

SEDIMENTATION SURVEY OF LAGO LOÍZA, PUERTO RICO, JULY 1985

By Ferdinand Quiñones, Bruce Green, and Luis Santiago

U.S. GEOLOGICAL SURVEY

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For the convenience of readers who may want to use metric (International System) units, the inch-pound units used in this report may be converted by using the following factors:

Multiply inch-pound unit	By	To obtain SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
square foot (ft ²)	0.09290	square meter (m ²)
mile (mi)	1.609	kilometer (km)
square mile (mi ²)	2.590	square kilometer (km ²)
acre	4,047	square meter (m ²)
acre-feet (acre-ft)	1,233	cubic meter (m ³)
acre-feet per year (acre-ft/yr)	1,233	cubic meter per year (m ³ /yr)
million gallons per day (Mgal/d)	0.04381	cubic meters per day (m ³ /d)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
ton, short	0.9078	megagrams (Mg)

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ABSTRACT

A survey of the sedimentation of Lago Loíza (Carraízo), in north-central Puerto Rico was conducted during July 1985. The survey showed that the actual capacity of the reservoir has declined from 21,700 acre-feet in 1953 to about 10,100 acre-feet in 1985. Sedimentation is depleting the reservoir's capacity at an average rate of about 439 acre-feet per year, or about 1.8 percent per year of the original capacity. The increase in capacity of 2,400 acre-feet produced in 1977 when flashboards were installed, has now been nullified by sedimentation. Under optimal conditions the remaining usable life of the reservoir is estimated to be about 23 years.

1980; Iivary, 1981) have shown that the sedimentation rate for the reservoir is about 1.8 to 2.0 percent per year of the original capacity.

In 1985, the U.S. Geological Survey (USGS), Water Resources Division, in cooperation with the U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS), conducted a comprehensive survey of the Loíza reservoir to determine its current capacity and the sedimentation rate. The survey was designed to include most of the transects utilized in previous surveys, but was expanded to include a greater number of transects to improve its reliability. This report presents the results of this study.

INTRODUCTION

Lago Loíza, located in north-central Puerto Rico (fig. 1), is one of the largest reservoirs on the island. The reservoir is located within the basin of the Río Grande de Loíza about 10 miles southeast of the San Juan Metropolitan area. About 47 percent of the public water supplies to the metropolitan area (1985 population of about one million) are from Lago Loíza (fig. 2). The basin is one of the most developed on the island, with extensive urban and agricultural activities from the headwaters to the immediate area of the reservoir (fig. 3). The development in the basin has resulted in increases in erosion and sedimentation of the lake. The basin is characterized by steep slopes with more than 50 percent of the terrain exceeding 40 percent slopes. Previous investigations (Hunt, 1975; Quiñones,

DAM AND RESERVOIR CHARACTERISTICS

The Loíza reservoir dam was built by the Puerto Rico Aqueduct and Sewer Authority in 1953, on the Río Grande de Loíza about 13.5 miles upstream from the river's mouth in the Atlantic Ocean. The principal tributaries to the Río Grande de Loíza are shown in table 1. Drainage areas of the tributaries and the damsite are also shown. The original capacity of the reservoir (at the spillway elevation of 102 feet) was about 21,000 acre-feet (acre-ft), although several figures ranging from 20,000 to 21,763 acre-ft are reported by previous investigators (for the purposes of this report and to provide a comparison with prior SCS investigations, 21,760 acre-ft will be used). In 1977, the capacity of the

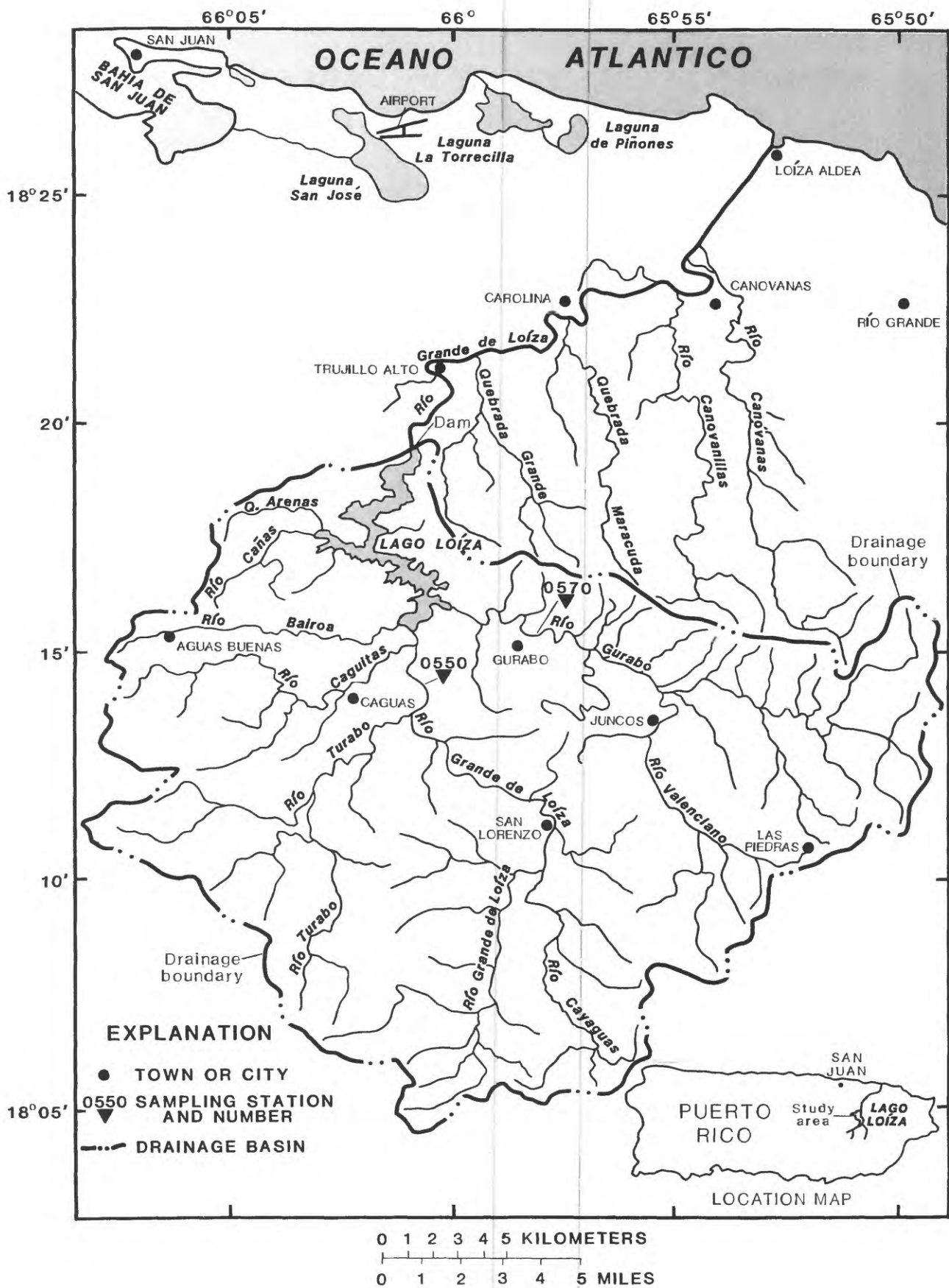


Figure 1.--Location of Lago Loíza in the Río Grande de Loíza basin.

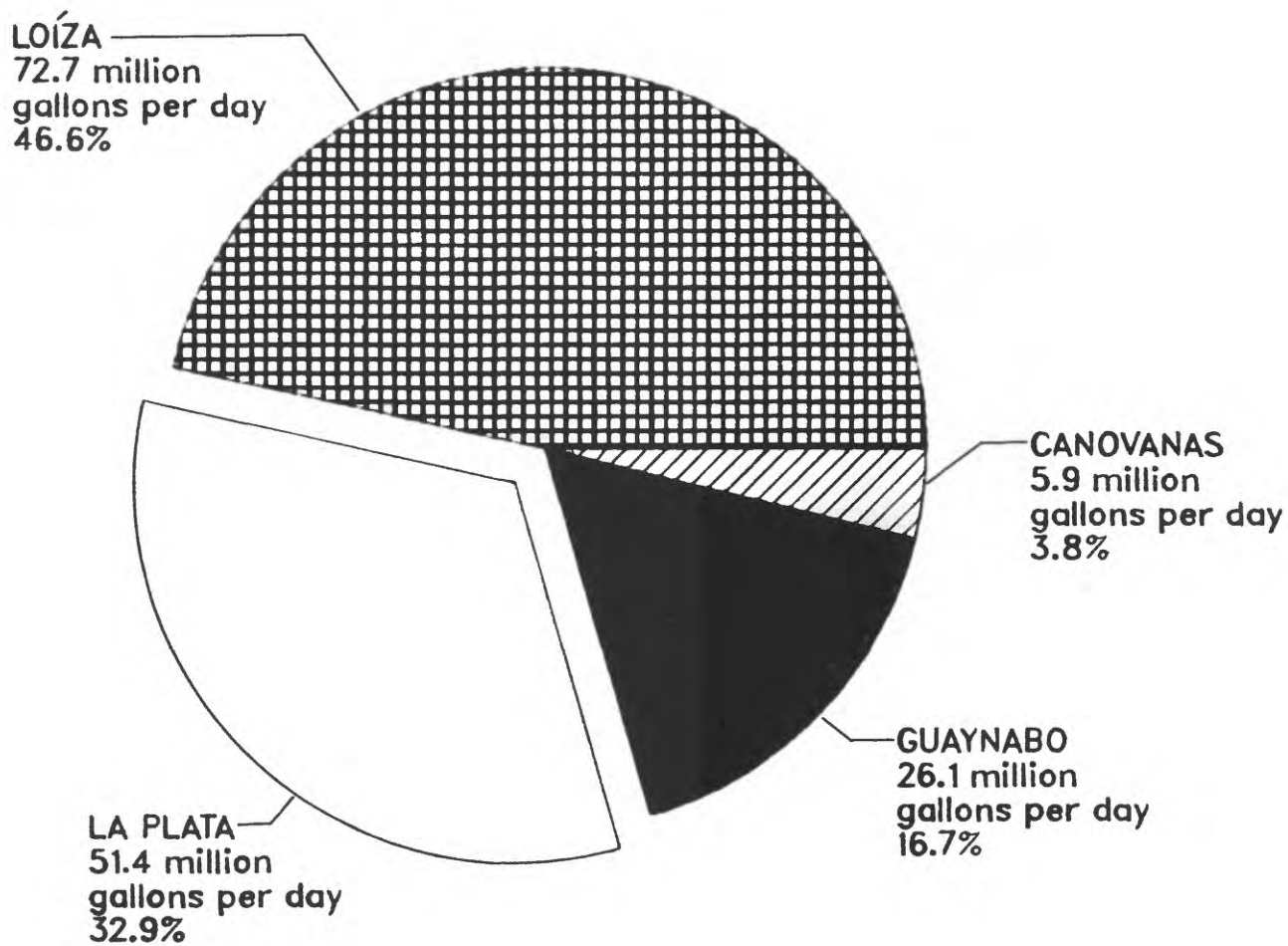


Figure 2.--Sources of public water supply for the San Juan Metropolitan area (Margarita Irizarry, Puerto Rico Aqueduct and Sewer Authority, oral commun., 1985).

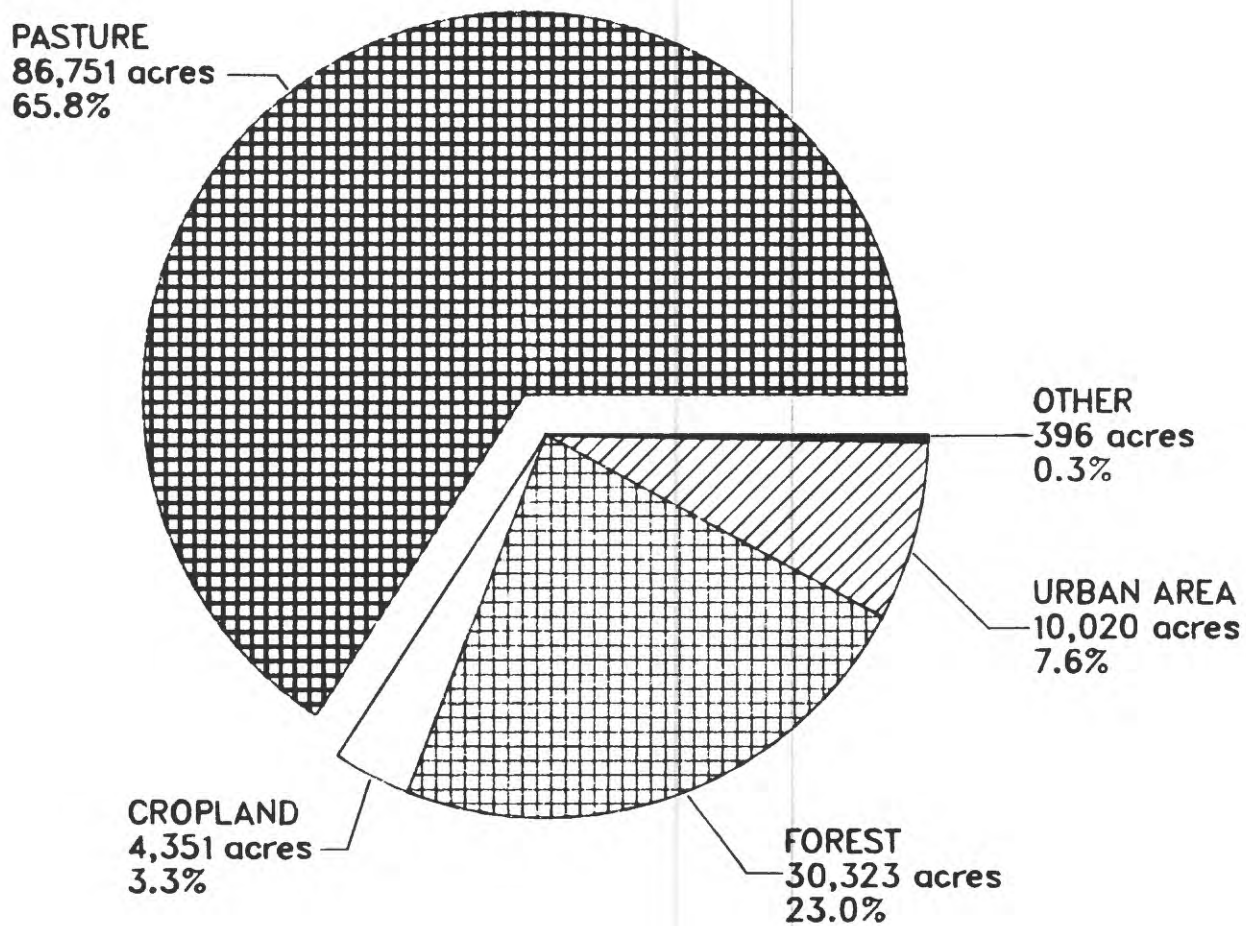


Figure 3.--Land use in the Río Grande de Loíza basin, 1985
(acres and percent of total drainage).

lake was increased 2,400 acre-ft by the installation of flashboards (fig. 4).

METHOD OF SURVEY

Table 1.--Principal tributaries to Lago Loíza

Tributary	Drainage area (square mile)	Mean annual discharge (cubic feet per second)
Río Grande de Loíza	90.8	218
Río Gurabo	60.9	131
Río Caguitas	14.2	unknown
Río Bairoa	5.5	unknown
Río Cañas	7.9	unknown

(Total drainage at damsite of 210 mi² includes area in the immediate lake vicinity).

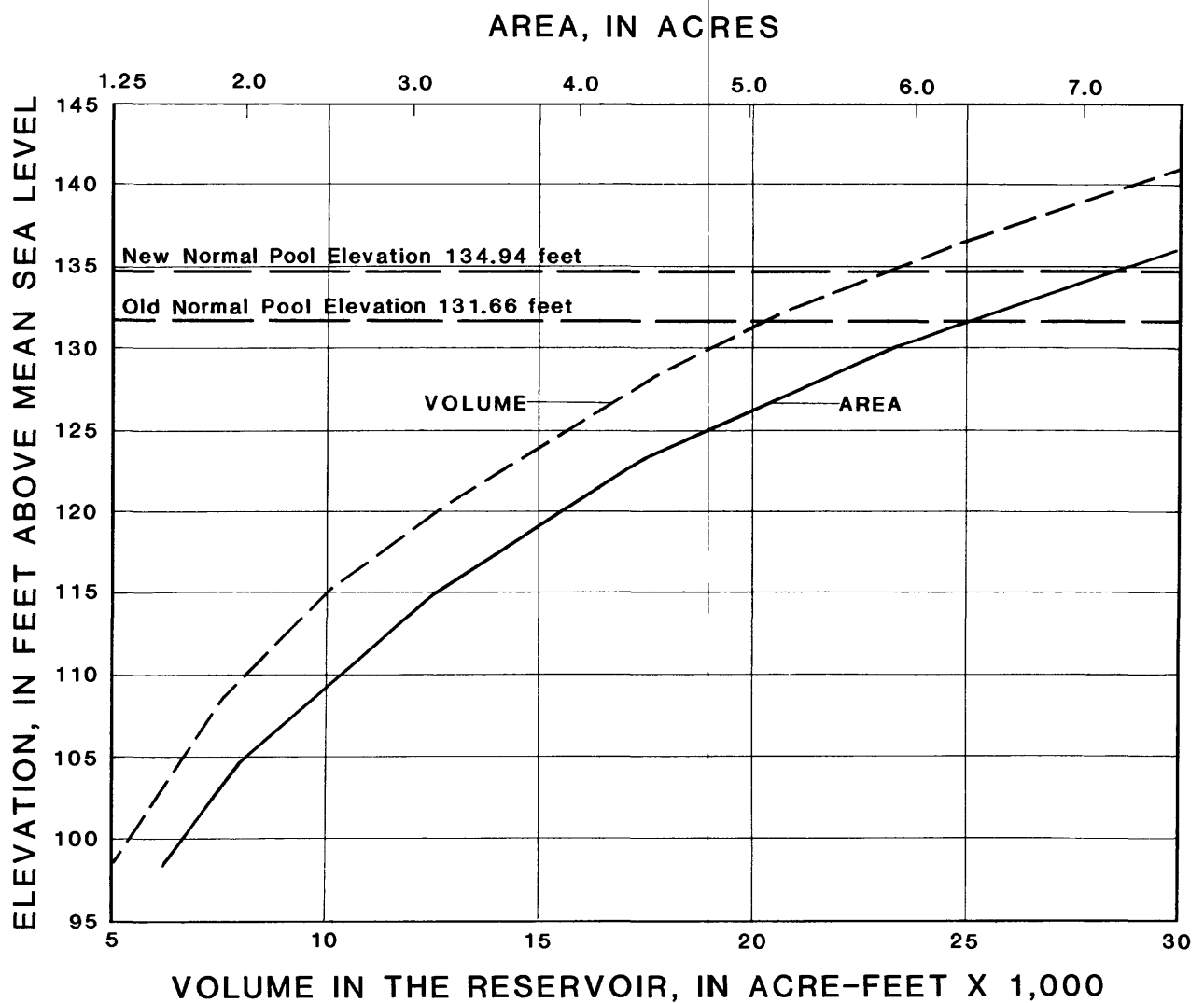
Lago Loíza also provides limited flood protection to coastal areas near Carolina and Loíza (fig. 1). A hydroelectric powerplant with a capacity of 3,000 kilowatts (three intakes) was also constructed, although it is currently out of operation. The overall characteristics of the dam and reservoir are summarized on table 2.

The actual capacity of the reservoir was determined from bathymetric surveys. Ranges (fig. 5) were surveyed utilizing an "Innerspace Model 412 Auto Track Digital Fathometer." The instrument is equipped with a printer to record depth of the water from the surface to the top of the sediment deposits. A transducer coupled to an Ott velocity meter mounted on a boat provides depth and distance from a reference point along the range. All recordings were made to a local datum and later corrected to mean sea level. The instrument operates over a range from 2 to 1,000 feet, with an accuracy of less than 0.5 foot in the 1 to 100-foot range. The instrument was calibrated frequently to a known depth in shallow water with a hand sound.

The ranges surveyed were approximated to those used by Hunt (1975) and Iivary (1981). A bathymetric map of the reservoir was developed from the surveyed ranges. The map was used to define additional auxiliary sections to be used in the current computations. Instead of limiting the survey to 25 to 27 ranges, as was done in previous surveys, a total of 63 ranges were surveyed.

Table 2. --Principal characteristics of Lago Loíza and structures

Length of dam	660 feet
Type of dam	concrete
Length of spillway	312 feet
Altitude of crest of spillway (gates opened)	102 feet
Discharge gates, radial, operated by electric hoists	8 feet
Original capacity (1953)	21,760 acre-feet
Added capacity in 1977	2,400 acre-feet
Effective storage elevations	91.8 to 134.8 feet
Dead storage elevations	49.9 to 91.8 feet
Installed powerplant capacity	3,000 kilowatts
Flooded area (elevation of 134.8 feet)	566 acres
Maximum depth during 1985 survey	55 feet



(Modified from original curves prepared by Miguel A. Quinones y Asociados Consulting Engineers, written comm., 1982.)

Figure 4.--Area and capacity curves for Lago Loíza.

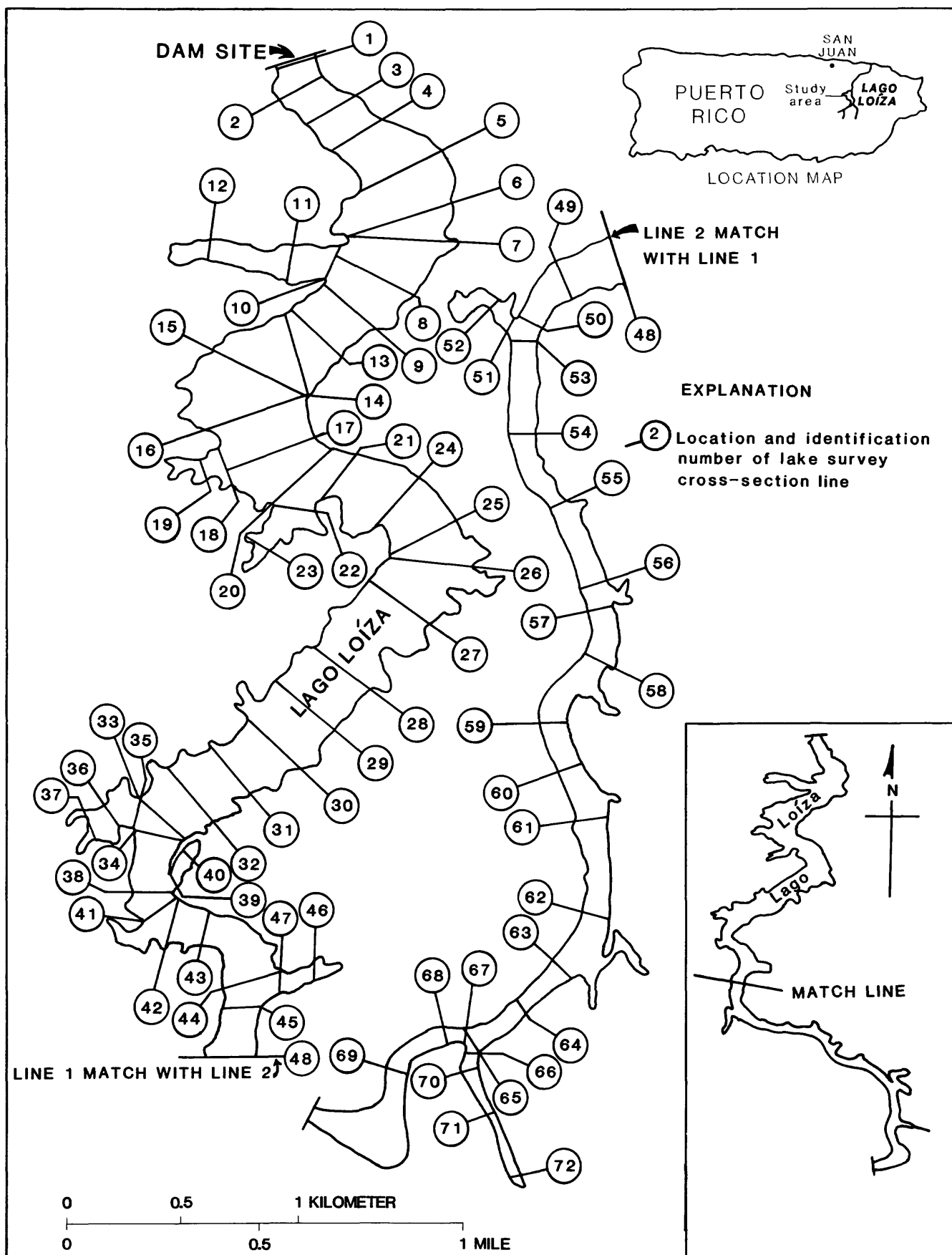


Figure 5.--Lago Loíza and cross sections surveyed in 1985.

The actual capacity of the reservoir was computed using the "Range Method" described in the USDA National Engineering Handbook, Chapter 6 (1983). The amount of sediment in the lake was obtained by subtracting the current capacity from the initial capacity adjusted for the increase in capacity in 1977.

A piston-type sampler was utilized to collect bottom sediment samples from 11 points in the reservoir ranging in depth from 6 to 60 feet, but the samples were not considered representative of the consolidated sediments and were discarded. The core sampler failed to obtain representative samples from the deeper and more consolidated deposits; therefore, a previously reported dry weight of 47 pounds per cubic foot

(Hunt, 1975; Iivary, 1981) was used (same value used in previous surveys by Hunt and Iivary).

ACTUAL CAPACITY AND SEDIMENTATION

The capacity of Lago Loíza in July 1985 was computed as 10,100 acre-ft. This capacity includes the additional storage provided by the flashboards installed in 1977. The results of the current and previous surveys are shown in table 3.

The results of the current survey suggest that the values obtained during the survey of 1979 may have underestimated the actual

Table 3.--Comparison of prior and current sedimentation surveys of Lago Loíza, Puerto Rico

	1953	1963	1971	1974 ¹	1977	1979	1985
Capacity (acre-feet per year).	21,760	18,707	15,628	12,100	+ 2,400 ²	14,771	10,100
Sediment accumulated (acre-feet per year).	0	3,053	6,132	9,660	--	9,389	14,060
Storage loss (percent).	0	-14	-28	-44	+ 11	-39	-58
Annual loss capacity (percent per year).	0	1.4	1.6	2.1	--	1.5	1.8
Sedimentation rate (acre-feet per year).	0	305	341	460	--	361	439
Years between surveys.	0	10	8	3	--	5	6
Remaining life (years).		61	46	26	--	36	23

¹ Survey conducted by the U.S. Geological Survey and published by Quiñones (1980).

² Increase in capacity due to the addition of flashboards in 1977.

sedimentation. The number of ranges utilized in the previous surveys [except the 1974 study conducted by Quiñones (1980)] may have been inadequate to compute accurately the volume of water in the reservoir. The sinuosity of the reservoir induces errors in the average width, area, and perpendicular values between the ranges. The area of the cross sections varies significantly when the distance between the ranges is large as in the 1971 and 1979 surveys. A comparison (table 4) of two sets of surveys (1971, 1979 and 1974, 1985) clearly indicates the difference caused by the more accurate methodology using more ranges.

Field data collected by the USGS and SCS suggest that the sedimentation rate of the reservoir has increased significantly during the last 15 years. Runoff and suspended-sediment data collected at the USGS streamflow stations at Río Grande de Loíza and Río Gurabo show that the floods of October 1970 and October 1979 may have contributed between 500 and 800 acre-ft of sediment to the reservoir. In contrast, the data show that the storm of September 1975 did not contribute any significant sediment to the reservoir. Table 5 shows the average daily water and

suspended-sediment discharge at the Río Grande de Loíza station for several high flow days during the indicated periods. A similar suspended-sediment load was contributed by Río Gurabo. Conservative estimates of the suspended-sediment discharge to the reservoir from these events is on the order of 900 acre-ft.

During the floods of May 1985, a peak discharge of about 30,000 cubic feet per second (ft^3/s) was recorded at Río Grande de Loíza above the reservoir (fig. 6). A higher peak of about 38,000 ft^3/s was recorded at Río Gurabo (fig. 7). The additional sediment load to the reservoir from this storm was also significant. Computations at the two gaging stations show that for the period of May 15-18, 1985, the suspended-sediment inflow to the reservoir was about 550 acre-ft. Field observations indicate that during a storm, sediment-laden water flows over the dam. The trap efficiency of the reservoir is probably less than the average values of about 77 percent computed by Hunt (1975) and Iivary (1981). If this is reduced to 50 percent, the contributions to the sedimentation of the reservoir from these storms would still be on the order of 275 acre-ft.

Table 4.--Comparison of sedimentation surveys conducted by the U.S. Department of Agriculture, Soil Conservation Service and the U.S. Geological Survey in Lago Loíza

	Original	SCS	Surveys	USGS	Surveys
Date	1953	1971	1979 ¹	1974	1985 ¹
Number of ranges	--	26	26	56	63
Capacity	21,760	15,628	14,771	12,100	10,100
Loss between surveys	--	6,132	3,257	9,660	4,400
Sedimentation rate (acre-feet per year) between surveys.	--	340	407	460	489

¹ Adjusted for increase in capacity of 2,400 acre-feet in 1977

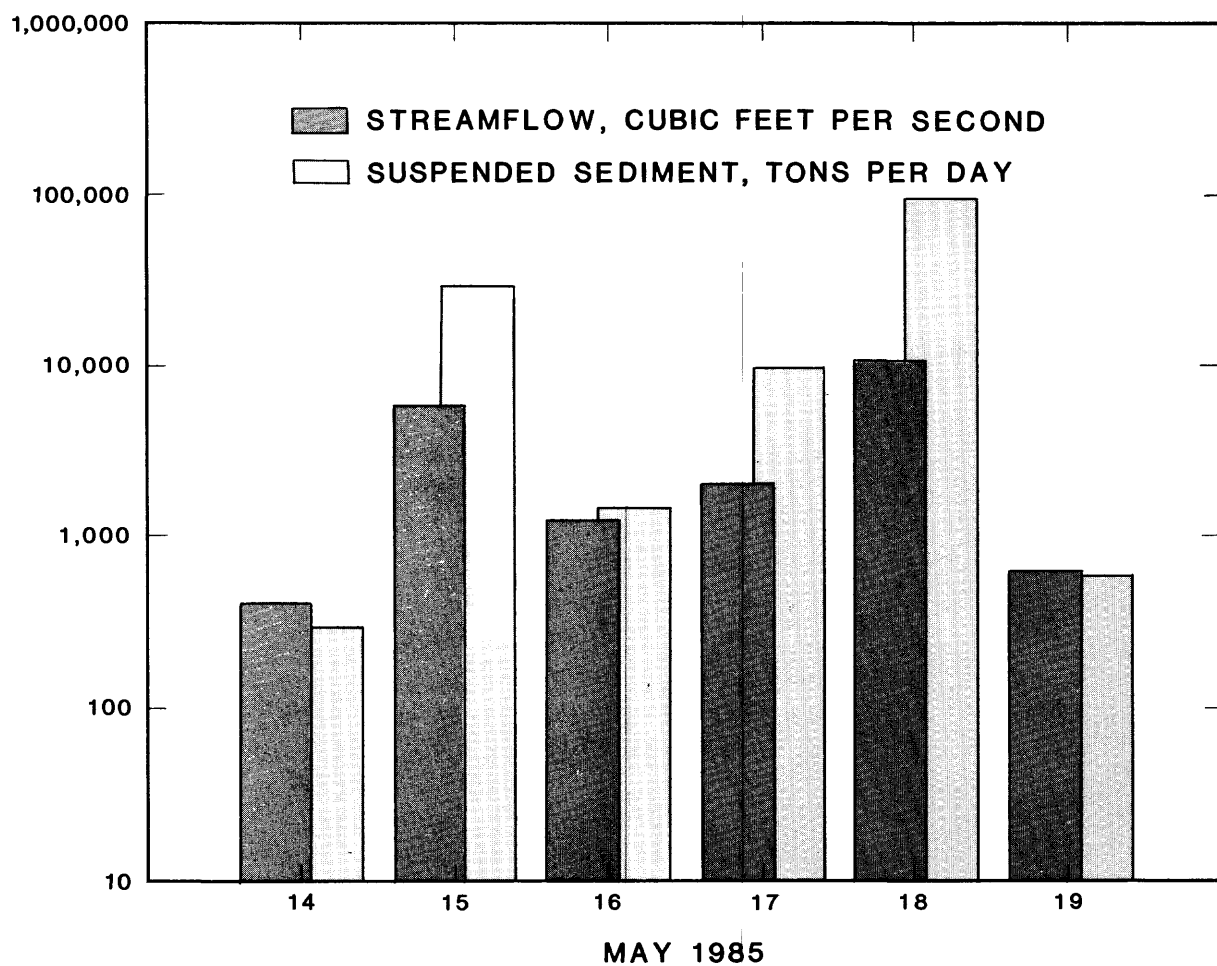


Figure 6.--Streamflow and suspended-sediment discharge during the flood of May 1985 at Río Grande de Loíza at Caguas.

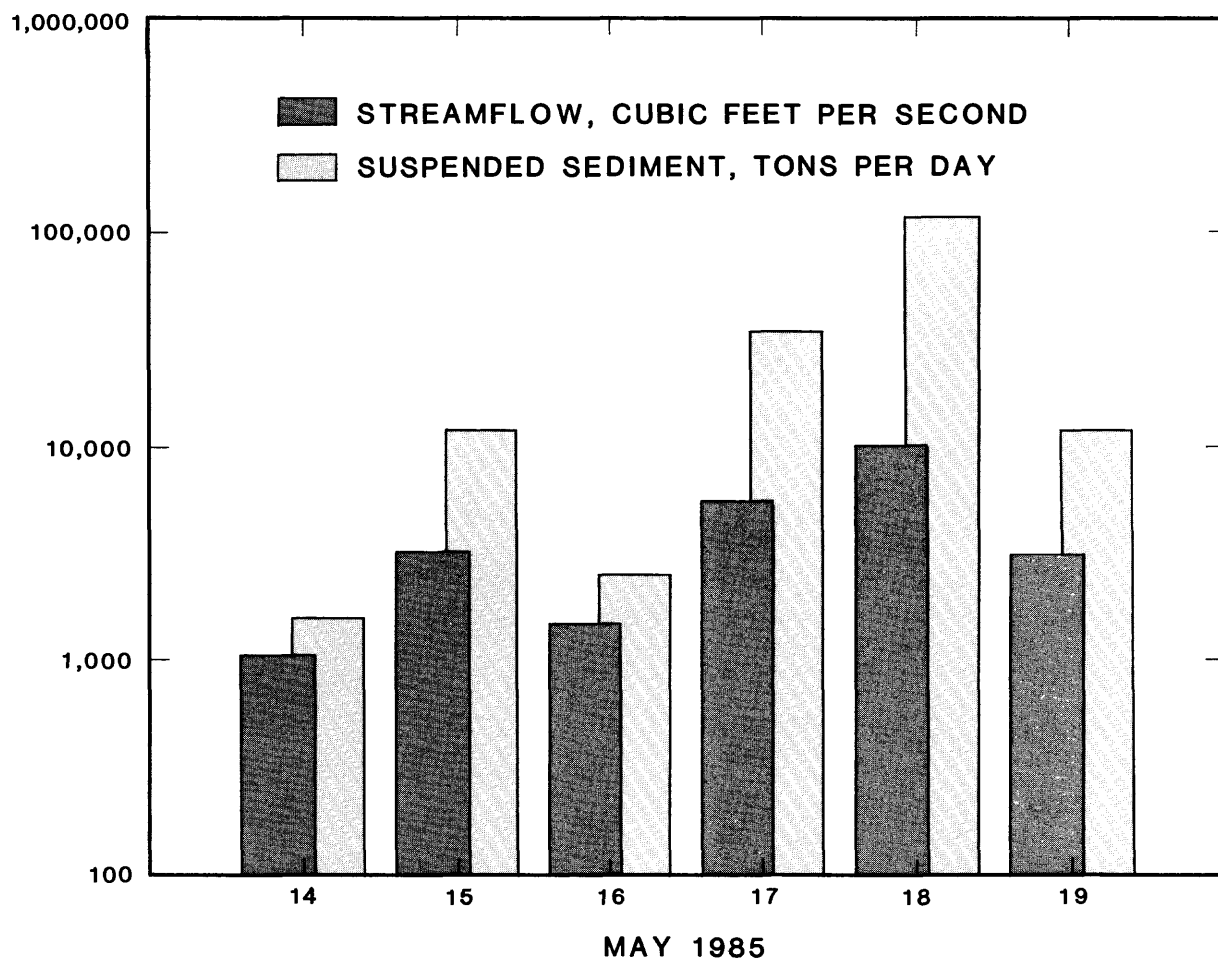


Figure 7.--Streamflow and suspended-sediment discharge during the flood of May 1985 at Río Gurabo at Gurabo.

Table 5.--*Estimated sediment loads from storm events during 1970, 1975, and 1979 at Río Grande de Loíza (above Loíza reservoir)*

October 1970			September 1975			October 1979		
Date	Qav	SS	Date	Qav	SS	Date	Qav	SS
10	9,990	90,000	6	3,150	40,000	24	4,000	40,000
11	10,600	100,000	7	1,800	10,000	25	8,800	90,000
12	6,500	50,000				26	10,700	100,000
13	17,900	300,000				27	9,970	100,000
						28	5,170	50,000
						29	4,000	30,000

Qav = Average daily discharge, cubic feet per second
SS = Suspended sediment, tons per day

The importance of storm events in the sedimentation of reservoirs in Puerto Rico is masked when average sedimentation rates are compared. Future sedimentation surveys of reservoirs on the island need to take into account the significant loads that a major storm can produce. The average computations of sedimentation rates over the years may vary significantly from one year to the next due to the uneven distribution of storm events.

The remaining life of the reservoir was estimated from the graphical correlation between the years of operation and the loss in capacity from the previous and actual surveys (fig. 8). At the current sedimentation rate, the ability of the reservoir to meet the water-supply needs of metropolitan San Juan will be greatly diminished, particularly during drought periods.

TRAP EFFICIENCY OF THE RESERVOIR

Average trap efficiencies of the reservoir have ranged from 72 to 83 percent, with a long-term average of about 77 percent. During the 1984 water year, the inflow of the two principal tributaries (Río Grande de Loíza and Río Gurabo) to the reservoir totaled about 215,000 acre-ft (Curtis and others, 1985). On the basis of

the current capacity of 10,100 acre-ft, the capacity-inflow ratio (C/I) is 0.047. By using Brune's relation (Brune, 1953), the trap efficiency is about 77 percent, or equal to the long-term average. The total amount of sediment that has passed through the reservoir downstream is about 4,200 acre-ft. This is equivalent to an annual downstream discharge of about 131 acre-ft per year.

The amount of sediment that has flowed into the reservoir since its construction is about 18,270 acre-ft. The watershed drains about 207 square miles (132,400 acres); therefore, the mean annual sediment yield of the basin is about 2.76 acre-ft per square mile.

BOTTOM PROFILES

Profiles of the bottom of the Loíza reservoir were developed from the field data collected. The deepest point in each range was plotted against the distance upstream from the dam structure. The auxiliary ranges developed from the bathymetric map were not used to define the profile. The 1985 profile was compared to the 1953 (original) and the 1979 (Iivary) profiles (fig. 9). Comparison of the 1979 and 1985 profiles show a significant accumulation of sediment in the deepest sections of the reservoir

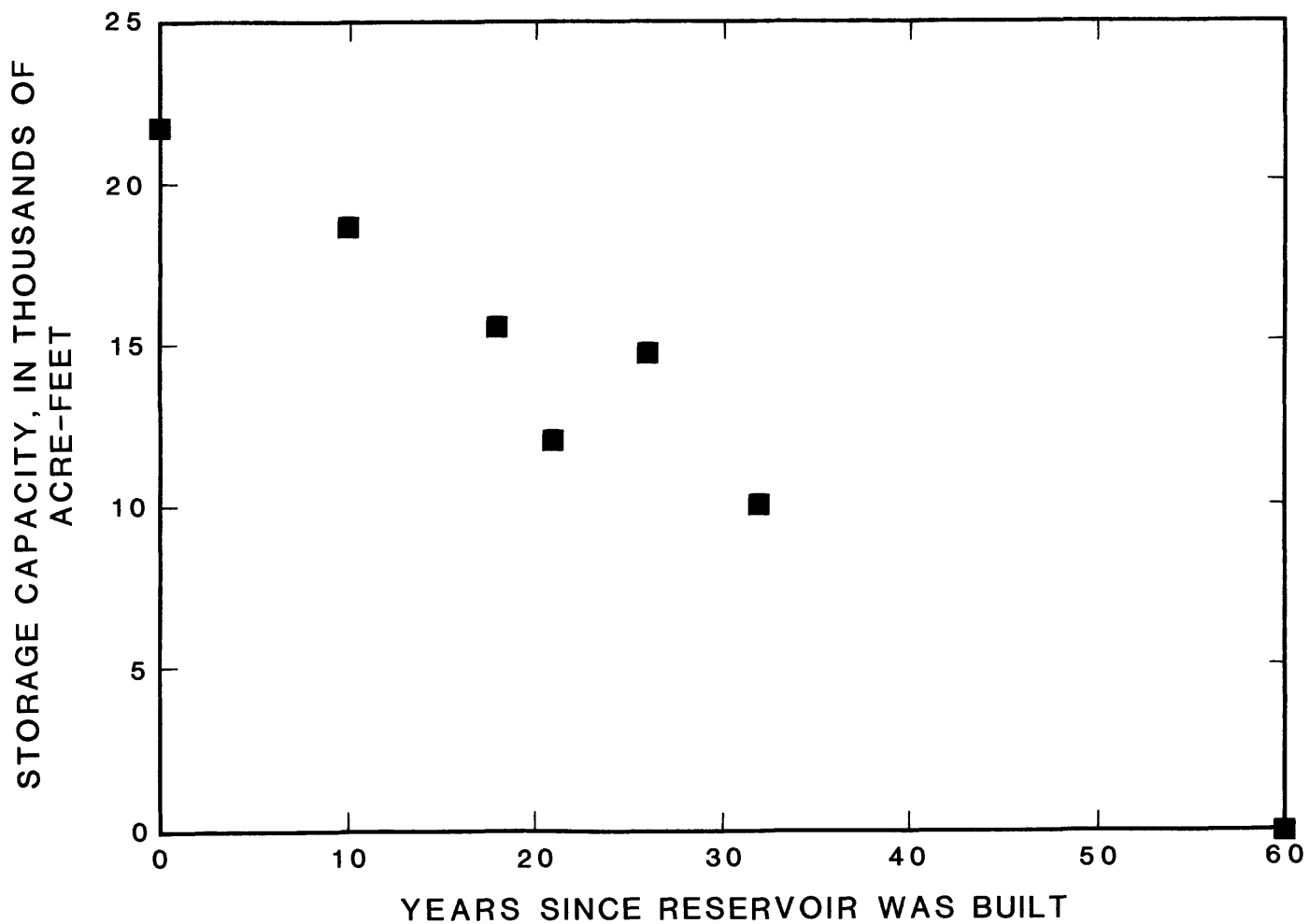


Figure 8.--Changes in storage capacity of Lago Lofza caused by sedimentation.

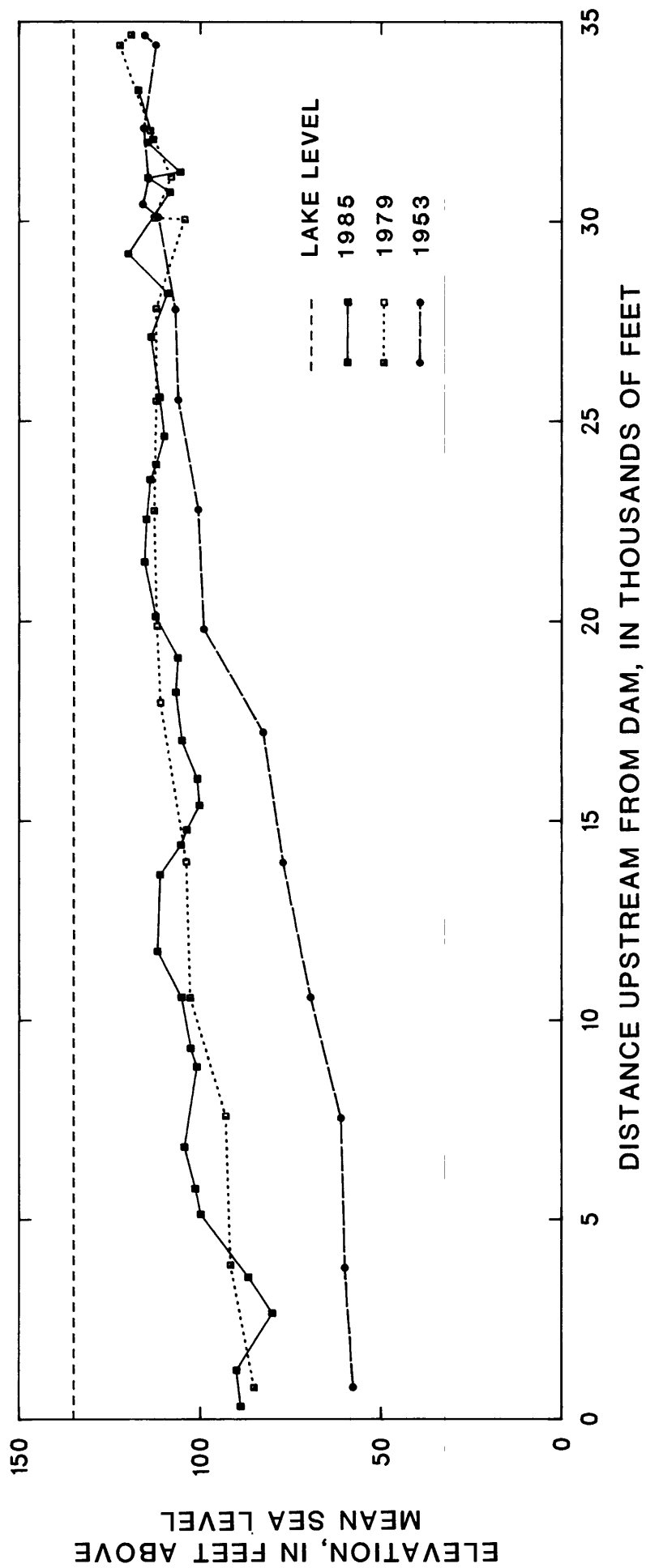


Figure 9.--Bottom profiles of Lago Loíza.

from about 5,000 to 10,000 feet upstream from the dam. There are no significant accumulations of sediment in the upper reaches of the reservoir. The comparison of the bottom profile also provides a quick estimate of the amount of sediment deposited in the reservoir since the construction of the dam. A layer of sediment averaging about 30 feet in thickness has been deposited over a reach of about 18,000 feet upstream from the dam. The reservoir averages about 1,000 feet in width along this reach. This is equivalent to a volume of about $5.4 \times 10^{*8}$ (10 to the eighth power) cubic feet of sediment, or about 12,000 acre-ft of sediment. This estimate is in agreement with the current survey.

NEEDS FOR FURTHER STUDY

Depending on flood events, surveys of storage capacity of the reservoir are needed at 2- to 5-year intervals for current definition of capacity and fill characteristics of the reservoir. A suspended-sediment station may need to be established downstream from the reservoir to assure the trap efficiency, particularly during storm events.

CONCLUSIONS

The 1985 survey of the sedimentation of Lago Loíza shows that the current capacity of the reservoir is about 10,100 acre-ft. The reservoir storage capacity is rapidly being deleted by a sedimentation rate of about 1.8 percent of the adjusted-original capacity per year. In spite of the increase in capacity from the installation of flashboards in 1977, the usable life of the reservoir continues to decrease rapidly. The effect of recent storm events and increased urban and agricultural developments in the basin appear to have contributed to accelerated sedimentation of the reservoir during the last 15 years (table 5).

The remaining usable life of Lago Loíza as a public water supply reservoir is in the order of 20 to 25 years. Under optimal conditions, it is estimated that at about the year 2010, the reservoir's usefulness, particularly during droughts, will be severely limited. Loss of storage capacity of the reservoir because of sedimentation may be even sooner if unprecedented flooding occurs.

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APPENDIX 1

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

RESERVOIR SEDIMENT DATA SUMMARY

SCS-ENG-034
02-85

Lago Loiza (Carraizo)

NAME OF RESERVOIR

1

DATA SHEET NO.

DAM	1. OWNER P.R.A.S.A.			2. STREAM Rio Grande de Loiza		3. STATE P.R.		
	4. SEC. TWP RANGE		5. NEAREST P.O. Trujillo Alto		6. COUNTY			
	7. LAT ° ' " LONG. ° ' "		8. TOP OF DAM ELEVATION 144.4 ft		9. SPILLWAY CREST ELEV. 131.7 ft			
RESERVOIR	10. STORAGE ALLOCATION		11. ELEVATION TOP OF POOL		12. ORIGINAL SURFACE AREA, ACRES		13. ORIGINAL CAPACITY, ACRE-Feet	
	a. FLOOD CONTROL						15. DATE STORAGE BEGAN March 1953	
	b. MULTIPLE USE							
	c. POWER							
	d. WATER SUPPLY		131.7 ft		743			
	e. IRRIGATION						16. DATE NORMAL OPER. BEGAN March 1953	
	f. CONSERVATION							
	g. INACTIVE		91.8 ft		Unknown			
17. LENGTH OF RESERVOIR 7.8		MILES		14. GROSS STORAGE, ACRE-Feet		21,764		
WATERSHED	18. TOTAL DRAINAGE AREA 208		SQ. MI.		22. MEAN ANNUAL PRECIPITATION 66*		INCHES	
	19. NET SEDIMENT CONTRIBUTING AREA 203.5		SQ. MI.		23. MEAN ANNUAL RUNOFF 30.0		INCHES	
	20. LENGTH 14.8 MILES		AV. WIDTH 13.9 MILES		24. MEAN ANNUAL RUNOFF 332,000		AC.-FT.	
	21. MAX. ELEV. 3,524 ft		MIN. ELEV. 50.0 ft		25. ANNUAL TEMP: MEAN RANGE			
	26. DATE OF SURVEY		27. PERIOD YEARS		28. ACCL. YEARS		29. TYPE OF SURVEY	
SURVEY DATA	30. NO. OF RANGES OR CONTOUR INT.		31. SURFACE AREA, ACRES		32. CAPACITY, ACRE-Feet		33. C/I. RATIO, AC.-FT. PER AC.-FT.	
	-----See table 2 in text-----							
	34. PERIOD ANNUAL PRECIPITATION		35. PERIOD WATER INFLOW, ACRE-Feet		36. WATER INFL. TO DATE, AC.-FT.			
	a. MEAN ANNUAL		b. MAX. ANNUAL		c. PERIOD TOTAL		d. MEAN ANNUAL	
	e. TOTAL TO DATE		f. TOTAL TO DATE					
	-----See table 2 in text-----							
	37. PERIOD CAPACITY LOSS, ACRE-Feet		38. TOTAL SED. DEPOSITS TO DATE, ACRE-Feet					
	a. PERIOD TOTAL		b. AV. ANNUAL		c. PER SQ. MI.-YEAR		d. TOTAL TO DATE	
	e. AV. ANNUAL		f. PER SQ. MI.-YEAR					
	-----See table 2 in text-----							
39. AV. DRY WGT., LBS. PER CU. FT.		40. SED. DEP., TONS PER SQ. MI.-YR		41. STORAGE LOSS, PCT		42. SED. INFLOW, PPM		
a. PERIOD		b. TOTAL TO DATE		c. AV. ANNUAL		d. TOT. TO DATE		
e. PERIOD		f. TOT. TO DATE						
July 1985		47**		2,210		1.8		
				58				

*At Juncos.

**Data from Iivary (1981).