



**Figure 1.** Location of Lago Garzas in the upper Rio Grande de Arecibo basin, Puerto Rico.

**Introduction**

Lago Garzas is located in west-central Puerto Rico, about 3.5 kilometers southwest of the town of Adjuntas, in the confluence of the Río Vacas and three other unnamed tributaries (fig. 1). The dam is owned and operated by the Puerto Rico Electric Power Authority (PREPA), and was constructed in 1943 for hydroelectric power generation and municipal water use along the southern coast.

The dam is a semi-hydraulic earthfill embankment lined with boulders, and has a height of 61.57 meters, a top width of 9.14 meters, a base width of 365.76 meters, and a crest length of 227.37 meters; State Road PR-518 crosses the top of the dam. A morning-glory-type spillway is located near the west abutment of the dam at an elevation of 736.12 meters above mean sea level (Puerto Rico Water Resources Authority, 1969). Figure 2 shows an aerial photograph of the Lago Garzas earthfill dam and the morning-glory spillway section. Additional information and operational procedures are provided in Soler-López and others (1999).

During July 17–18, 2007, the U.S. Geological Survey (USGS) Caribbean Water Science Center, in cooperation with the Puerto Rico Aqueduct and Sewer Authority, conducted a bathymetric survey of Lago

Garzas to update the reservoir storage capacity and update the reservoir sedimentation rate by comparing the 2007 data with the previous 1996 bathymetric survey results. The purpose of this report is to describe and document the USGS sedimentation survey conducted at Lago Garzas during July 2007, including the methods used to update the reservoir storage capacity, sedimentation rates, and areas of substantial sediment accumulation since 1996.

**Method of Survey and Analysis**

The field techniques and bathymetric data reduction processes used for the 2007 survey were performed following procedures established by the USGS Caribbean Water Science Center and described in the previous bathymetric survey report of Lago Garzas (Soler-López and others, 1999). The July 2007 bathymetric survey was conducted using a differential global positioning system (DGPS) coupled to a digital depth sounder similar to the setup used for the survey conducted in September 1996 (Soler-López and others, 1999). Survey navigation lines were



**Figure 2.** Aerial photograph of the Lago Garzas earthfill dam and spillway section, taken during a dam safety inspection in May 2006. Photograph courtesy of the Puerto Rico Electric Power Authority.

established at 50-meter intervals and oriented parallel to the dam face of the reservoir, continuing upstream to the reservoir tail along the different river branches. Geographic positions and water depths were acquired simultaneously using a DGPS interfaced to a depth sounder. The pool elevation of the reservoir was measured at the USGS lake-level station 50020100, Lago Garzas near Adjuntas, Puerto Rico. The soundings were subsequently adjusted to represent water depths below the spillway elevation.

The 2007 data were stored and transferred into the USGS geographic information system (GIS), where final analysis and volume calculations were made following procedures similar to those used to develop the 1996 bathymetric map of Lago Garzas reservoir (Soler-López and others, 1999). The field data were used to generate a bathymetric map representing the reservoir bottom in July 2007 (fig. 3). A triangulated irregular

network (TIN) surface model of Lago Garzas was then created from the bathymetric map, and the reservoir volume was calculated using GIS. The TIN surface model was used with the digital data for 1996 and 2007 to generate a stage-storage curve and table, as well as longitudinal profiles along the different tributary branches of Lago Garzas.

**Storage Capacity, Sedimentation Rates, and Useful Life**

The storage capacity of Lago Garzas decreased from 5.11 million cubic meters in 1996 (Soler-López, 1999), to 4.99 million cubic meters by July 2007 (table 1). This decrease represents a reduction from 1996 to 2007 of 120,000 cubic meters (or 2.3 percent over 11 years), for an annual storage-capacity loss rate of about 10,909 cubic meters. The long-term sedimentation rate of Lago Garzas has decreased slightly from 13,019 cubic meters per year in 1996 to 12,656 cubic meters per year in 2007 (table 1). The nearly unchanged sedimentation rate of Lago Garzas from 1996 to 2007 (table 1) may be due to the largely undisturbed Lago Garzas drainage area (fig. 4). An actualized storage capacity table and curve were generated by calculating the TIN volume at 1-meter elevation intervals (table 2, fig. 5).

Sediment accumulation within the majority of Lago Garzas between 1996 and 2007 has been minimal, with the exception of one deposition area along the northwestern branch of the reservoir (fig. 6). The profiles shown in figure 6 indicate that a patch of sediment about 5 meters thick has accumulated along the northwestern branch of the reservoir between about 550 to 650 meters upstream of the dam. The Lago Garzas long-term drainage area sediment yield rate has remained relatively unchanged, decreasing slightly from 565 to 550 cubic meters per square kilometer per year from 1996 to 2007 (table 1; Soler-López and others, 1999).

As of 2007, Lago Garzas has lost 14 percent of its original storage capacity of 5.80 million cubic meters (Soler-López and others, 1999). Based on the current long-term storage-capacity loss of 12,656 cubic meters per year estimated for 2007, the Lago Garzas has an estimated useful life of about 394 years, which may end by the year 2401.

**Summary and Conclusions**

During July 2007, the U.S. Geological Survey, in cooperation with the Puerto Rico Aqueduct and Sewer Authority, conducted a bathymetric survey of Lago Garzas to update the reservoir storage capacity and estimate the reservoir sedimentation rate by comparing the 2007 data with the previous 1996 bathymetric survey results.

The Lago Garzas storage capacity in September 1996 was 5.11 million cubic meters, and decreased to 4.99 million cubic meters by July 2007. This difference represents a reservoir storage capacity loss of 120,000 cubic meters between 1996 and 2007. The long-term (1943-2007) sedimentation rate of the reservoir is 12,656 cubic meters per year. As of 2007, the reservoir has experienced a total storage loss of 14 percent compared to its original storage capacity of 5.80 million cubic meters.

Most of the storage capacity loss of Lago Garzas is distributed uniformly across the reservoir bottom; however, one area of sediment deposition is evident along the northwestern tributary branch, where an average of about 5 meters of sediment has accumulated between 1996 and 2007. The long-term Lago Garzas drainage area sediment yield has remained relatively unchanged from 1996 to 2007, decreasing slightly from 565 to 550 cubic meters per square kilometer per year.

The 2007 life expectancy of about 394 years for Lago Garzas is not a pressing concern, assuming a long-term storage-loss rate of about 12,656 cubic meters per year. Sediment accumulation along the northwestern and southeastern branches of the reservoir, however, will continue forward towards the deepest parts of Lago Garzas, which will eventually start filling the reservoir near the dam. If the long-term sedimentation rate of 12,656 cubic meters estimated for 2007 continues, the useful life of Lago Garzas may end by the year 2401.

**References Cited**

Puerto Rico Water Resources Authority, 1969, Engineering and Construction Division: Inspection and Maintenance Reports of the Garzas Dam and Related Facilities, 8 p., 4 pls.

Soler-López, L.R., Webb, R.M.T., and Pérez-Blair, Francisco, 1999, Sedimentation survey of Lago Garzas, Puerto Rico, September 1996: U.S. Geological Survey Water-Resources Investigations Report 99-4143, 20 p., 2 pls.

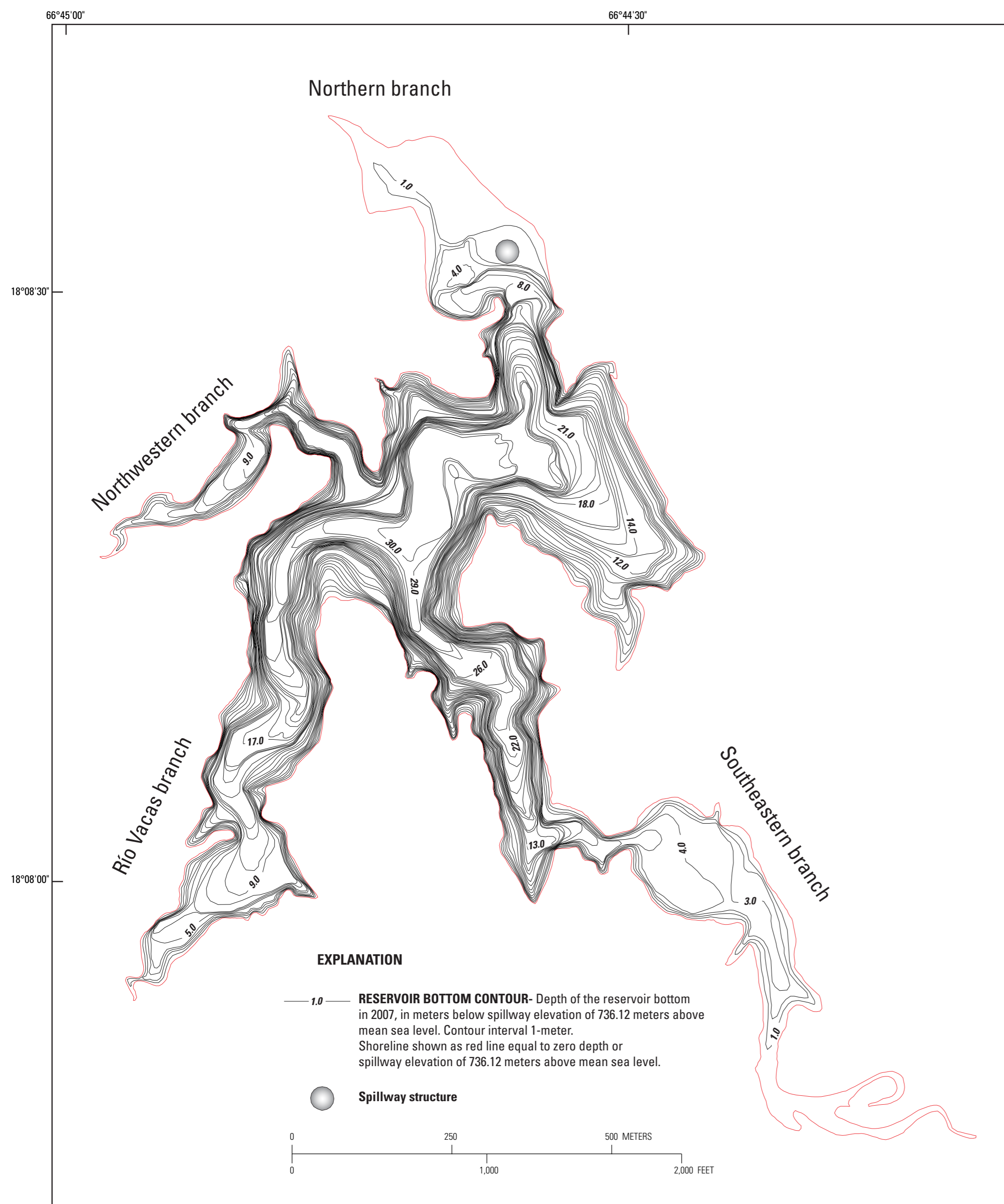
**Table 2.** Storage capacity for Lago Garzas, Puerto Rico, July 2007.

Pool elevation, in meters above mean sea level	Storage capacity, in million cubic meters
736.12	4.99
735.12	4.56
734.12	4.18
733.12	3.82
732.12	3.49
731.12	3.20
730.12	2.92
729.12	2.66
728.12	2.41
727.12	2.19
726.12	1.98
725.12	1.79
724.12	1.61
723.12	1.44
722.12	1.28
721.12	1.13
720.12	1.00
719.12	.87
718.12	.76
717.12	.65
716.12	.55
715.12	.46
714.12	.38
713.12	.31
712.12	.24
711.12	.19
710.12	.13
709.12	.09
708.12	.05
707.12	.02
706.12	.00

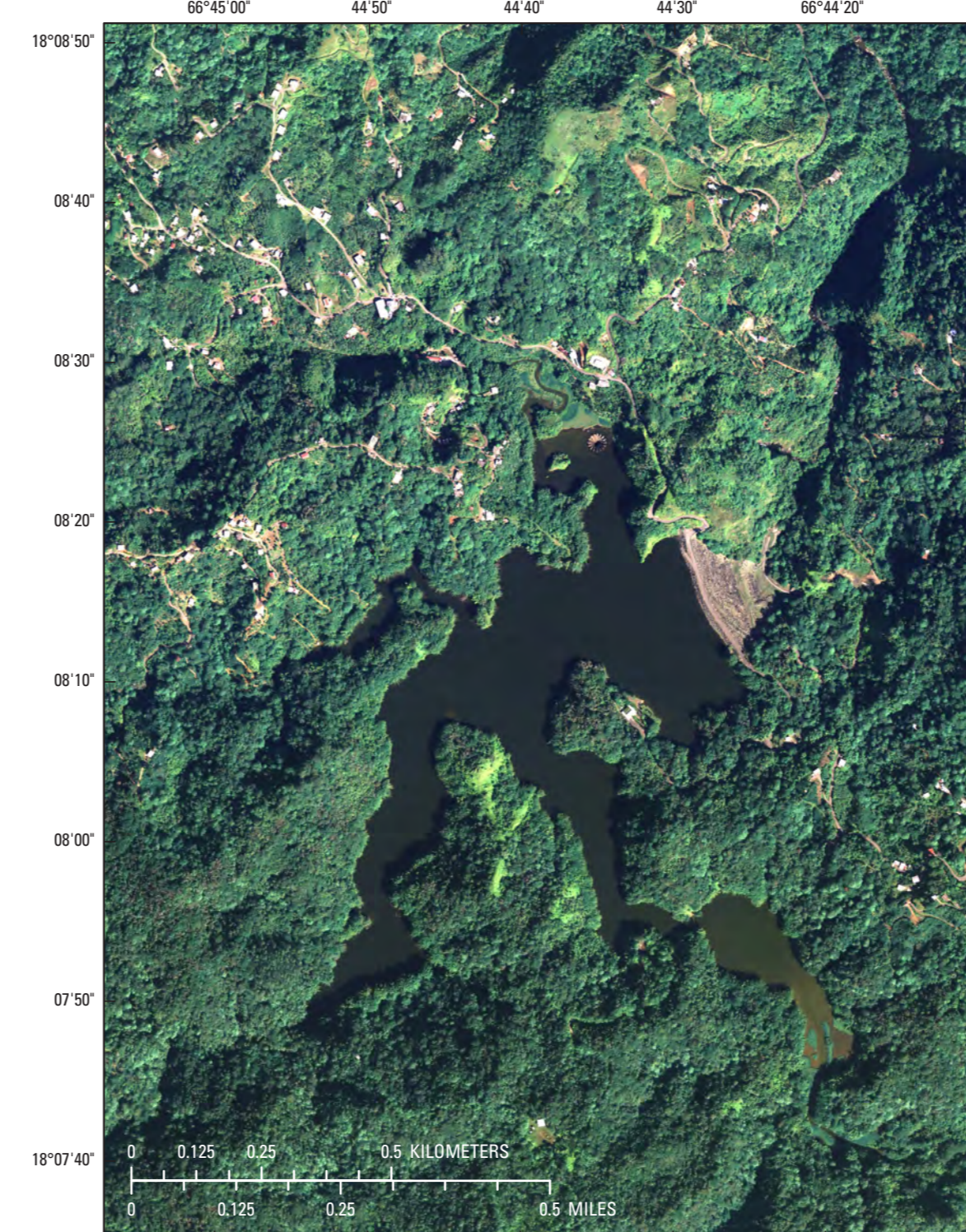
**Table 1.** Lago Garzas data comparison for 1996, and July 2007.

Data descriptor	Year of survey	
	1996	2007
Years since construction <sup>1</sup>	53	64
Years since previous survey	18	11
Total storage capacity, in million cubic meters	5.11	4.99
Sediment accumulated since construction, in million cubic meters	.69	.81
Sediment accumulation since previous survey, in million cubic meters	.47	.12
Storage loss since construction, in percent	12	14
Annual loss of capacity since construction, in cubic meters	13,019	12,656
Annual loss of capacity since construction, in percent	.23	.22
Estimated sediment trapping efficiency, in percent	95	95
Sediment yield, in cubic meters per square kilometer per year	565	550
Estimated year the reservoir would fill with sediments	2388	2401

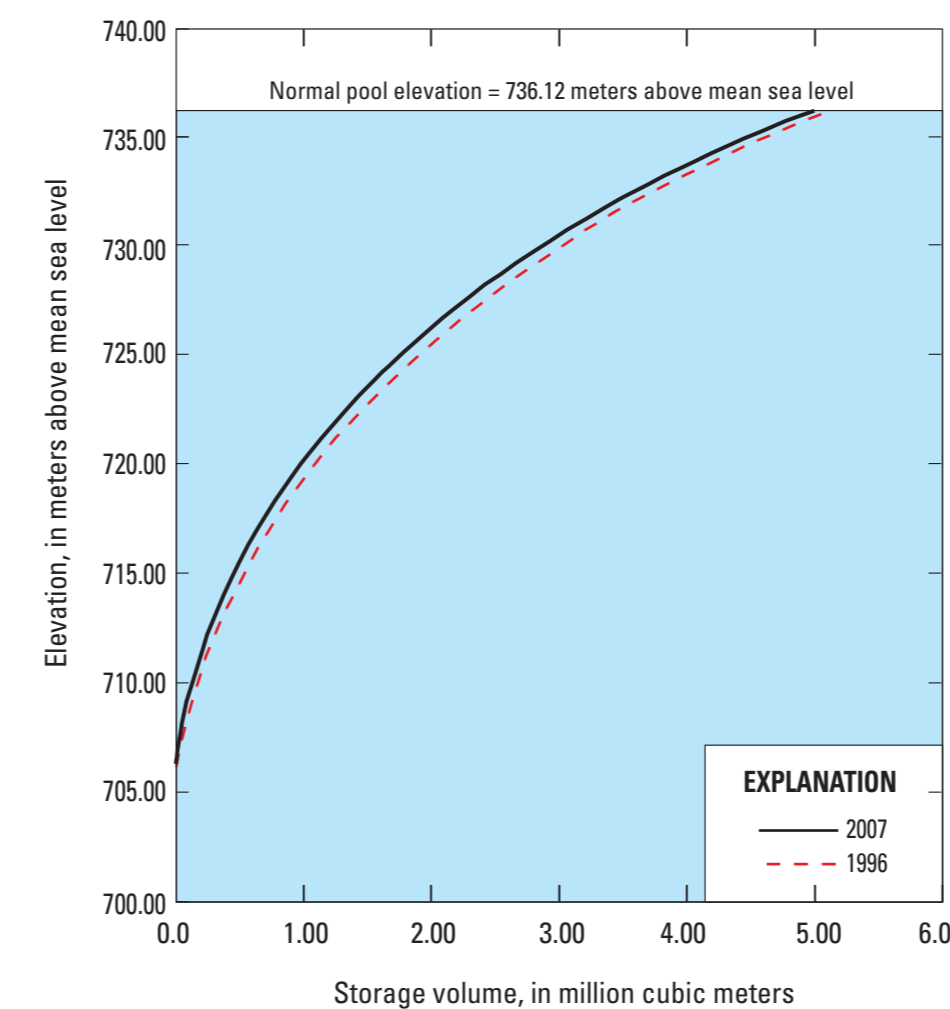
<sup>1</sup> Using the construction date of 1943.



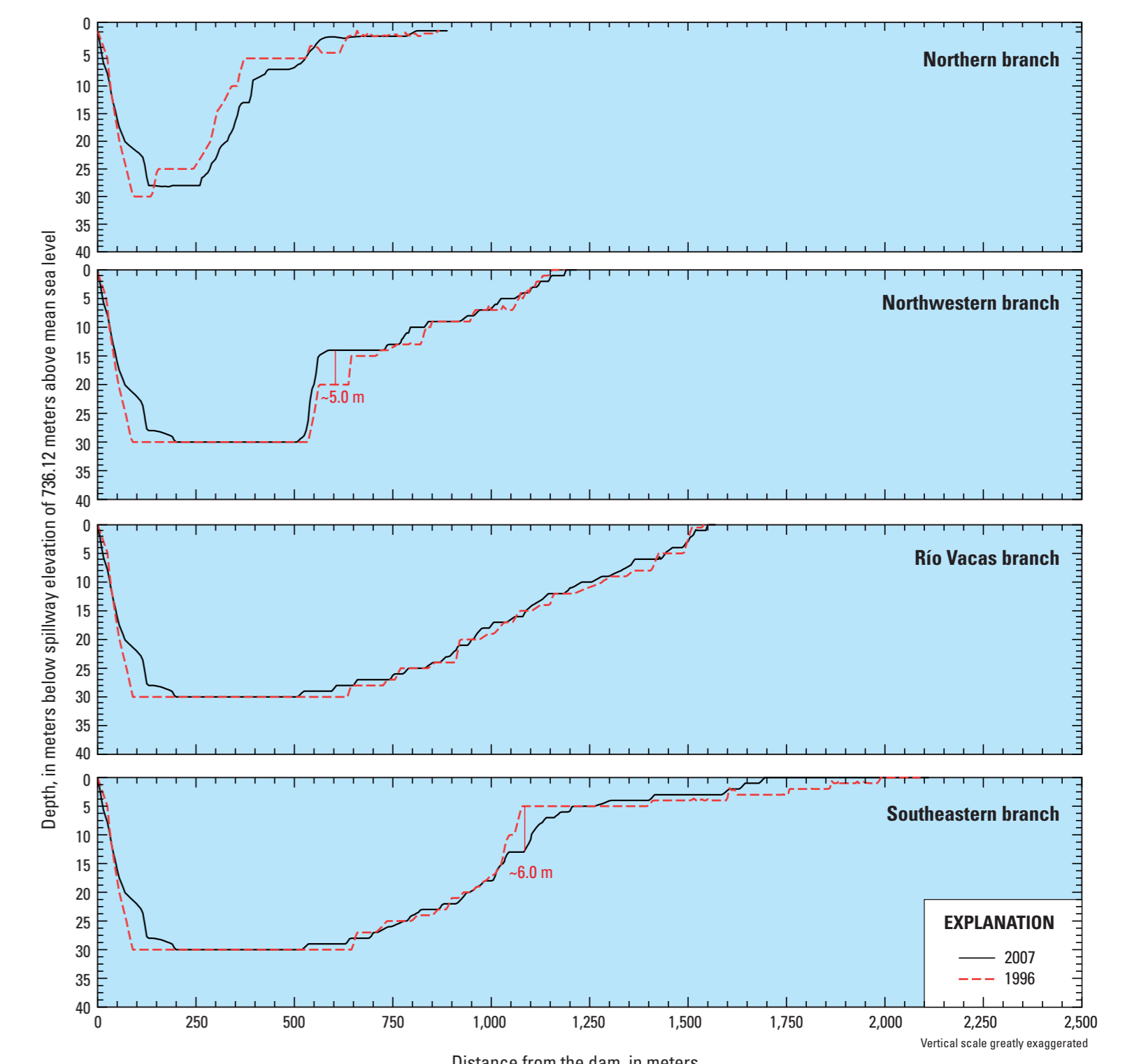
**Figure 3.** Bathymetric map of Lago Garzas, Puerto Rico, July 2007.



**Figure 4.** Aerial photograph of the Lago Garzas and its immediate surroundings. Photograph from the U.S. Army Corps of Engineers, Puerto Rico.



**Figure 5.** Relation between pool elevation and storage capacity of Lago Garzas for 1996 and 2007.



**Figure 6.** Longitudinal bottom profiles along the thalweg of Lago Garzas, within the northern, northwestern, Rio Vacas, and southeastern branches of the reservoir, for 1996 and 2007.

**Storage Capacity and Sedimentation Trends of Lago Garzas, Puerto Rico, 1996-2007**

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