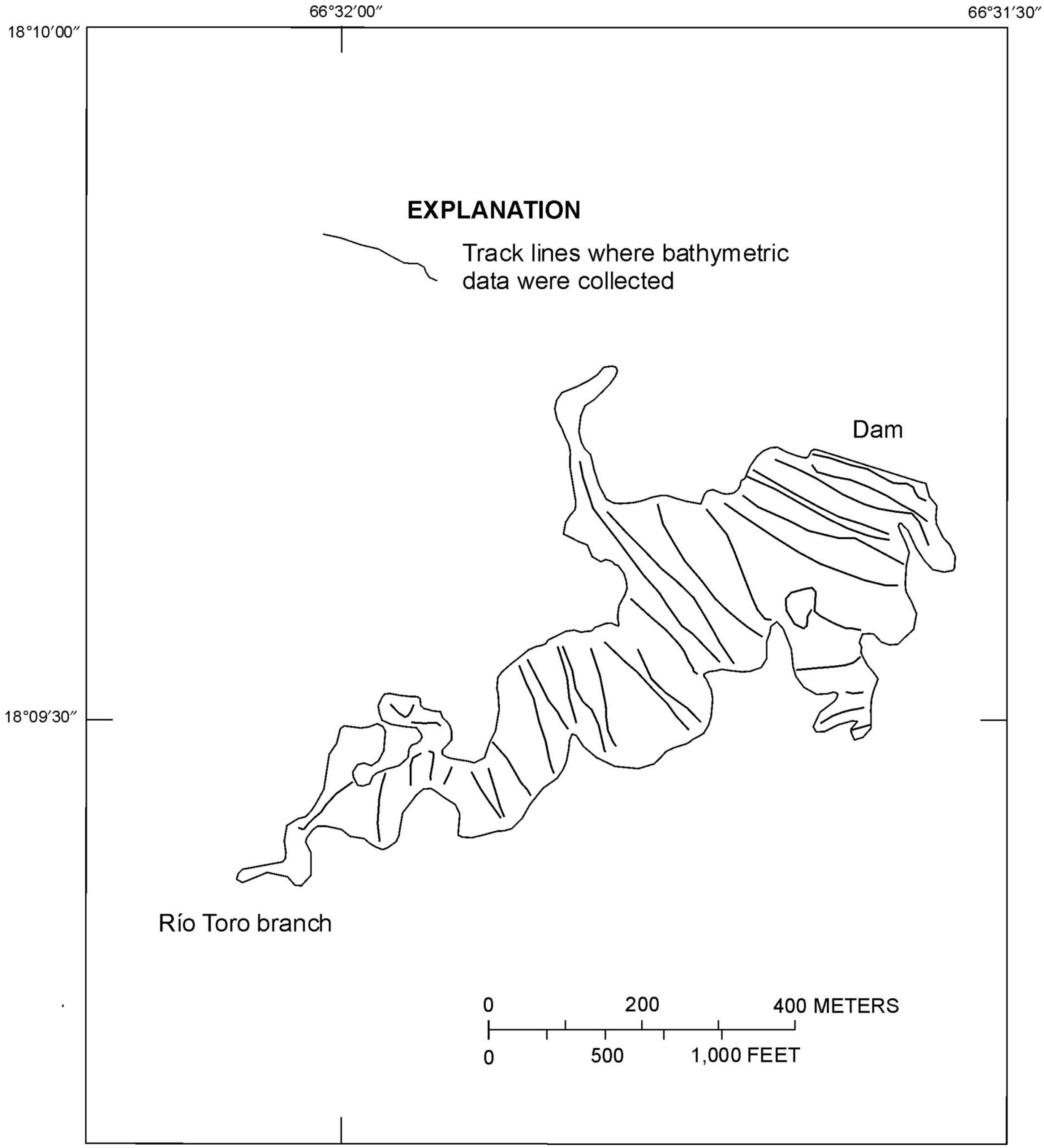


Figure 5. Actual track lines where bathymetric data were collected for the October 2001 sedimentation survey of Lago El Guineo, Puerto Rico. Shoreline from the 1:5,000 U.S. Geological Survey digital orthophoto quadrangle.

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 the correct preceding and following positions. The depth readings also were corrected to eliminate incorrect depth readings. Incorrect depth readings can result from insufficient signal gain or because floating debris interfere with the transducer face. The incorrect depth readings were corrected by interpolating the correct preceding and following depth readings. Once corrected, the edited data were then transferred into the GIS database. The Arc/Info software was customized by generating a look-up table, a set of directives that color-coded the depth values according to different depth ranges (fig. 6). It should be noted that figure 6 is provided for illustrative purposes only, and so the color values are not defined in a legend. Data points of the same color were then connected by a line between them, and a contour map of the reservoir bottom was generated (plate 1). Because contours from the July 1986 bathymetric survey were already delineated (plate 2), the only adjustments made 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 July 1986 and October 2001, respectively. The TIN represents the reservoir bottom as thousands of adjoining triangles with x, y, and z coordinates assigned to each vertices (Environmental System Research Institute, 1992). An example of the October 2001 TIN surface model of Lago El Guineo is shown in figure 7.

Selected cross sections representing flooded areas of the reservoir bottom for each survey also were generated from the TINs. The TINs were sampled every 5 meters along these cross sections to generate profiles representing the reservoir bottom from shore to shore for July 1986 and October 2001 (fig. 8). Longitudinal profiles along the thalweg of Lago El Guineo for July 1986 and October 2001 are shown in figure 9. These longitudinal profiles represent the deepest part of the reservoir bottom, along the central portion for each survey.

STORAGE CAPACITY AND SEDIMENT ACCUMULATION

The storage capacity of Lago El Guineo has decreased from 2.29 million cubic meters in 1931 to 2.03 million cubic meters in July 1986, and to 1.89 million cubic meters in October 2001 (table 2). This represents a total storage loss of 260,000 cubic meters by July 1986 and 400,000 cubic meters by October 2001, or a loss of 11 and 17.5 percent, respectively. The average annual storage-capacity loss (equal to the sedimentation rate) of Lago El Guineo was 4,727 cubic meters for the period of 1931 to July 1986 (or 0.21 percent per year), increasing to 5,714 cubic meters for the period of 1931 to October 2001 (or 0.25 percent per year).

The storage capacity of Lago El Guineo as a function of pool elevation is listed at 1-meter intervals in table 3. The graphical relation between pool elevation and storage capacity is shown in figure 10. A comparison between the July 1986 and October 2001 selected cross sections to analyze sediment accumulation and distribution within the reservoir bottom is not adequate for most of the cross sections presented in figure 8, because of the difference between the two sets of shorelines and contour locations. For example, a comparison of cross section number 10 (fig. 8) shows what appears to be a different orientation in the plotting origin of the cross sections. However, if the 1986 cross section is mirror-imaged, the resulting cross section aligns fairly well with the 2001 DGPS-collected data and cross section. This misalignment may have happened when manually plotting the depth data in the 1986 bathymetric map (plate 2), since the difference is also noted when comparing plates 1 and 2. Although the 1986 shoreline and contours could be adjusted to fit the rectified October 2001 shoreline, it would create inconsistencies in the contour data, which would result in discrepancies. To properly adjust the 1986 dataset, the raw field data would be required, which are not available.

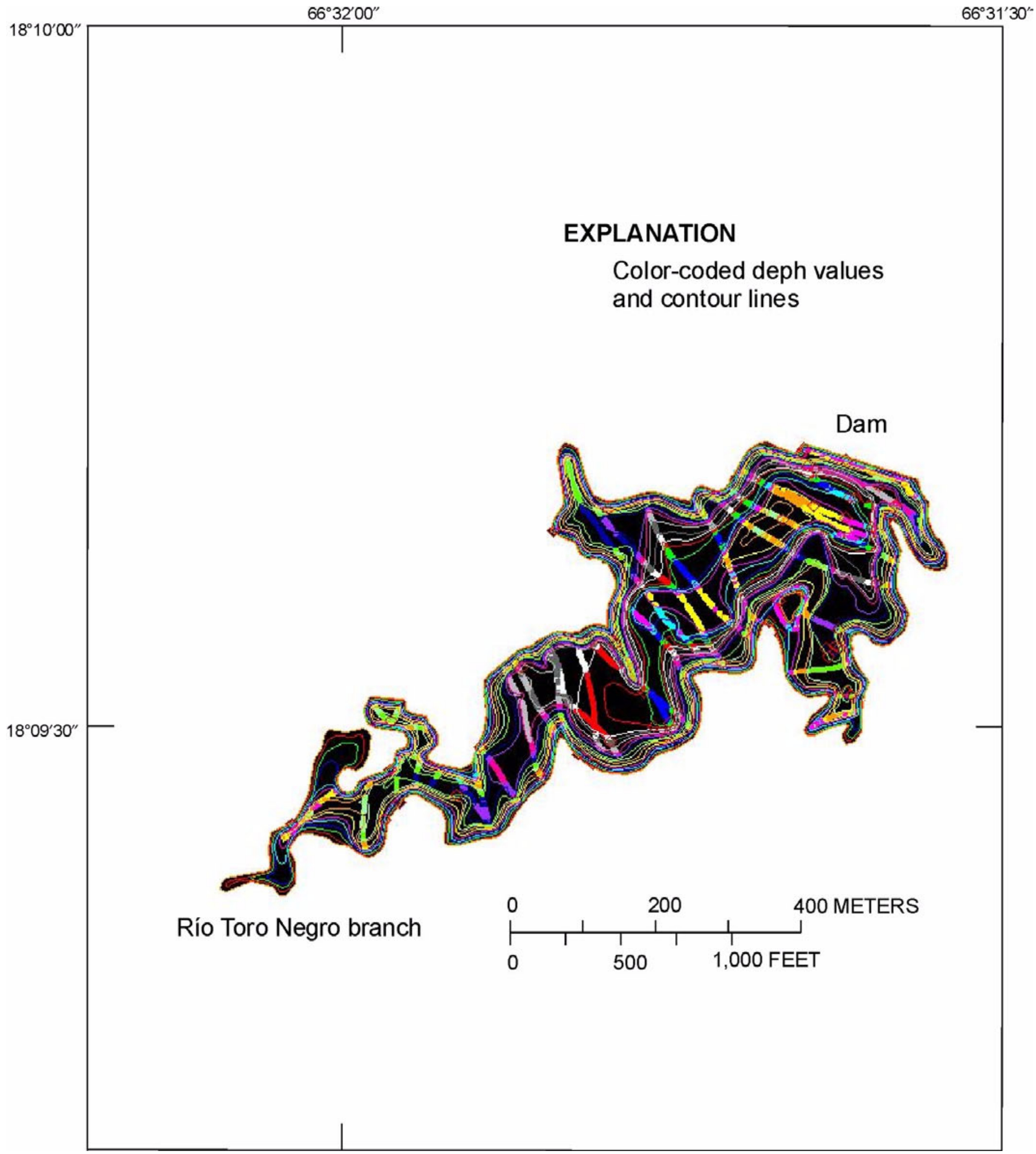


Figure 6. Lago El Guineo color-coded depth values and contour lines generated using Arcplot. The figure is for illustrative purposes only.

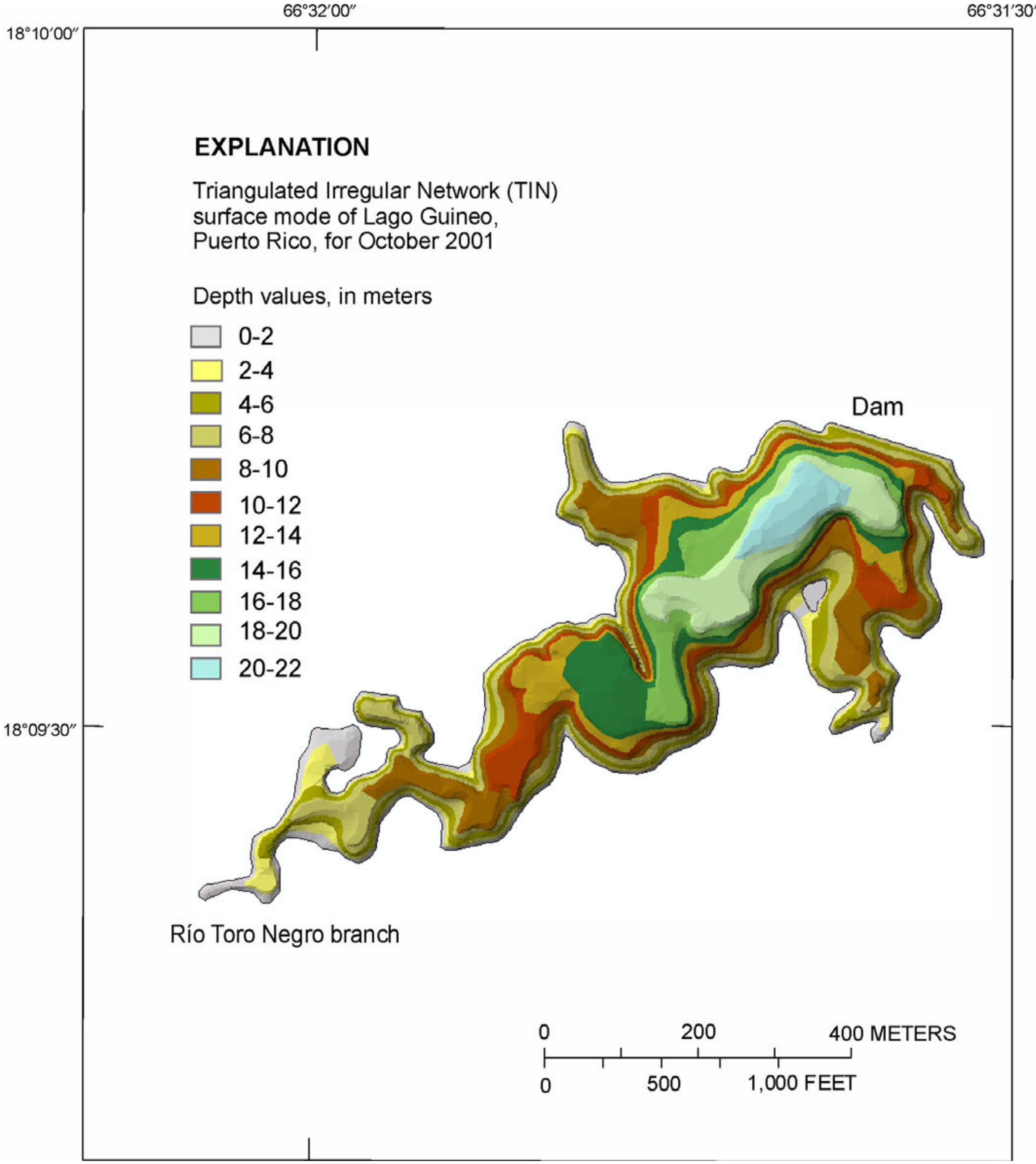


Figure 7. Lago El Guineo triangulated irregular network (TIN) surface model generated using Arc/Info.

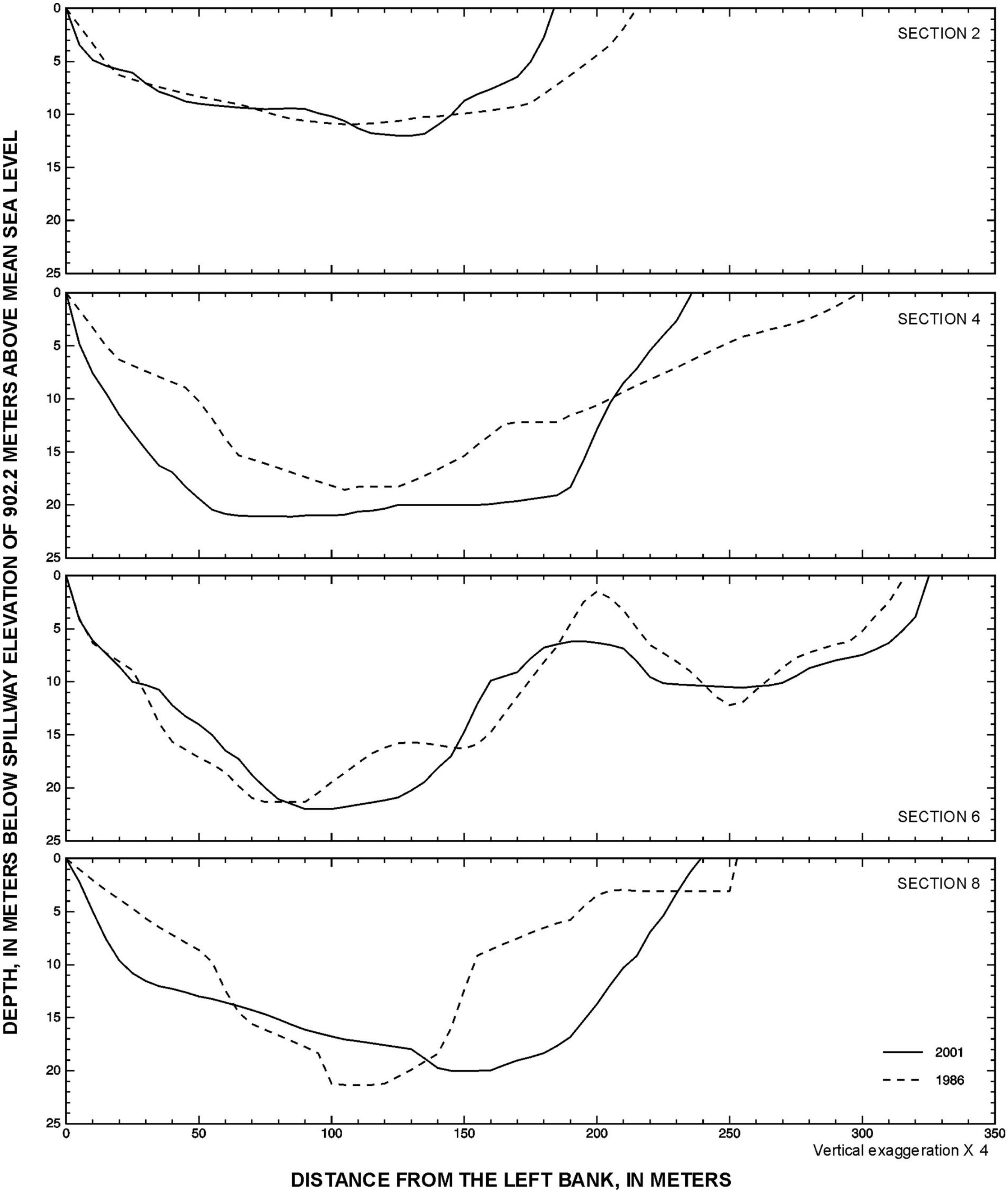


Figure 8. Selected cross sections generated from the triangulated irregular network (TIN) surface model of Lago El Guineo, Puerto Rico, for July 1986 and October 2001. Refer to figure 2 for cross-section locations.

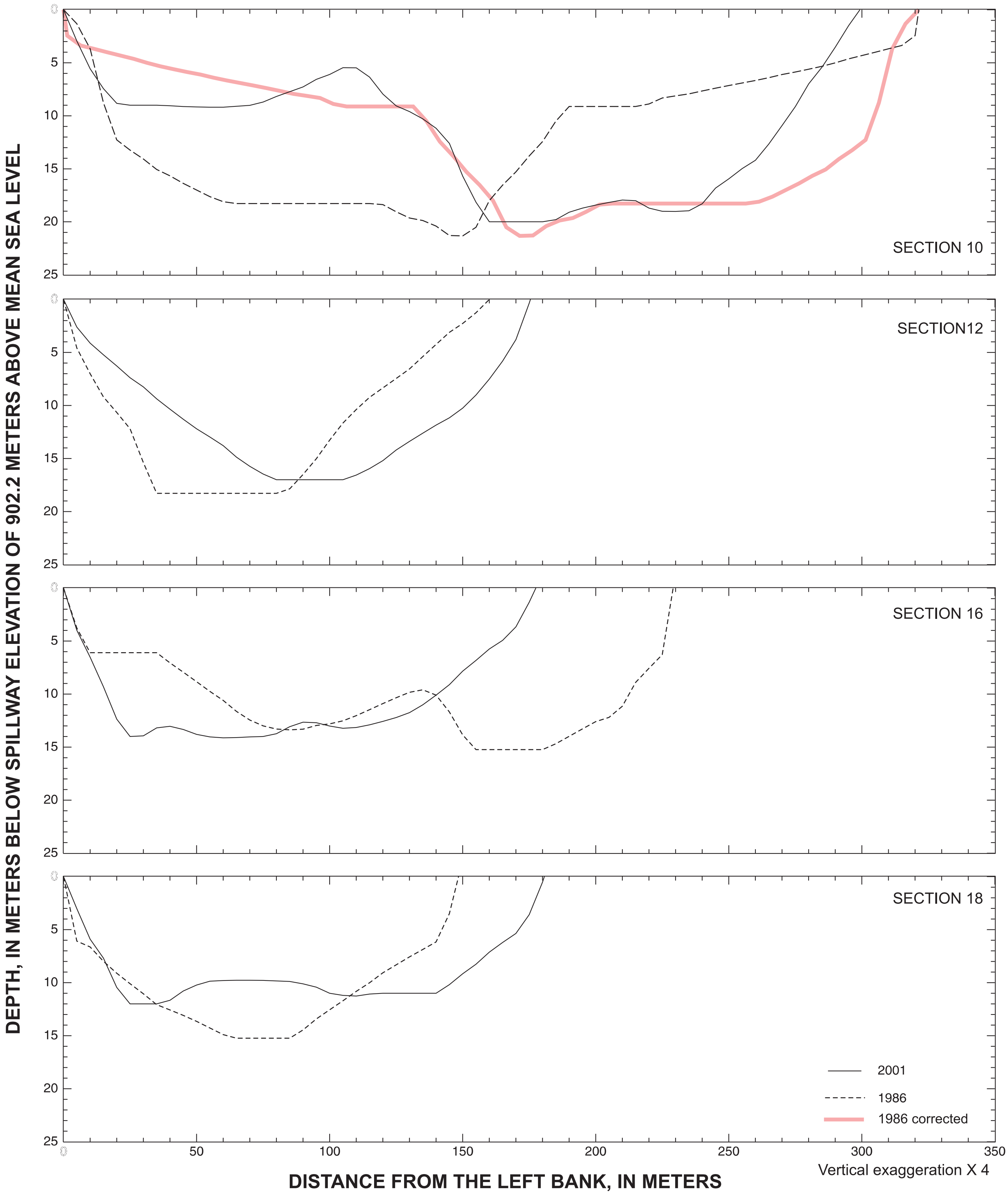
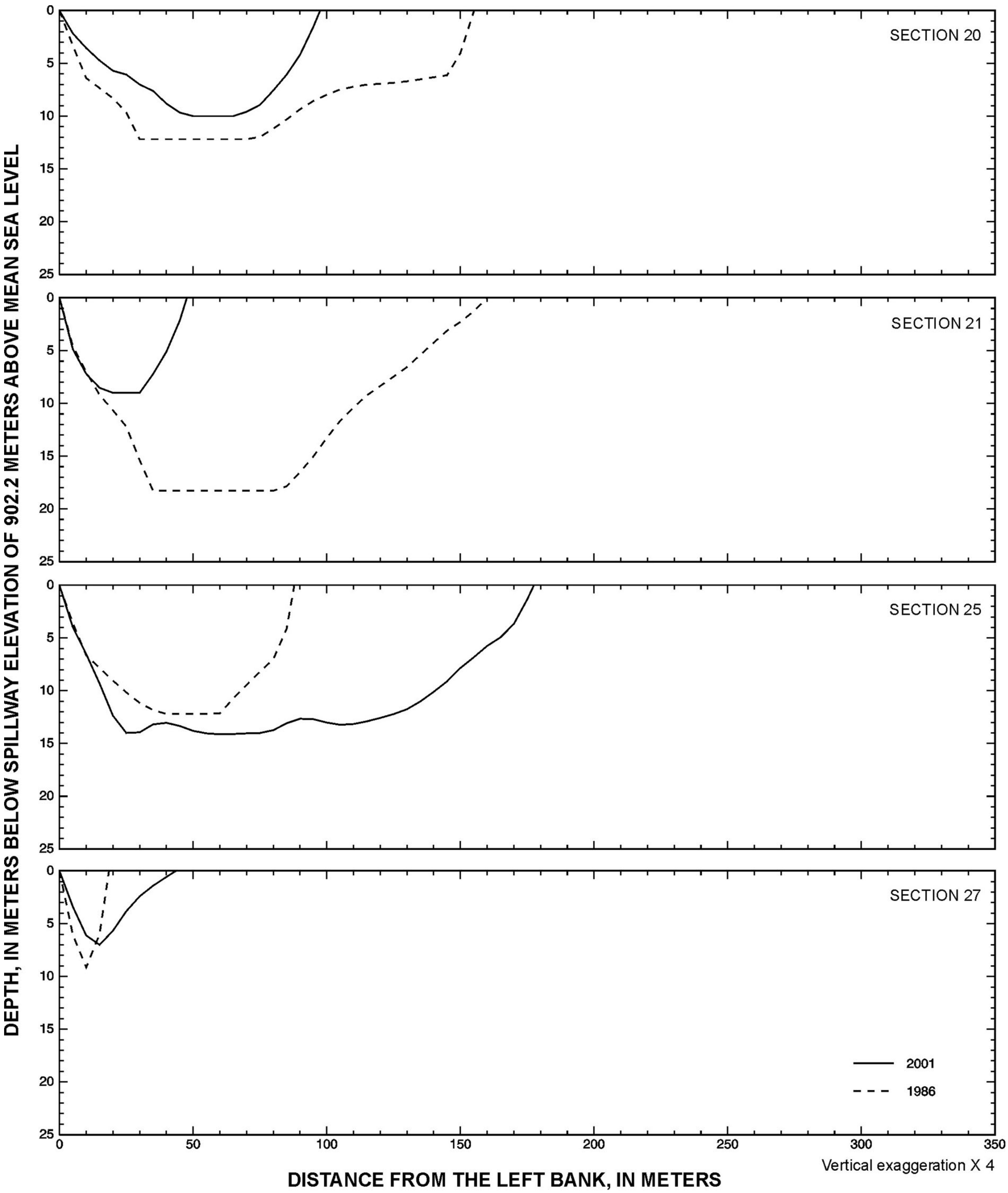


Figure 8. Selected cross sections generated from the triangulated irregular network (TIN) surface model of Lago El Guineo, Puerto Rico, for July 1986 and October 2001. Refer to figure 2 for cross-section locations—Continued.



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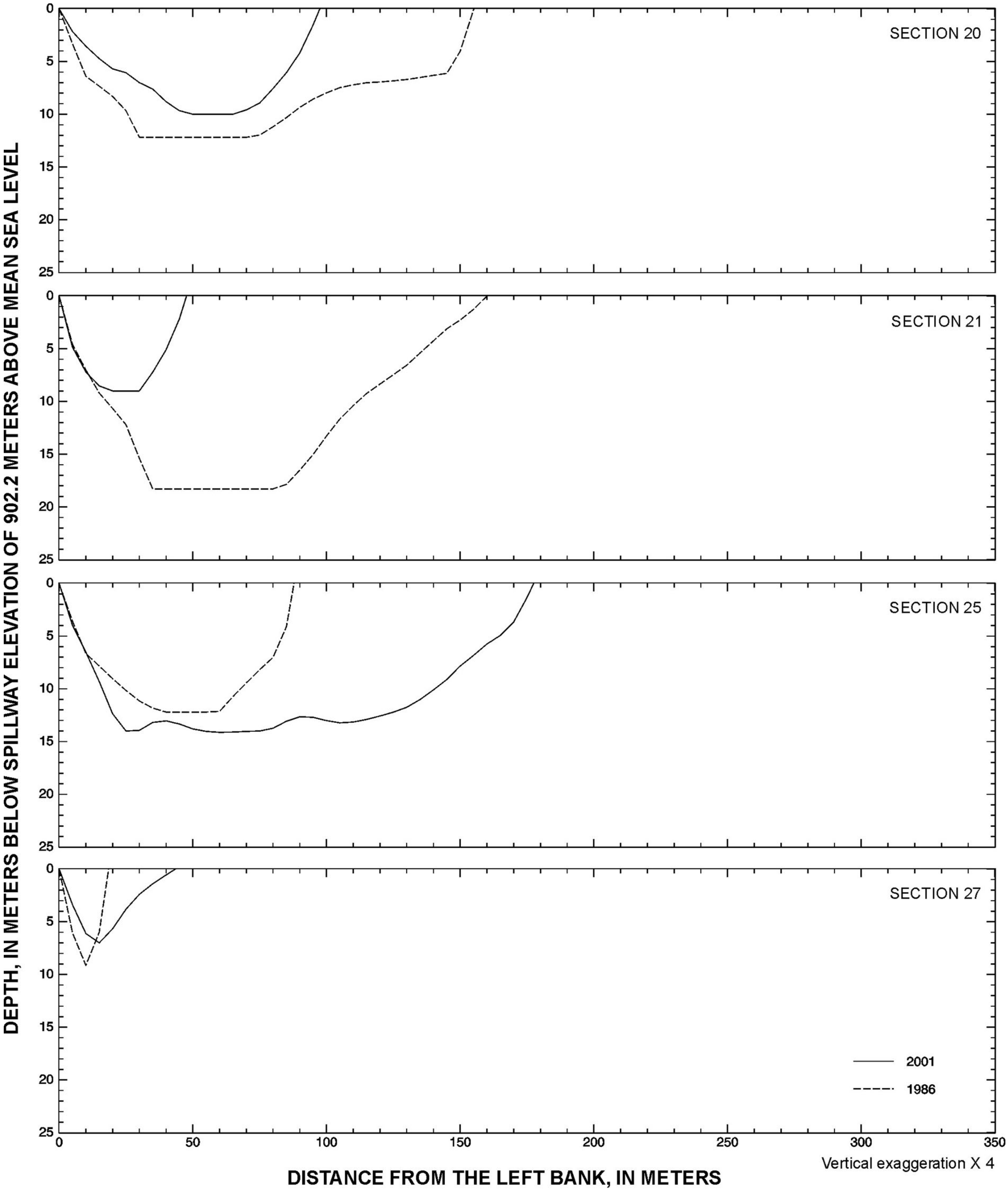

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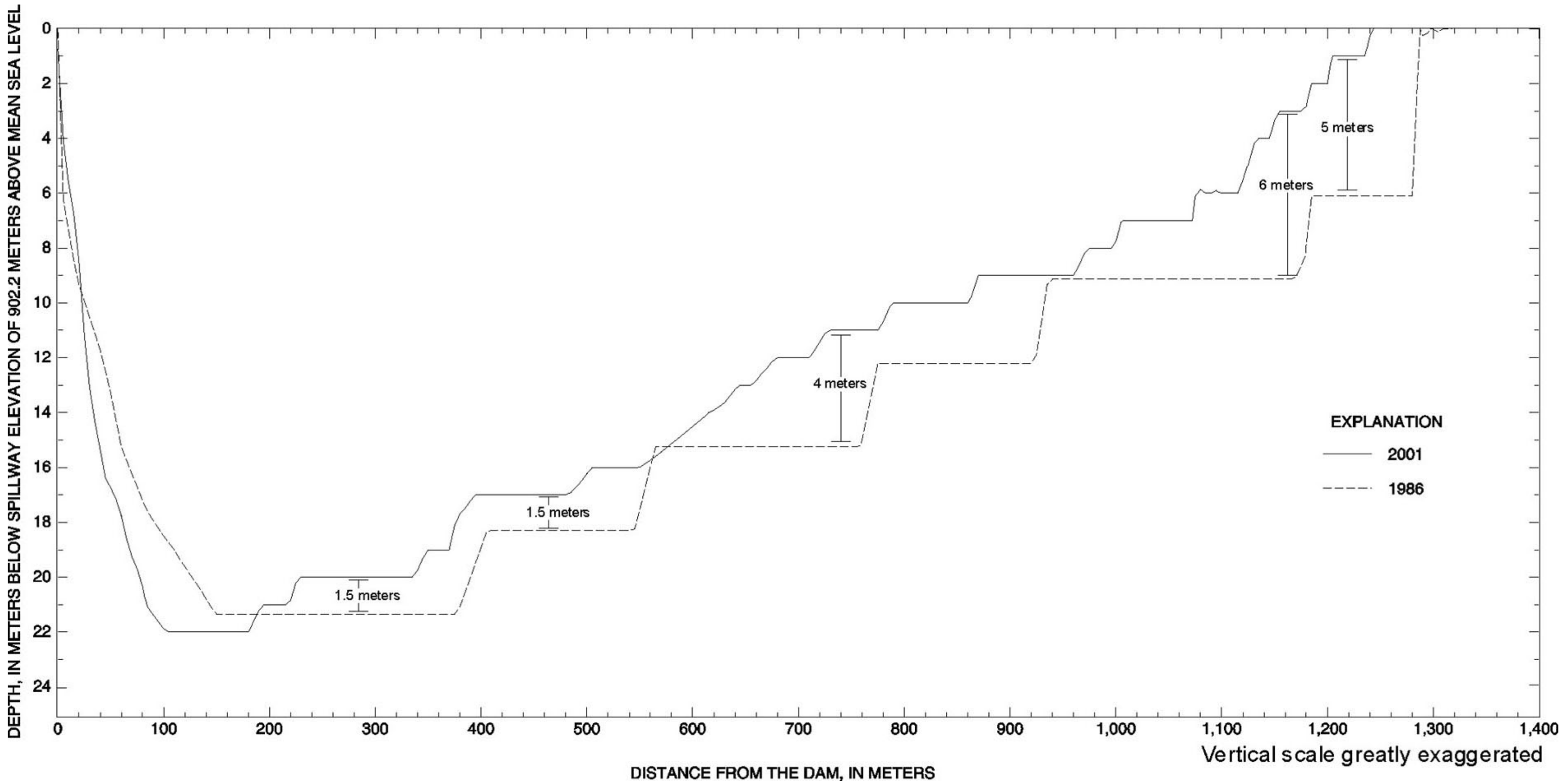

Figure 9. Longitudinal profiles along the thalweg of the Lago El Guineo, Puerto Rico, for July 1986 and October 2001.

Table 2. Comparison of the 1931, July 1986, and October 2001 sedimentation surveys of Lago El Guineo, Puerto Rico

[--, undetermined]

Year of survey	1931	1986	2001
Available storage capacity, in million cubic meters	2.29	2.03	1.89
Sediment accumulated, in million cubic meters	0	0.26	0.40
Years since construction	0	55	70
Storage loss, in percent	0	11	17.5
Annual storage capacity loss, in percent	0	0.21	0.25
Long-term sedimentation rate, in cubic meters per year	0	4,727	5,714
Trapping efficiency, in percent[1]	97	96	95
Drainage basin sediment yield, in megagrams per square kilometer per year[2]	--	1,159	1,471
Year that the reservoir would fill with sediment	--	2415	2332[3]

[1] Using the capacity-inflow ratio described by Brune (1953).
[2] Assuming a sediment dry bulk density of 1 gram per cubic centimeter.
[3] Assuming that the reservoir would continue to fill at the 2001 calculated long-term sedimentation rate.

Table 3. Storage capacity of Lago El Guineo, Puerto Rico, October 2001

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

Pool elevation	Storage capacity
902.21	1.89
901.21	1.70
900.21	1.53
899.21	1.36
898.21	1.20
897.21	1.06
896.21	0.91
895.21	0.78
894.21	0.66
893.21	0.56
892.21	0.46
891.21	0.38
890.21	0.31
889.21	0.25
888.21	0.19
887.21	0.14
886.21	0.10
885.21	0.07
884.21	0.04
883.21	0.02
882.21	0.10
881.21	0.003
880.21	0.00

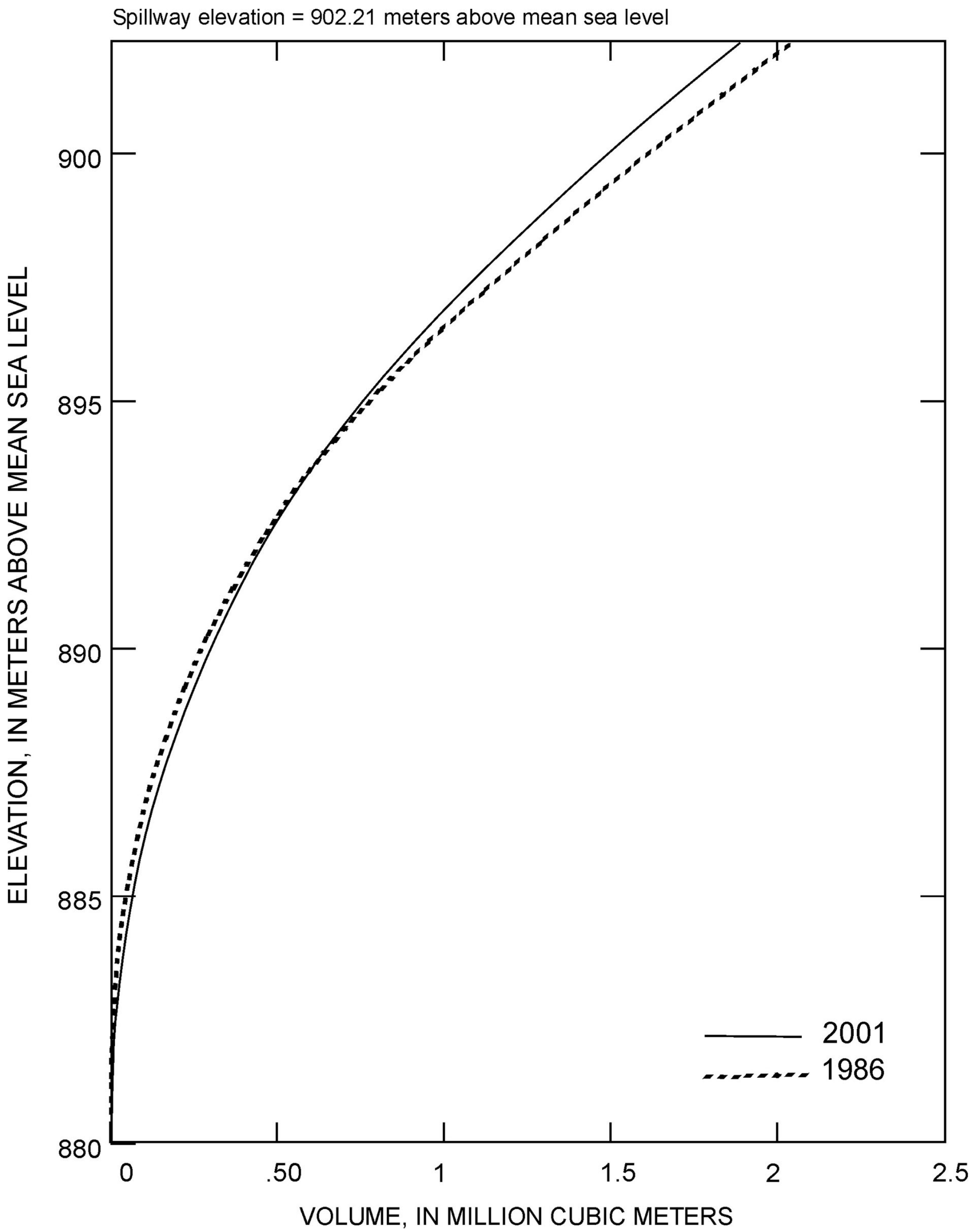

Figure 10. Relation between water-storage capacity and pool elevation of Lago El Guineo, Puerto Rico, for July 1986 and October 2001.

Although these discrepancies impeded the comparison of these two cross-section datasets, the overall calculations of volume for the July 1986 survey are considered to be adequate because no anomalies are evident when comparing the historical sedimentation trends of Lago El Guineo (table 2). The increase in sedimentation rate and annual storage loss from 1986 to 2001 is probably the result of large sediment loads associated with Hurricanes Hortense and Georges in 1996 and 1998, respectively, as these storms severely impacted other upland reservoirs in Puerto Rico (Soler-López, 2000, 2001a).

The longitudinal profiles of Lago El Guineo for July 1986 and October 2001 are more appropriate than cross-section data for the analysis of the extent of sediment accumulation in the reservoir bottom because the profiles are more easily overlaid, and the discrepancies between the two sets of shorelines are negligible using the side-view perspective. From the profiles presented in figure 9, the rise on the reservoir bottom caused by sediment accumulation is evident. There are three distinct areas where sediment accumulation is substantial; approximately 750 meters, 1,050 meters, and 1,250 meters upstream from the dam. Although sediment accumulation is evident in practically all areas of the reservoir, the greater sediment accumulation has occurred in the upper reach, approximately 1,250 meters upstream from the dam, where the RíoToro Negro enters the reservoir (fig. 9). An average of about 5.5 meters in thickness of sediment has accumulated in this area, giving a sediment deposition rate of about 0.4 meter per year for the period of July 1986 to October 2001. Approximately 750 meters upstream from the dam, a thickness of 4 meters of sediment has accumulated, for a deposition rate of about 0.3 meter per year during the same period. From the dam to about 500 meters upstream, the material accumulation is less and more uniform; a layer about 1.5 meters thick has accumulated in the same period, resulting in a deposition rate of about 0.1 meter per year.

The power-generating intake structure is located in the deepest part of the reservoir, approximately 120 meters upstream from the dam and has a crown elevation of 876.30 meters above mean sea level. According to the 2001 survey data, the reservoir bottom has reached an elevation of 880.21 meters above mean sea level and although the intake tunnel is surrounded by a layer of sediment of about 4 meters thick, the structure is still operational. It is likely that the daily water releases for operation of the irrigation canal and power-generating process, along with the trashrack, maintain the intake clear of material deposition. This accumulation of material, however, has depleted the reservoir of the dead-storage volume used to accommodate sediment without disabling the intake structure. In addition, if water releases are discontinued for a prolonged period, the intake structure could be rendered inoperative. This situation has been noted in many of the reservoirs in Puerto Rico (Soler-López, 2001b).

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 parameters 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 water discharge schedules (Verstraeten and Poesen, 2000).

Many empirical studies showing the relation between reservoir storage capacity, water inflow, and trapping efficiency have been conducted, of which Brune's (1953) is the most widely used and accepted. Brune developed a curve that is used to estimate the trapping efficiency of a reservoir based on the ratio of storage capacity to annual water inflow volume (fig. 11). The trapping efficiency of Lago El Guineo was estimated using the relation established by Brune.

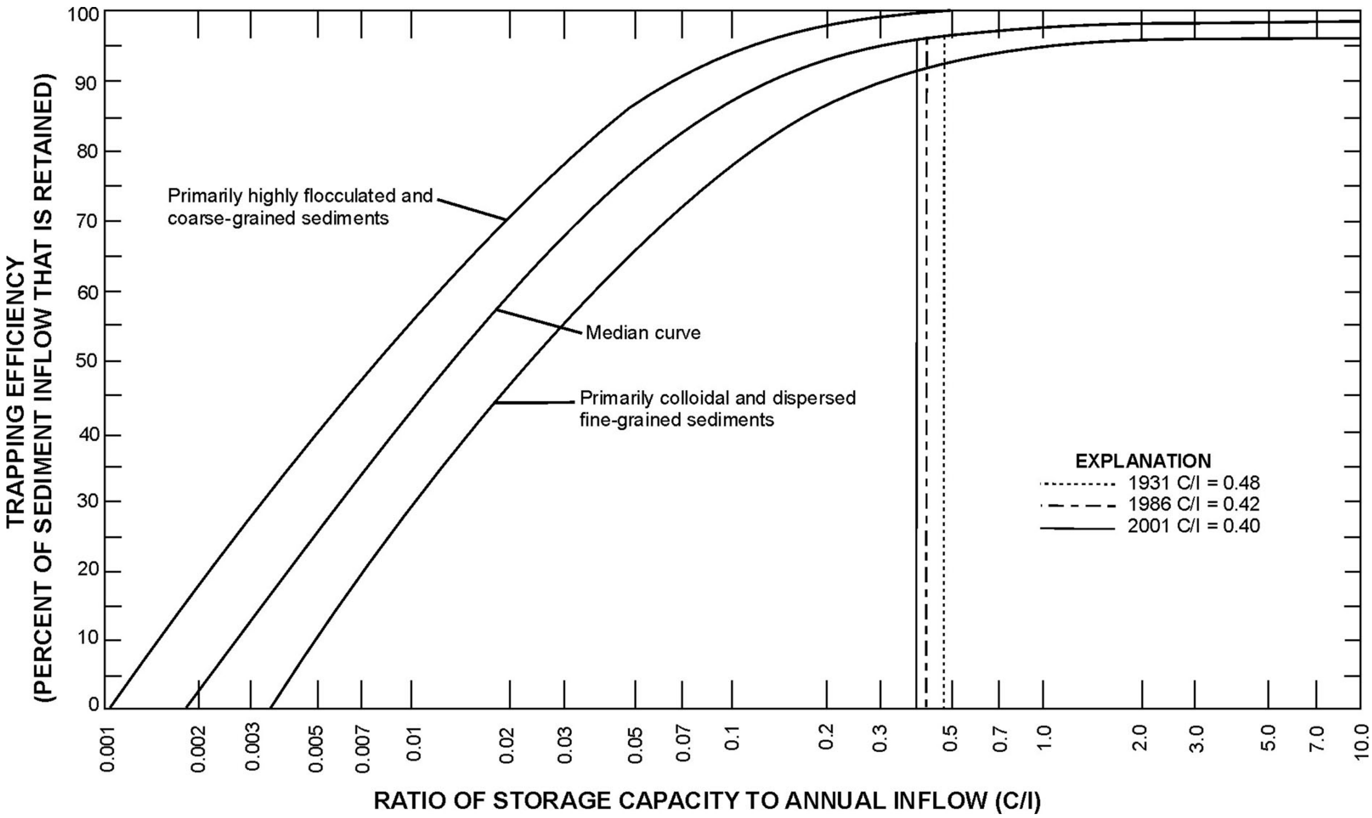

Figure 11. Reservoir trapping efficiency as a function of the ratio between storage capacity and annual water inflow volume.

The Lago El Guineo drainage area has no stream gaging station to measure annual inflow to the reservoir. To estimate how much rainfall becomes runoff in the Lago El Guineo drainage area, the neighboring basin of Río Saliente was used to estimate the rainfall/runoff ratio of the Lago El Guineo drainage area. The Río Saliente drainage area has similar topography, land use, elevation, and hillslopes, and therefore the rainfall/runoff ratio can be used for the Lago El Guineo Basin.

The USGS surface-water station Río Saliente at Coabey near Jayuya, Puerto Rico (number 50025155), has an average annual runoff of 1.12 meters for the period from 1989 to 1999 (Díaz and others, 2000). The average annual rainfall for the Río Saliente Basin is 2.29 meters (Calvesbert, 1970). Thus, the rainfall/runoff ratio equals 0.49. The Lago El Guineo drainage area has the same average annual rainfall of 2.29 meters as the Río Saliente drainage area (Calvesbert, 1970), therefore, the Lago El Guineo estimated runoff is assumed to be approximately 1.12 meters per unit of area per year. Multiplying this value by the Lago El Guineo drainage area (4.27 square kilometers) gives an estimated annual inflow value of 4.78 million cubic meters. Using the median curve of Brune (fig. 11), the estimated trapping efficiency of Lago El Guineo was about 97, 96, and 95 percent during 1931, 1986, and 2001, respectively, resulting in an average long-term trapping efficiency of 96 percent for Lago El Guineo.

SEDIMENT YIELD

Sediment yield has been defined by the American Society of Civil Engineers as the total sediment outflow from a catchment or drainage basin, measurable at a point of reference for a specified period of time per unit of surface area (McManus and Duck, 1993). For Lago El Guineo, the total amount of sediment that has entered the reservoir (0.42 million cubic meters) was estimated by dividing the accumulated sediment (0.40 million cubic meters) by the long-term trapping efficiency (0.96). To determine the average annual rate of sediment influx, 0.42 million cubic meters was divided by the age of the reservoir (70 years), resulting in 6,000 cubic meters per year. The sediment yield of the Lago El Guineo drainage basin was calculated by dividing 6,000 cubic meters per year by 4.08 square kilometers (the drainage area minus the reservoir surface area), resulting in a yield of 1,471 cubic meters per square kilometers per year. Assuming a sediment dry bulk density of 1 gram per cubic centimeter (Webb and Soler, 1997), the estimated sediment yield of the Lago El Guineo drainage area is about 1,471 megagrams per square kilometer per year for the period from 1931 to 2001.

Using the same calculations, the average annual sediment yield of Lago El Guineo was 1,159 megagrams per square kilometer per year for the period from 1931 to 1986. This represents a 21-percent increase in erosion rates within the Lago El Guineo Basin since 1986. However, the true sediment yield of the basin is likely higher because these calculations do not account for eroded material (that was not trapped by the reservoir) and material resulting from Hurricanes Hortense and Georges, in addition to other recent rainfall events, which is temporarily stored sediment in river channels upstream from the reservoir. These high runoff flows flush previously eroded material downstream and also deposit additional material in the river beds upstream of the reservoir. This temporarily stored material has the potential to further reduce the storage capacity of the reservoir when transported and deposited into the reservoir by future high-flow events.

Based on the October 2001 storage capacity and the long-term sedimentation rate, Lago El Guineo has a useful life of about 331 more years. However, the actual life expectancy of Lago El Guineo could be somewhat shorter or longer depending on future rainfall frequencies and magnitudes, as well as land-use practices within the basin. Although the life expectancy of Lago El Guineo does not seem to be a pressing concern, sediment accumulation in the vicinity of the water intakes could disable the structure if water releases are discontinued for a prolonged period of time. This could affect water utilization even if the reservoir can store a substantial volume of water.

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