CONSOLIDATION OF SEDIMENTS IN A SMALL RESERVOIR IN NORTH MISSISSIPPI MEASURED IN SITU WITH A GAMMA PROBE [1/]

by

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INTRODUCTION

The accumulation of sediment in a reservoir is determined by a sediment survey. Depths of sediment measured at selected points within the reservoir are used to compute the volume of sediment. To calculate the total weight of the accumulated sediment, it is necessary to supply a value for the density of the sediment. In many sediment surveys, densities of sediments are estimated, not measured. The difficulty in accurately measuring the densities of sediments in place is partly responsible for the omission.

The use of the attenuation of gamma radiation to measure densities of sediment in place is one of the recent developments in nuclear technology (1).[2/] Gamma-emitting radioactive sources are used because the gamma rays are more penetrating than other radioactive emissions. The strength of the observed gamma radiation generally decreases with increases in density of the medium tested. The magnitude of the gamma-ray attenuation is influenced by the radioisotope used, its concentration, the chemical composition of the medium, and the geometry of the detector.

The single gamma probe, used to measure the density of materials, consists of a single probe containing a radioactive source and a detector separated by a lead shield. The gamma rays emitted by the source are subjected to reflection and absorption and the measured intensity of the reflected and scattered gamma rays can be related empirically to the density of the medium. It is possible to measure the density of sediments in place with an accuracy of 0.5 lb/ft^3 or better using the single probe.

1/ Contribution from the USDA Sedimentation Laboratory in cooperation with the University of Mississippi and the Mississippi Agricultural Experiment Station.

2/ Numbers in parentheses refer to reference citations.

A number of sediment surveys have been made on Powerline Reservoir, a small reservoir near Oxford, which was built in 1953. In 1962, and again in 1967, sediment densities were measured with a single probe as part of the sediment survey. Calculations of the change in sediment density in situ with time are possible from these measurements as well as calculations of volume and weight of sediments. It is the purpose of this paper to present data from two density surveys made on Powerline Reservoir with the single probe, which show that the single probe can be used to measure compaction of reservoir sediments in place and to obtain data necessary to calculate volumes and weights of accumulated sediments.

MATERIALS AND METHODS

Equipment: The single probe used in the 1962 survey has been described (2, 4). The probe used in the 1967 survey was a slightly modified version. A new outer shell, new cables and new cable connectors improved the handling characteristics of the single probe without significantly changing the response of the probe to gamma radiation.

Powerline Reservoir: Powerline Dam was built as a sediment retention structure near the headwaters of Toby Tubby Creek which flows into Sardis Reservoir. The drainage area is about 311 acres, of which 52 acres were considered active gullies when a land use survey was made in 1958. The volume of the pool at the emergency spillway originally was 88 acre-feet and the pool at the drop inlet elevation (396.55 feet) contained about 31 acre-feet. Measurements of sediment density were made in 1958 and during subsequent sediment surveys. Ranges for sampling were established at the time of the first survey and it is on these ranges that sites for sediment measurements are located (Figure 1).

Sampling: Density measurements were made at 55 selected sites on 5 ranges. The 1967 measurements were made, in most cases, at the same locations as those made in 1962. At each location, measurements were made at 6-inch intervals from the surface of the sediment downwards until the probe could be pushed no deeper. The probe easily penetrated the accumulated sediment but in most cases did not penetrate significantly into the old ground surface. Each measurement consisted of a one-minute reading of the gamma-ray intensity at that point. Duplicate readings were taken at frequent intervals. Field data indicated good agreement of the replicated measurements. The measurements of radiation intensity (gamma-ray flux) were converted to total (wet) density values, g/cm^3, by the use of an appropriate calibration curve (2). The conversion of total (wet) density values, in metric units, to dry (bulk density) weight, in pounds per cubic foot, was made assuming the specific gravity of the sediment was 2.65 g/cm^3, i.e., the specific gravity of SiO_2. The calibration curves used equate the reading of the single probe in water with a density of 1.000 g/cm^3. Several readings were taken with the probe in water at each site before measuring the densities of the sediment in that vertical. This was done to insure that the single probe was operating correctly and to permit correcting the observed readings to the standard base. The ratio of the observed mean water readings to the standard water reading was used as the correction factor.

EXPERIMENTAL DATA

Measurements were made on the five ranges in the permanent pool of Powerline Reservoir. The ranges (R) are O-I, M-N, J-K, H-G, and C-D as shown in Figure 1. Measurements of density were made at 55 sites on these five ranges. The ranges not sampled, e.g., A-B and L-M, were no longer under water at the time of the 1962 survey owing to the accumulation of sediment.

The depth of the sediment at the measuring sites ranged to 4 feet in 1962 and to 4.5 feet in 1967. At most observation sites the depth of sediment accumulation was 6 inches greater in 1967 than in 1962 (Table I). As illustrative of the study, selected data, in this case from Range M-N, will be presented and discussed in some detail.

Nine sites were used on Range M-N for measuring density. The stations were at 50, 85, 100, 140, 150, 190, 200, 225, and 250 feet from the east (N) bank marker. The water elevation shown, 396.55 feet, was that of the drop outlet pipe. The density profile of the sediment at each site is shown in Table I. Two facts are readily discernible from the data: (1) sediment depth increased with time, and (2) at all depths sediment density generally increased from 1962 to 1967. This increase in density was small in most cases (Table I).

There was an average increase in weight of 28.6 pounds per profile of sediment for the eight sites sampled (excluding the 250-foot location) on Range M-N. This increase amounted to nearly 625 tons per surface acre of the reservoir. Weights were calculated on the basis of a profile one foot square and the depth of the measured sediment.

Similar data were collected on each of the other four tested ranges. Qualitatively the results were similar to those reported for Range M-N. The mean increase for the five ranges in weight of sediment per profile was 35 pounds per square foot. The increase in weight is the sum of the weight of sediment deposited between 1962 and 1967 and the increase in weight due to compaction and increased density of the old sediment. The increase in weight per profile is the equivalent of a 6-inch depth of sediment whose density corresponds to 70 lb/ft^3 (1.70 g/cm^3). This amount of sediment is equivalent to 760 tons per acre. If the increased depth of sediment (up to 6 inches) between 1962 and 1967 were assumed to consist of sediment whose total density was 1.70 g/cm^3, the total weight of sediment would be approximately that measured with the single probe. However the data indicate the sediment accumulated from 1962 to 1967 was not this dense (Table I), and the data further show that a portion of the increase in weight per profile was due to an increase in density of the sediment deposited prior to 1962 (Table I). In previous sediment surveys on Powerline Reservoir, an assumed weight of 78 lb/ft^3 was used to calculate sediment weights from volume measurements. For recent sediments this value is too high.

The mean increase in weight of sediment per vertical profile was related to its position within the reservoir. The mean increases in sediment weight per profile (one square foot) were 15.1, 28.6, 35.2, 44.5 and 51.7 lb/ft^3 for the five sampled ranges in order from the dam upstream (Figure 2). The data in Figure 2 show a larger deposit of sediment from 1962 to 1967 in the upstream portion of the reservoir. At the same time there was an increase in the mean weight of the vertical profile, indicating an increased density. The increase in density of the upstream profiles was due in part, no doubt, to the deposition of coarser sized particles in the upstream reservoir pool and in part to some compaction of existing sediment.

The stage-capacity curve for Powerline Reservoir is shown in Figure 3. The curves for 1962 and 1967 show less than 6 inches difference in depth throughout the reservoir. The stage-capacity curve was based on the sediment survey data and not on the single probe data.

The sedimentation rate for the nine years, 1953 to 1962, was computed in 1962 on the basis of the volume of sediment measured by the sediment survey. Within the normal pool, i.e., below 396.55 feet, the sedimentation rate was equivalent to the erosion of 0.042 inch per year from the entire (305 acres) watershed. For the flood pool, i.e., 402.55-foot elevation, the rate was 0.069 inch/year and at the 410.0-foot contour, the sediment measured within the 6-acre pool area corresponded to an erosion rate of 0.079 inch/year for nine years. The sediment survey in 1967 showed sedimentation and erosion rates were decreasing. The corresponding sedimentation rates for the normal pool, flood pool, and the 410-foot contour were equivalent to erosion rates of 0.001, 0.007, and 0.007 inch per year for the five years, 1962 to 1967.

Calculations based on the data obtained with the single probe in 1962 and 1967 show a sedimentation rate equivalent to an erosion rate of 0.012 inch per year from the watershed. This was for the material accumulated in the pool, which covered about 4 acres in 1967. If the amount of sediment measured in the existing 1967 pool were assumed to be deposited throughout the original 6-acre pool, the calculated equivalent erosion rate would be 0.019 inch/year.

The erosion rates calculated from single probe measurements are greater than those calculated from volume measurements from the sediment survey for the same period. Both sets of calculations show that the sedimentation rate, and equivalent erosion rate, from 1962 to 1967 was considerably less than from 1953 to 1962. The reduced erosion rate is probably a reflection of the decreased intensity of land use in the watershed and of the increased effectiveness of various conservation practices, viz., pine plantings and gully protection. No account is taken of deposition upstream of the reservoir pool.

Sedimentation rates for 1962 to 1967 calculated from the single probe data are greater than those obtained from volume measurements, partly because the observed increase in sediment density is included in the single probe data. The indicated increase in sediment depth, 6 inches, was also used. The volume data indicated a smaller increase in sediment depth than did the single probe data.

SUMMARY AND CONCLUSIONS

Sediment surveys, including measurements of in place densities of sediments, were made in 1962 and 1967 on Powerline Reservoir, a small reservoir near Oxford. The single gamma probe was used to measure the in place densities of sediments. The average depth of sediment had increased, the greatest increase being in the upstream portion of the reservoir pool. The data show a small increase in the density of sediment with time. The calculated erosion rate for the study period, based on sedimentation rates in the reservoir pool, was 0.012 inch/year for the 1967 pool area or 0.019 inch/year for the original 6-acre reservoir pool. This is less than the erosion rate of 0.078 inch per year calculated for the nine-year period, 1953-1962. The decrease in erosion rate is attributed to changes in land use and the effectiveness of various conservation practices initiated within the watershed.

The single probe can be used to determine the volume and weight of sediment accumulated between times of successive measurements. An increase in the density of sediments is accurately reflected in the computed weight of sediments. The observed increase in volume of sediment is similarly suitably corrected for density.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the cooperation and assistance given by various members of the staff of the USDA Sedimentation Laboratory in the collection of data and the preparation of this report. The work of Mr. O. W. Sansom in modifying and maintaining the electronic equipment is acknowledged. We wish, especially, to thank Mr. Donald A. Parsons, former Director, for his support of this study.

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Table 1.--Total wet densities of sediments measured with a single probe on Range M-N, Powerline Reservoir, Lafayette County, Mississippi, 1962 - 1967.

Depth below water surface*	50 feet		85 feet		100 feet	
	1962	1967	1962	1967	1962	1967
(feet)			(g/cm^3)**			
7.5		1.000				
8.0		1.005				
8.5	1.000	1.336		1.000		1.000
9.0	1.383	1.660	1.000	1.146	1.000	1.155
9.5	1.688	1.722	1.305	1.554	1.290	1.621
10.0	1.696	1.717	1.620	1.693	1.663	1.684
10.5	1.736	1.712	1.679	1.723	1.703	1.711
11.0	1.738	1.767	1.718	1.716	1.716	1.724
11.5	1.759	1.774	1.729	1.737	1.715	1.725
12.0			1.736	1.753	1.724	1.752
12.5			1.767	1.777	1.767	1.763
13.0					1.765	

* Water surface elevation was 396.55 feet.

** To convert total wet densities in grams per cubic centimeter to dry weight per cubic foot, substract 1.000 from the given value and multiply by 100.

Table 1.--Continued.

Depth below water surface	140 feet		150 feet		190 feet	
	1962	1967	1962	1967	1962	1967
(feet)			(g/cm^3)			
7.0						
7.5						
8.0		1.000		1.000	1.000	1.000
8.5	1.000	1.066	1.000	1.057	1.064	1.358
9.0	1.160	1.480	1.267	1.613	1.427	1.667
9.5	1.620	1.668	1.658	1.676	1.683	1.716
10.0	1.696	1.708	1.705	1.725	1.688	1.728
10.5	1.729	1.738	1.719	1.755	1.734	1.735
11.0	1.730	1.747	1.719	1.734	1.738	1.756
11.5	1.737	1.752	1.746	1.760	1.774	1.763
12.0	1.760	1.771	1.774	1.781	1.778	1.785
12.5	1.788	1.783*	1.769	1.794		
13.0	1.783					

* = 12.25 feet

Table 1.--Continued.

Depth below water surface	200 feet 1962	200 feet 1967	225 feet 1962	225 feet 1967	250 feet 1962	250 feet 1967
(feet)			(g/cm^3)			
7.0				1.000	(4.0)1.000	1.000
7.5		1.000	1.000	1.220	(4.5)1.074	1.228
8.0	1.000	1.057	1.240	1.642	(5.0)1.723	1.531
8.5	1.171	1.412	1.670	1.704		
9.0	1.620	1.686	1.715	1.731		
9.5	1.713	1.742	1.730	1.735		
10.0	1.726	1.724	1.749	1.751		
10.5	1.719	1.741				
11.0	1.756	1.768				
11.5	1.767	1.782				
12.0	1.761	1.781				
12.5						
13.0						

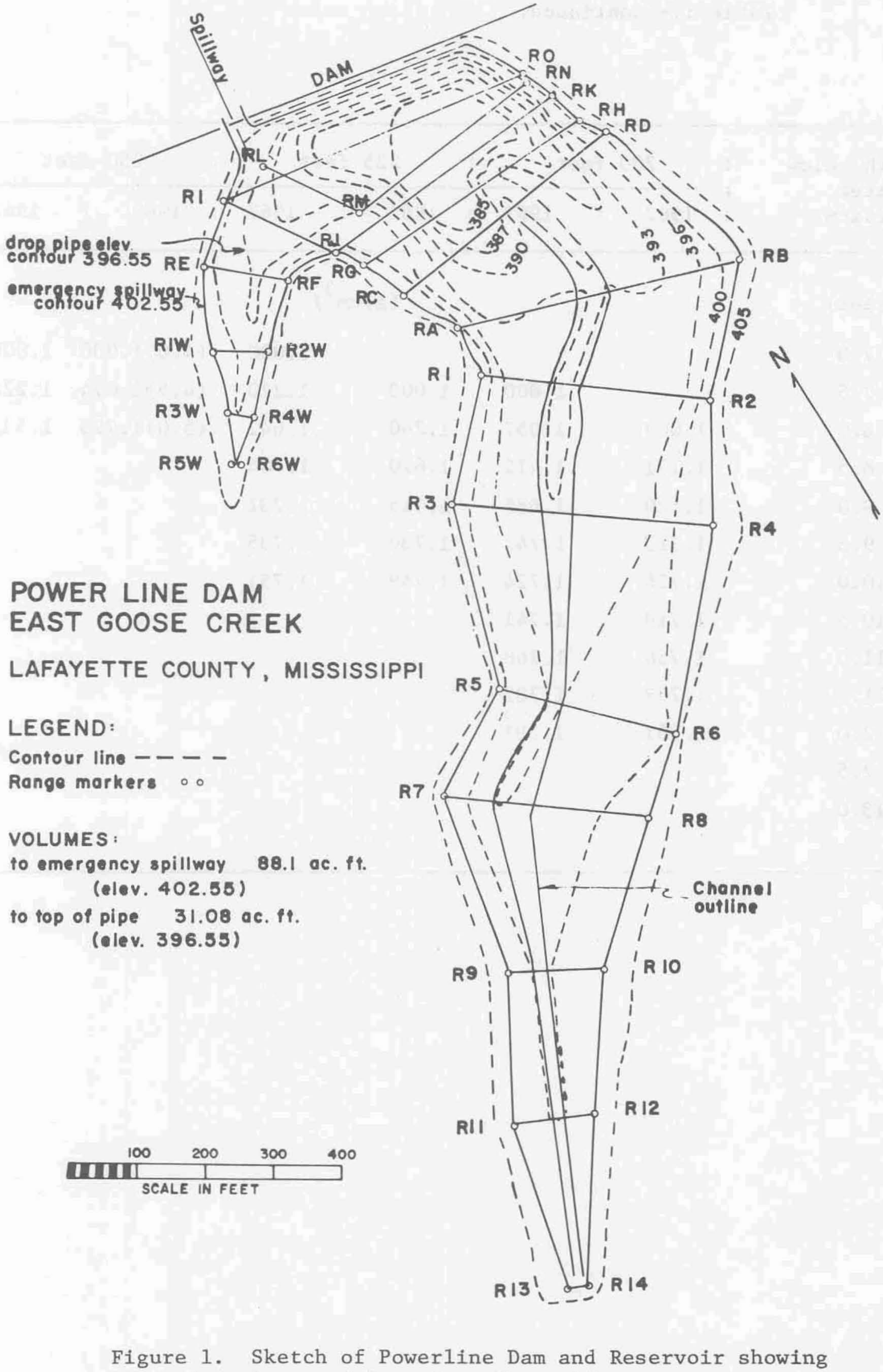

Figure 1. Sketch of Powerline Dam and Reservoir showing elevations and location of sampling ranges.

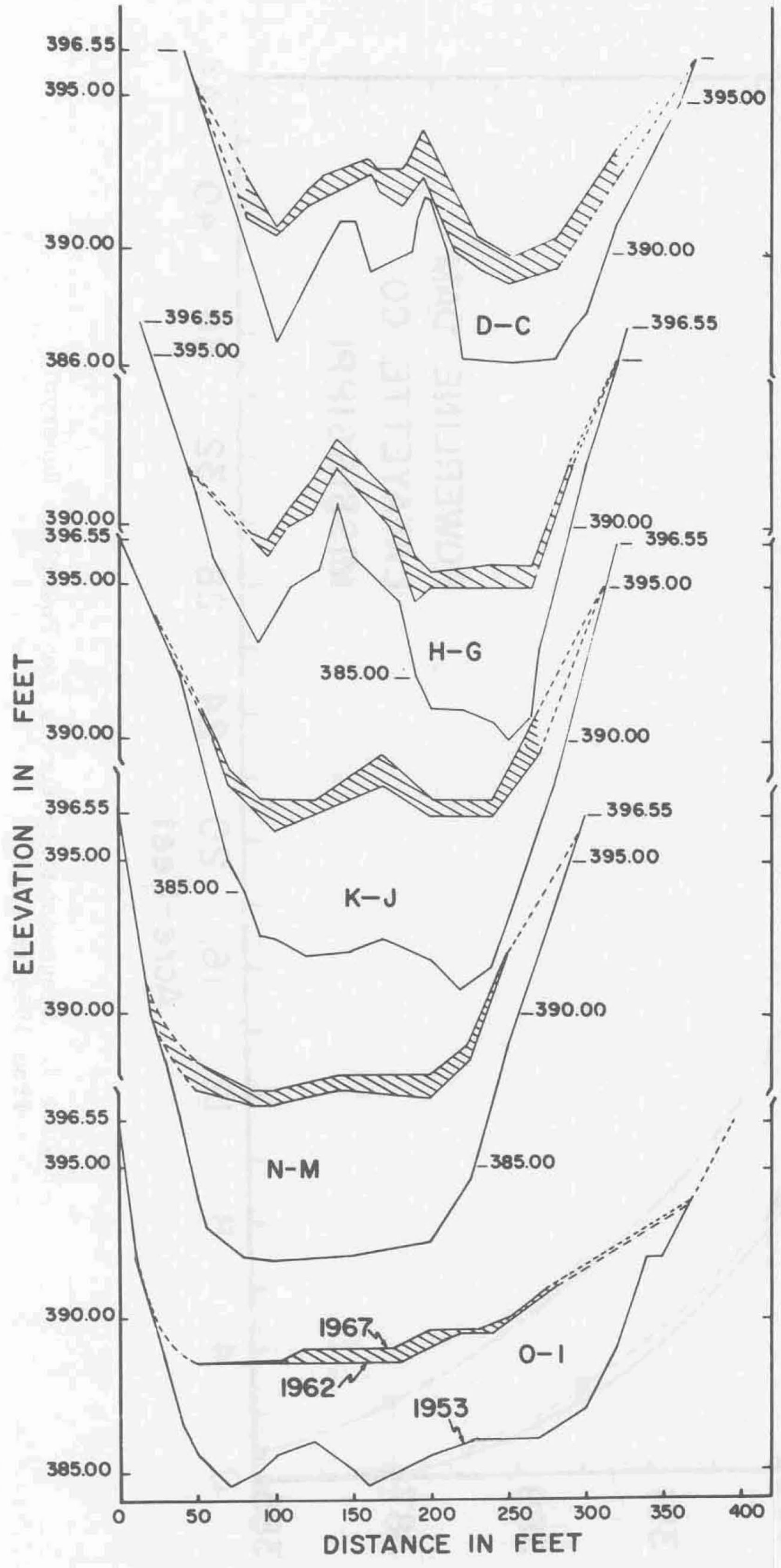

Figure 2. Diagram showing the accumulation of sediment in Powerline Reservoir from 1958 to 1967 for the five sampled ranges. The ranges are shown in order above the dam; Range O-I being closest to the dam, Range D-C being farthermost.

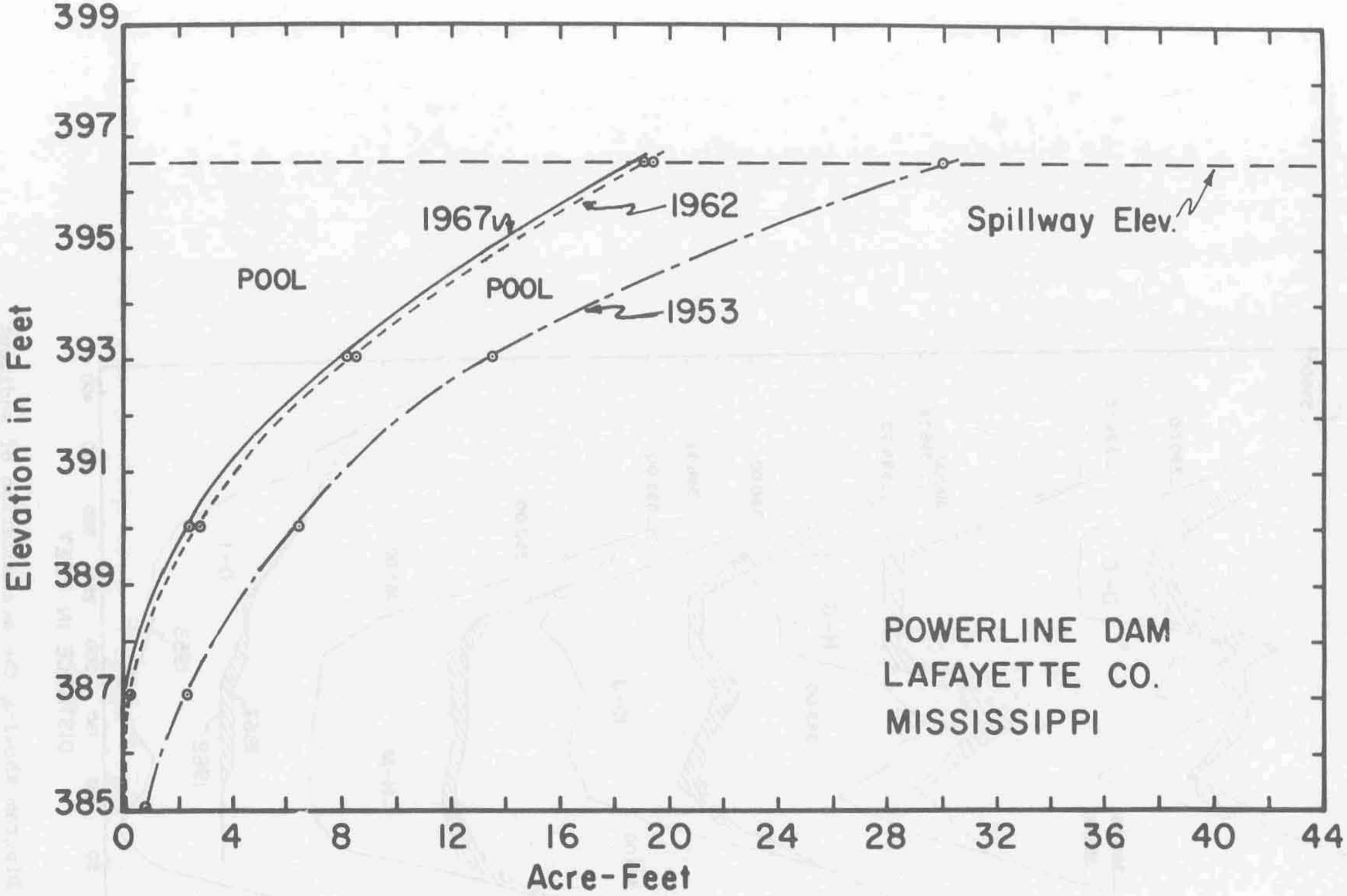

Figure 3. Stage-capacity curves for Powerline Reservoir from 1953 to 1967.