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

Prepared in cooperation with the
Puerto Rico Aqueduct and Sewer Authority

Scientific Investigations Map 3369
Sheet 1 of 1

Introduction

Lago La Plata is operated by the Puerto Rico Aqueduct and Sewer Authority (PRASA) and is part of the San Juan Metropolitan Water District. The reservoir serves a population of about 425,000 people. During 2013 the reservoir provided 0.307 million cubic meters (Mm^3) of water per day (about 81 million gallons per day), which is equivalent to 31 percent of the total water demand for the metropolitan area (Wanda L. Molina, U.S. Geological Survey, written commun., 2015). The dam was constructed in 1974 and is located about 5 kilometers (km) south of the town of Toa Alta and 5 km north of the town of Naranjito (fig. 1). The drainage area upstream from the Lago La Plata dam is about 469 square kilometers (km^2). The storage capacity at construction in 1974 was 26.84 Mm^3 with a spillway elevation of 47.12 meters (m) above mean sea level (msl). Storage capacity was increased to 40.21 Mm^3 in 1989 after the installation of bascule gates to provide a normal dam pool elevation at 52 m above msl (Puerto Rico Electric and Power Authority, 1979). The maximum height of the dam is about 40 m above the river bottom near the dam, and the intake structure consists of six 1.82-m-diameter ports facing upstream, with 6-m vertical spacing that begins at an elevation of 19 m above msl.

The U.S. Geological Survey (USGS), in cooperation with the PRASA, conducted a bathymetric survey of the Lago La Plata reservoir during March and April 2015. The hydrographic survey was designed to provide an update of the reservoir storage capacity and sedimentation rate. Areas with substantial sediment accumulation are also discussed in this report. The results of the survey were used to prepare a bathymetric map showing the reservoir bottom (fig. 2) referenced with respect to the spillway elevation. This report also includes a summary of a previous bathymetric survey conducted in 2006 (Soler-López, 2008).

Method of Survey and Analysis

For the 2015 bathymetric survey, measurements of water depth and global positioning system (GPS) information were determined according to the field techniques and data-processing methods described in Soler-López and others (2000). The bathymetric survey was conducted using the bathymetric survey system, which consists of a differential global positioning system (DGPS) coupled to a digital depth sounder. Water depth was measured with an accuracy of 0.10 m ±0.1 percent of the measured depth, and the geographic position data had an accuracy of less than 2 m. The data were referenced horizontally to the North American Datum of 1983 (NAD 83), and the fathometer was calibrated each day prior to data collection using the bar-check method (Wilson and Richards, 2006).

The bathymetric data were collected using established navigation lines that serve as reference paths, beginning at the dam structure and continuing upstream along the longitudinal extent of the reservoir. A total of 264 survey navigation lines were established at intervals of about 50 m (fig. 3). The reservoir pool elevation was continuously monitored during the period of the survey by recording the data from USGS gaging station 50045000, Lago La Plata at Damsite near Toa Alta, PR (fig. 1). Depth information collected during the bathymetric survey was adjusted to the spillway elevation by adjusting the point depth measurements to normal pool elevation, which is the maximum allowed water surface elevation, not considering the flood surcharge (State of Nevada, 2013), on the basis of the pool elevation measurements made at USGS gaging station 50045000. Therefore, the measurements made by the depth sounder represent water depths below normal pool elevation.

Bathymetric survey data were transferred to the geographic information system (GIS) developed by Esri ArcGIS for post processing and to calculate reservoir volume. Data points collected along each established navigation line were used to generate a bathymetric map representing the reservoir bottom (figs. 2 and 3). Using customizing tools in the GIS program, points were color coded according to their specific depths; contour lines were created by connecting the same-color points throughout the longitudinal extent of the reservoir. The calculations of volume at 1.0-m intervals for the reservoir were determined using the triangulated irregular network (TIN) surface model tool available in the GIS program (see table 1) and are plotted in figure 4. The 2015 TIN surface model was also used to generate the profiles along the longitudinal extent and tributaries of Lago La Plata reservoir (fig. 5). In those small reservoir branches with excessive debris or shallow water depths, a survey was not conducted and reservoir bottom contours were extrapolated on the basis of nearby areas. In the Río Guadiana branch, additional water depth data were obtained on the basis of hand soundings from a bridge located at the upstream reservoir branch boundary. Spatial data associated with the 2015 survey are presented in Gómez-Fragoso, 2016.

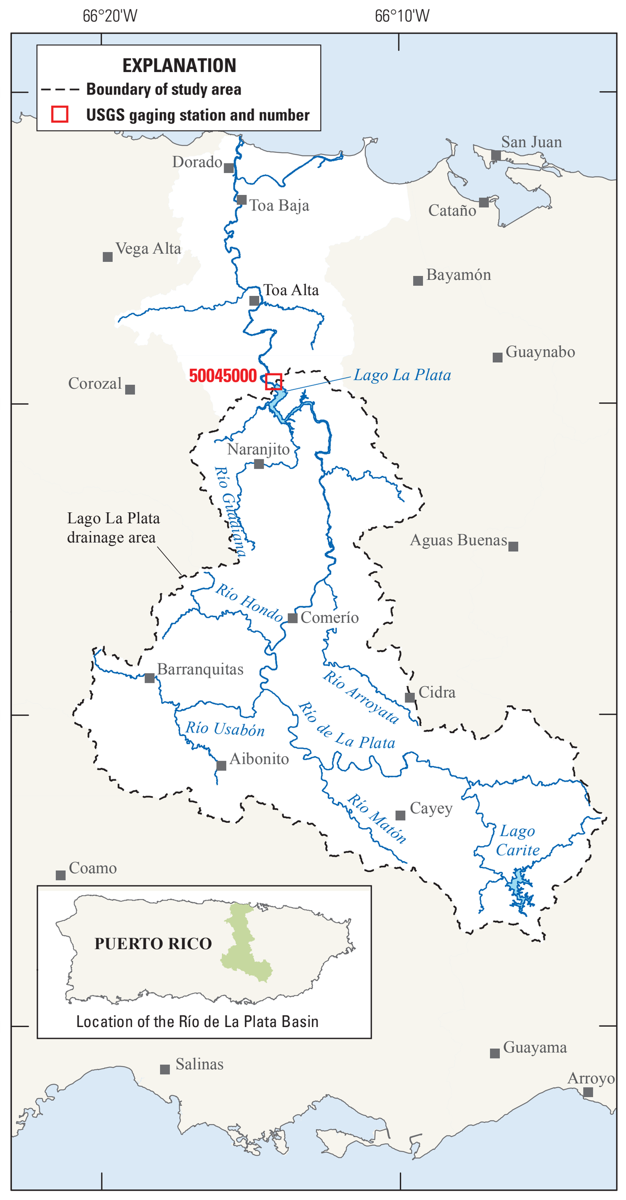

Figure 1. Location of Lago La Plata, Toa Alta, Puerto Rico.

Storage Capacity, Sedimentation Rate, and Useful Life

The 2015 bathymetric survey indicated that the storage capacity of Lago La Plata was 30.88 Mm^3 at a normal pool elevation of 52.00 m above msl, a decrease of about 9.33 Mm^3 from a capacity of 40.21 Mm^3 (table 2), which was provided after the installation of bascule gates in 1989. The reference date used in computation of the sedimentation rate is 1974 and assumes a capacity of 40.21 Mm^3 is provided since dam construction. This reduction in storage capacity represents a long-term storage loss of 23 percent in the 41 years since construction. A previous survey conducted in 2006 indicated a total storage capacity of 31.27 Mm^3, which represents a storage capacity loss of 8.94 Mm^3 (Soler-López, 2008). The inter-survey (2006–2015) sediment accumulation was about 0.39 Mm^3. The long-term annual storage capacity loss rate for the period 1974 to 2015 was 0.23 million cubic meters per year (Mm^3/yr), and the inter-survey annual loss of capacity rate for the period 2006 to 2015 was 0.04 Mm^3/yr. The inter-survey annual capacity loss rate preceding the 2006 survey (1998–2006) was 0.52 Mm^3/yr, which is an order of magnitude greater than that preceding the 2015 survey. A fixed source for the reduction of the sedimentation rate is complex and difficult to determine; however, this reduction in the sedimentation rate could be attributed to the absence of atmospheric systems delivering a substantial amount of rainfall to the island of Puerto Rico since the last bathymetric survey (National Oceanic and Atmospheric Administration, 2012). Among the peakflows recorded at USGS streamgaging station 50043800 for the period 1998 to 2006, a peak discharge of 75,100 cubic feet per second (ft^3/s) was recorded on September 15, 2004, and is associated with Hurricane Jeanne. Another possible factor that may have contributed to the decrease in the inter-survey sedimentation rate for the Lago La Plata reservoir is the decline in urban development in the drainage basin of the reservoir, particularly those activities associated with the construction of the built cable-stayed bridge crossing Río de La Plata and surrounding roads that were built since the last bathymetric survey. Uncertainties in factors such as upland erosion, soil moisture, rainfall amounts, sediment characteristics, and watershed activities make it difficult to identify the sources for either a decrease or an increase in the rate of sedimentation in a reservoir (Nagle and others, 1999).

The reservoir bottom profiles along the central part of the reservoir were generated using Lago La Plata dam as the starting point and continuing upstream along the longitudinal extent of each of the tributaries of the reservoir (fig. 5). Sediment accumulation observed in the reservoir bottom profiles in the 2006 and 2015 surveys along Río de La Plata (fig. 5*A*) and Río Cañas (fig.5*B*) branches was up to 4 m thick and occurred at about 7,000 and 2,000 m, respectively, upstream from the dam structure. Sediment accumulations depths in the Río Guadiana (fig. 5*C*) branch reached up to 2 m and were uniformly distributed throughout the tributary.

Reservoir trapping efficiency is defined as the ratio of deposited sediment to the total sediment inflow for a given period within the reservoir's useful lifetime. Several studies have been conducted to determine the sediment accumulation rate in the reservoir and cite trapping efficiency as one of the most informative descriptors of storage capacity loss in the reservoir. The sediment trapping efficiency of Lago La Plata for the 2015 bathymetric survey was estimated using the empirical-based curves developed by Brune (1953). This method is widely used for reservoir storage loss analysis and relates trapping efficiency to the ratio of storage capacity to annual water inflow volume. Using the water storage capacity of 30.88 Mm^3 determined during the 2015 survey and the estimated annual water inflow volume into Lago La Plata of 277.11 Mm^3/yr (Soler-López and others, 2000), the capacity to inflow ratio was estimated as 0.11. Therefore, the sediment trapping efficiency of Lago La Plata is 87 percent, based on the results of the 2015 survey.

Sediment yield is defined as the total sediment outflow from a drainage basin measurable at a point of reference for a specific period of time (McManus and Duck, 1993). The sediment yield of the Lago La Plata Basin was determined by dividing the amount of sediment accumulated in the reservoir (9.33 Mm^3) by the average long-term trapping efficiency of the reservoir (0.87), which resulted in a net volume of 10.72 Mm^3 of sediment eroded from within the basin. The net sediment volume was divided by the sediment-contributing drainage area of the basin (the 469 km^2 total drainage area minus the 3 km^2 surface area of the reservoir) and the number of years since impoundment (41 years). The long-term drainage area sediment yield rate of Lago La Plata was 561 cubic meters per square kilometer per year ($[m^3/km^2]$/yr) for the period 1974 to 2015. This sediment yield rate is 18 percent lower than the rate estimated for the period 1974 to 2006 (689 $[m^3/km^2]$/yr). Inter-survey drainage area sediment yields were 1,292 (m^3/km^2)/yr in 2006 and 107 (m^3/km^2)/yr in 2015. On the basis of the current long-term storage-capacity loss of about 0.23 Mm^3/yr and assuming a constant sedimentation rate, the projected useful life of Lago La Plata is about 134 years, ending in 2149. The predicted useful life of Lago La Plata is slightly longer than the previously estimated useful life of 112 years, ending in 2118 (Soler-López, 2008).

Summary and Conclusions

During March and April 2015, the U.S. Geological Survey conducted a sedimentation survey to update the reservoir storage capacity information and the sedimentation infill rate estimates, and to describe the location of accumulated sediments in the reservoir. The data for this study were collected using a digital depth sounder coupled to a differential global positioning system device. The general results of the 2015 bathymetric survey data and the previous 2006 survey are presented and analyzed.

The results of the sedimentation survey indicated that the storage capacity of Lago La Plata decreased from 31.27 Mm^3 in 2006 to 30.88 Mm^3 in 2015. The survey results indicated a long-term storage capacity loss of about 23 percent, corresponding to a decrease of about 0.23 Mm^3/yr. Comparison of the 2015 survey with previous sedimentation surveys showed that on a long-term basis, the storage loss rate did not appreciably change. The inter-survey sediment accumulation was estimated as 0.39 Mm^3, which is equivalent to an average storage capacity loss of 0.04 Mm^3/yr from 2006 to 2015.

Most of the accumulated sediment and associated storage capacity loss of Lago La Plata was observed along the Río de La Plata and Río Cañas tributaries; sediment accumulation depths reached up to 4 m. Deposition and scour along the Río Guadiana tributary of the reservoir were much less. The trapping efficiency of Lago La Plata is estimated to be about 87 percent. The Lago La Plata drainage area sediment yield decreased slightly from 689 (m^3/km^2)/yr in 2006 survey (for the period 1974–2006) to 561 (m^3/km^2)/yr in 2015 (1974–2015). On the basis of a constant long-term sedimentation rate of 0.23 Mm^3/yr, the useful life of Lago La Plata is estimated to extend until 2149.

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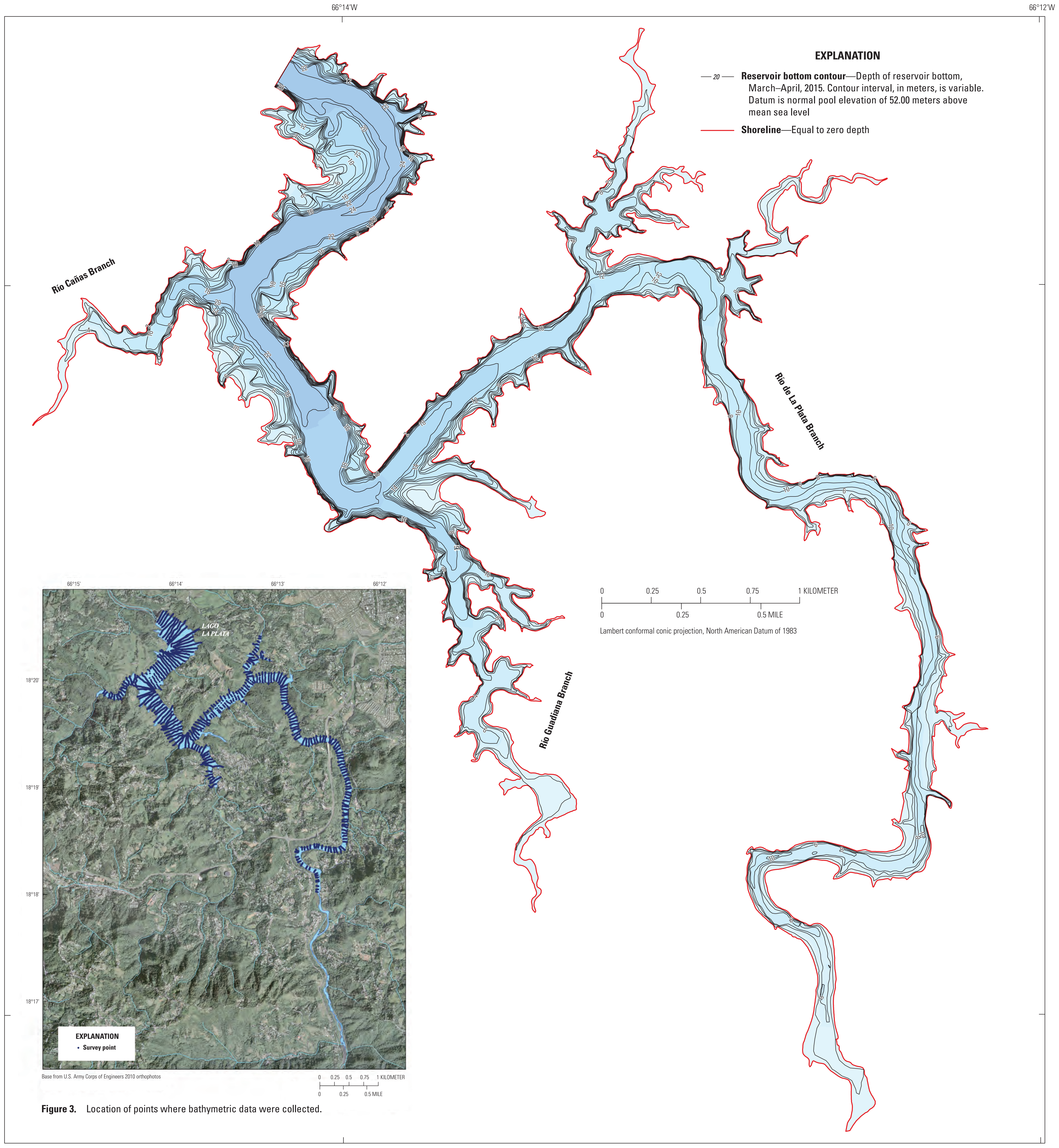

Figure 3. Location of points where bathymetric data were collected.

Figure 2. Bathymetric map of Lago La Plata, Toa Alta, Puerto Rico, March–April 2015.

Table 1. Comparison between the 2006 and the May 2015 sedimentation surveys of Lago La Plata, Toa Alta, Puerto Rico.

Data descriptor	Years of survey 2006	Years of survey 2015
Total capacity, in million cubic meters	31.27	30.88
Live storage, in million cubic meters[1]	30.33	30.29
Dead storage, in million cubic meters[1]	0.94	0.59
Years since construction	32	41
Sediment accumulation, in million cubic meters	8.94	9.33
Inter-survey sediment accumulation, in million cubic meters	[2]4.19	0.39
Long-term storage loss, in percent	22	23
Long-term annual loss of capacity, in million cubic meters per year	0.28	0.23
Annual loss of capacity, in percent	0.7	0.6
Inter-survey annual loss of capacity, in million cubic per meters per year	[2]0.52	0.04
Sediment trapping efficiency, in percent[3]	87	87
Long-term sediment yield, in cubic meters per square kilometer per year	689	561
Inter-survey sediment yield, in cubic meters per square kilometer per year	[2]1,292	107
Estimated year the reservoir could fill with sediment[4]	2,118	2,149

[1]Live storage is the volume calculated above the reservoir's intake structure (31 meters above mean sea level); dead storage is calculated from the difference between total reservoir volume for the survey year and live storage.

[2]Period between 1998 and 2006 surveys.

[3]Using the capacity/inflow ratio described by Brune (1953).

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

Table 2. Storage capacity at 1-meter intervals from spillway elevation for Lago La Plata, Toa Alta, Puerto Rico, 2015.

Pool elevation, in meters above mean sea level	Storage capacity in million cubic meters
52.00	30.88
51.00	27.92
50.00	25.12
49.00	22.56
48.00	20.12
47.00	17.86
46.00	15.74
45.00	13.87
44.00	12.14
43.00	10.64
42.00	9.25
41.00	8.06
40.00	6.94
39.00	5.94
38.00	5.00
37.00	4.17
36.00	3.36
35.00	2.66
34.00	2.00
33.00	1.47
32.00	0.96
31.00	0.59
30.00	0.25
29.00	0.11
28.00	0.00

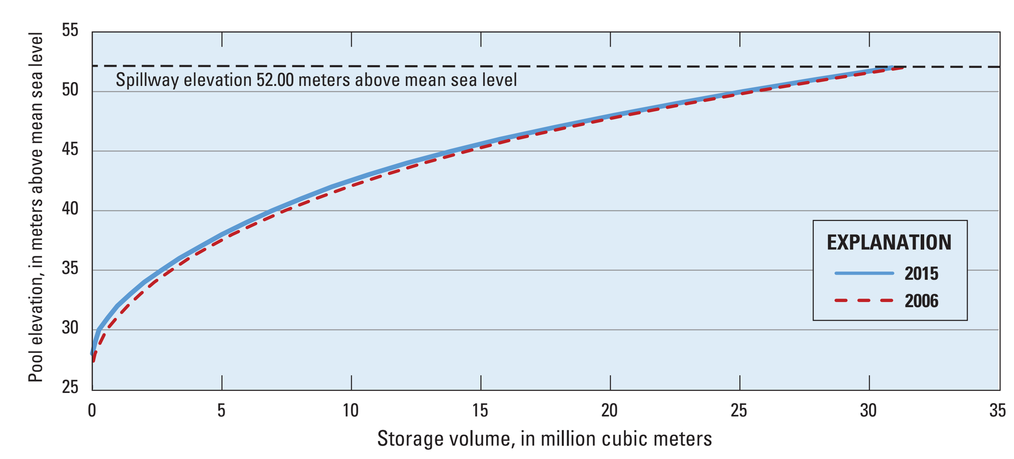

Figure 4. Relation between water-storage capacity and pool elevation of Lago La Plata, for 2006 and 2015.

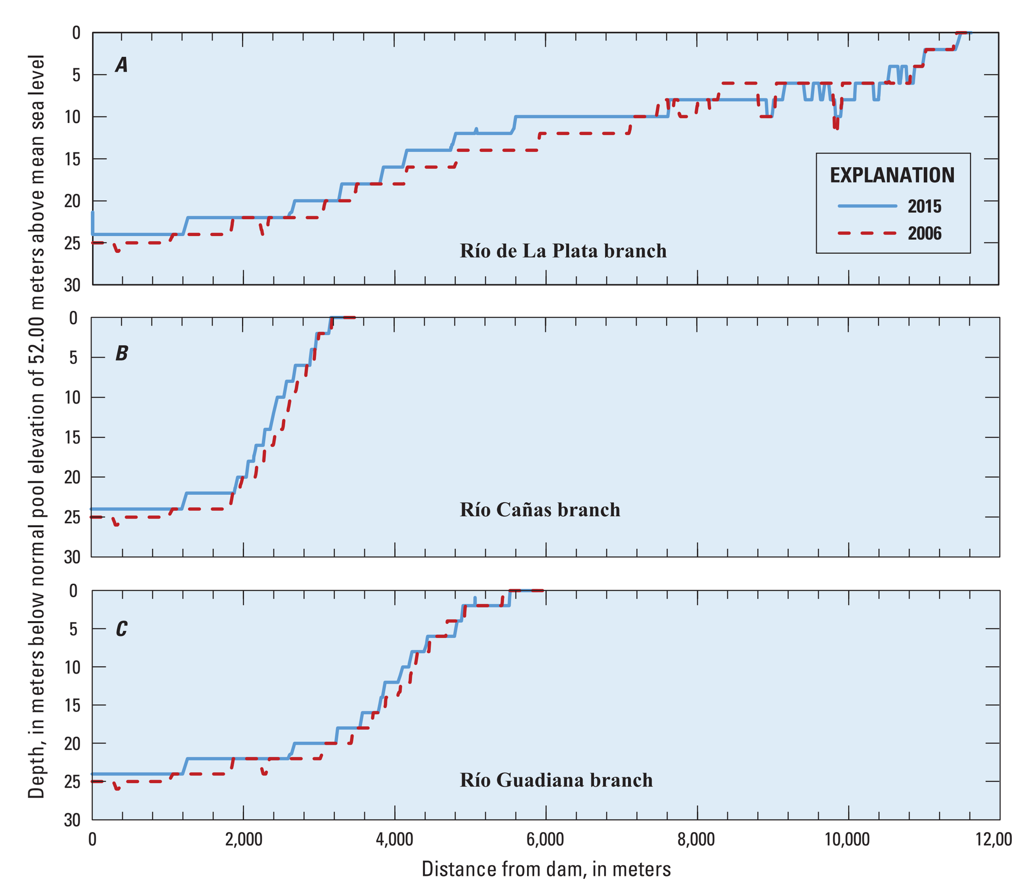

Figure 5. Longitudinal bottom profiles for 2006 and 2015 along the *A*, Río de La Plata; *B*, Río Cañas; and *C*, Río Guadiana branches of Lago La Plata, Toa Alta, Puerto Rico.

Sedimentation Survey of Lago La Plata, Toa Alta, Puerto Rico, March–April 2015

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