# THE EFFECT OF RECREATION ON WATER QUALITY

by

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The research leading to this report was supported by the OFFICE OF WATER RESEARCH AND TECHNOLOGY, USDI, under the Allotment Program of Public Law 88-379, as amended, and by the University of California, Water Resources Center, as a part of Office of Water Research and Technology Project No. A-064-CAL and Water Resources Center Project UCAL-WRC-W-531.

TECHNICAL COMPLETION REPORT

January 1979

# ABSTRACT

The purpose of this research was to assess the effect of motorboat usage on the long-term lead concentration of a multipurpose reservoir, Turlock Lake in Stanislaus County, California. As the study was made during two drought years, it was possible to examine the effects of large volume changes in the lake. Samples were taken at weekly intervals at the inlet canal where water enters the lake, at the outlet and at the boat dock, then lead analyses were made.

An apparent correlation was found to exist between the lead level at the boat dock and the boats per-unit-volume. Also, at the boat dock, the largest lead concentration correlated with the highest boat concentration. The inlet and outlet lead data obtained were treated in terms of a simple plug-flow model. In order to correlate between the change in lead concentration obtained from the plug-flow model and boat concentration, a calculation was made to estimate the number of boats that would have to be launched on the lake to give the observed value of $\Delta(Pb)$. It was found the increase in the lead level of the water as it passes through the lake is greater, by at least a factor of 15, than would be expected on the basis of the number of boats on the lake.

The lead concentration was found to correlate with lake volume. Experiments were done to find if an alternate source of lead in the lake is the sediment. The mechanism linking lake volume and lead concentration is unclear but is likely to involve migration of lead from the sediment, which was found to contain exchangeable lead, and/or biotic processes.

# THE EFFECT OF RECREATION ON WATER QUALITY

The recreational use of the nation's lakes, streams and reservoirs is increasing steadily. On a national basis, boating and fishing rank among the top ten most popular outdoor activities (1). Outboard motorboats, of course, play a significant role in this recreation. They are also a potential source of water pollutants such as lead and hydrocarbons (2,3,4).

Such pollutants are potentially harmful to the aquatic ecosystem. English _et al_. (2) showed that water containing outboard motorboat exhaust is toxic to fat-head minnows and blue gills, and that the flesh of fish exposed to this water acquired an oily taste. In a related study, Adams (5) showed that brook trout exposed to water containing snowmobile exhaust exhibited reduced stamina in comparison to control fish, as well as an uptake of lead and hydrocarbons.

Many lakes and reservoirs are used for boating as well as for drinking and irrigation water. The efficient management of such multi-use water reservoirs requires an understanding of the relationship between water quality and recreational usage.

The purpose of the work described here was to assess the effect of motorboat usage on the long-term lead concentration of a multi-use reservoir, Turlock Lake in Stanislaus County, California.

Turlock Lake is located in a rural area in the foothills of the Sierras in eastern Stanislaus County, California. The lake normally covers an area of 3,552 acres and has an average depth of 14 feet (see Figure 1). This lake is a man-made reservoir. Its primary function is to provide irrigation water for the Turlock Irrigation Distrct. The Lake is also used for boating, and other water-based recreational activities. It is fed by a canal which carries water from a snow-fed reservoir at a higher elevation. Except for a slight contribution from rainfall and runoff in the winter, this canal is the only source of Turlock Lake water. The only outlet for the water is the Turlock Irrigation District main canal. Water is metered from behind a dam into the canal. The lake shore on one side is occupied by a state park which includes the boat-launching facilities. The rest of the lake is surrounded by open rangeland.

Turlock Lake is an ideal system for the study of long-term lead concentration and its dependence on outboard motor usage. The lake has a well-defined source of water and a single outlet. The lake volume and the rates of inflow and outflow, are controlled and monitored daily by the Turlock Irrigation District. The entire area surrounding the lake and the reservoirs and canals which feed it is essentially uninhabited except for a few scattered ranches. Hence, the effects of industry and urbanization on the water composition can be neglected. The only evident sources of lead in the water in summer, other than natural sources, are boating and windborne particulates originating from automobile exhaust. The lack of rainfall in summer rules out contributions from runoff. Furthermore, the California Department of Parks and Recreation keeps a daily record of the number of boats launched. Such data are essential for the assessment of the effect of motorboat usage on water quality.

Another interesting aspect of this study is that 1976 and 1977, the years during which this study was conducted, were drought years in California, and the volume of Turlock Lake in 1976 was double what it was in 1977. Hence, we were able to study the effects of large volume changes on lead levels.

PROCEDURE: Our procedure was to take samples at weekly intervals at three stations: at the mouth of the inlet canal where water enters the lake, at the outlet, and at the boat dock next to the boat-launching ramp. Samples were taken from the surface with polyethylene bottles. Lead analyses were accomplished with a Perkin Elmer Model-103 Spectrophotometer equipped with an HGA-2100 graphite furnace and a high intensity lead hollow cathode lamp. The method of Standard Additions was used. All samples were gravity filtered with S and S #589 fine porosity filter paper to remove suspended solids. Duplicate samples filtered using 0.5 μM Millipore filters gave identical lead concentrations as those filtered with the filter paper. All samples were analyzed within two hours after collection.

The pH of Turlock Lake water is fairly constant at around 6.6 ±0.1. The data of Subramanian et al. (6) show that at this pH, the rate of adsorptive loss of lead on the container wall might be significant, whereas no losses were observed by them at a pH of 1.6. We checked our procedure for losses on the container walls as follows. Duplicate samples were taken; one was filtered and acidified with nitric acid to a pH of 1.6 immediately after sampling. The other sample was filtered in the laboratory and not acidified. Analysis of the two samples gave identical results. Thus, there was no significant loss of lead onto the container walls for our unacidified samples during the interval between sampling and analysis.

Consequently, the majority of our samples were not treated with acid. This is consistent with reports indicating that sample containers previously equilibrated with natural waters showed no adsorption of lead from solution (7).

The lead concentrations reported here are accurate to within ±15%.

RESULTS AND DISCUSSION.

Water samples were analyzed at weekly intervals during the periods: June 15 to August 31, 1976; October 14 to December 12, 1976; March 2 to April 18, 1977; and June 8 to September 21, 1977. The data are shown in Figures 2, 3, 4, 5.

During the time of this study, the flow conditions in the lake varied. In the summers (Figures 2 and 3), water flowed continuously through the lake. The fluctuations in lake volume shown in Figures 2 and 3 arise from changing irrigation demands. During both summers, the average residence time of the water in the lake was seven days.

During the interval October 14, 1976 to December 12, 1976 (Figure 6), no water was released from the lake, although some was fed into it during the first part of the interval and the lake volume increased.

During the period March 2, 1977 to April 18, 1977, periods of zero outflow occurred (Figure 7), and these account for the periods of increasing volume.

In general, the lead levels at the inlet and outlet seldom exceeded 2.0 ppb. The highest observed levels were obtained at the boat dock.

THE SUMMER DATA. During both summers (Figures 2 and 3), the concentration of lead was consistently higher at the outlet than at the inlet. Since water was flowing continuously through the lake at these times, the implication is that lead was introduced into the water as it passed through the lake. To investigate the possibility that this increase in lead was due to outboard motorboats in the lake, we prepared histograms of the total number of boats launched per-unit-volume of lake water over a one-week period. "Boats per-unit-volume" was used to compensate for fluctuations in lake volume. Furthermore, the number of boats used was the total number of all types of boats. But since virtually all of the boats on the lake are outboard motorboats, the histograms accurately indicate the variation in motorboat concentration with time.

An apparent correlation exists between the lead level at the boat dock and the boats per-unit-volume (Figures 8 and 9). This is especially evident in Figure 9. The largest maximum in lead concentration correlated with the high boat concentration during the week of July 4, 1977. A similar but smaller rise is observed during the week of July 4, 1976 (Figures 8). No direct correlation is evident between the boat concentration and either the inlet or outlet lead concentrations.

PLUG-FLOW MODEL. The inlet and outlet lead data obtained in the summers were treated in terms of a simple plug-flow model. The average residence time of water in the lake in the summer was approximately seven days. This was the time required for the total lake volume to flow out of the lake. Thus, according to the model, the water at the outlet entered the lake about seven days previously. To calculate the increase in lead concentration in a given volume of water as it passed through the lake, we subtracted the inlet lead concentration at the beginning of a seven-day interval from the outlet lead concentration at the end of that interval.

This difference will be referred to as $\Delta$(Pb). Thus, $\Delta$(Pb) represents the change in the lead concentration for an average plug of water as it traverses the lake.

The plug-flow model could only be applied to data gathered in the summers, since only at these times did conditions in the lake approximate a flow system. At other times of the year (Figures 6 and 7), periods of zero outflow occurred.

Values of $\Delta$(Pb) are shown in Figures 8 and 9. They show the same general behavior as the lead concentrations at the dock, except that they are shifted in time. The shapes of the plots of $\Delta$(Pb) and boats per unit volume vs. time are similar. This is especially evident in the period immediately following the July 4th weekend.

Both the boat concentrations and the $\Delta$(Pb) values show the same temporal dependence during both summers. A consideration of Figures 8 and 9 shows that although the temporal variations of $\Delta$(Pb) and the boat concentrations correlate with one another, their absolute values do not show a correlation. The boat concentrations in the summer of 1977 were nearly twice as great as in the summer of 1976, due to the very low level of the lake during the drought year of 1977 and the nearly constant number of boats launched during both summers. The doubling of the boat concentration is not reflected in the $\Delta$(Pb) values, however. The range of these values is roughly the same for both summers.

It must be emphasized that, due to the irregular shape of the lake, wide fluctuations from the average residence time, and other factors, the plug-flow model is a very low order approximation of the actual flow conditions within the lake.

FALL AND SPRING DATA. These data (Figures 4 and 5) are characterized by smaller boat concentrations than the summer data, and also by periods of zero outflow. The absolute lead levels are roughly the same as those in the summers. Some correlation between the lead concentration at the boat dock and the boat concentration appears in Figure 4, but not in Figure 5. Another feature of these data is that in several instances the inlet lead concentration exceeds the value at the outlet. This probably arises from the changes in flow conditions caused by periods of zero outflow.

INFLUENCE OF NUMBER OF BOATS ON LEAD LEVEL.

Boat Dock Data: As shown in Figure 1, the boat dock is located in a cove somewhat isolated from the main body of the lake, and the water in the vicinity of the dock is probably not well mixed with that of the rest of the lake. The dock area is the area of greatest boating activity for two reasons. Firstly, all boats launched must pass through this area. Secondly, fueling facilities are located in this area, and hence the potential for small spills is greater than elsewhere in the lake. Thus, any impact of boating on water composition should be most apparent in the boat dock area, especially in the drought year of 1977 when the volume of water in the cove was relatively low. In fact, as mentioned earlier, the data show a correlation between the lead level at the boat dock and boat concentration. The strongest correlation is observed in the data for the summer of 1977 (Figure 9). Weaker correlations exist in the summer 1976 and fall 1976 data (Figures 8 and 4, respectively).

In Figures 10 and 11, the boat dock lead concentrations during both summers are compared with histograms showing total boats launched rather than boats per-unit-volume. A correlation between the number of boats and lead concentrations exists during both summers. The lead concentrations in the summer of 1977 show both greater fluctuations and greater maximum values than those of the summer of 1976. This is probably due to the fact that in both summers the number of boats launched was approximately the same, but the lake volume in 1976 was twice as great as in 1977. Thus, the impact of boating in the boat dock area appears to depend on the volume of water in the lake. For example, during the July 4th week of both summers, approximately 400 boats were launched. In 1976, this produced a lead concentration of about 1.2 ppb, whereas in 1977, the lead concentration was about 4.0 ppb.

NUMBER OF BOATS AND $\Delta$(Pb) VALUES: In order to evaluate the possible correlation between $\Delta$(Pb) obtained from the plug-flow model, and boat concentration, a calculation was made to estimate the number of boats that would have to be launched on the lake to give the observed value of $\Delta$(Pb). The calculation was based on the assumption that $\Delta$(Pb), the rise in the lead level of the lake water, comes entirely from the combustion of gasoline and that all of the lead in the exhaust gases is absorbed in the water. The calculation was made using some typical average data: $\Delta$(Pb) = 0.5 ppb, lake volume = 25,000 acre-feet, and the lead content of gasoline was taken to be 0.87 g of lead per gallon.[2] The result is that approximately $1.4 \times 10^4$ gallons of gasoline would have to be burned in order to obtain the observed $\Delta$(Pb) value.

If we make the further assumption that each outboard motorboat uses an average of two gallons of gasoline and that the residence time of the water is seven days, then we obtain the result that 7000 motorboats must be launched in seven-day intervals to give $\Delta$(Pb) = 0.5 ppb. The maximum number of boats launched in a seven-day interval during our study was 450.

Usually the number was much less. Thus, the increase in the lead level of the water as it passes through the lake is greater, by at least a factor of 15, than would be expected on the basis of the number of boats on the lake. Although this discrepancy might possibly be due to deficiencies in the plug-flow model an alternate lead source seems most likely.

Thus, in view of the large difference between calculated and observed lead levels and the lack of correlation between the lead levels of the two summers, when the boat concentration differed by a factor of two, the correlation between lead build-up and boats-per-unit-volume is coincidental.

THE INFLUENCE OF SEDIMENT. An alternative source of lead in the lake water is the sediment. In preliminary experiments, lake sediment containing 20 ppm lead was placed in contact with deionized water having an initial lead concentration of 1.0 ppb. Teflon containers were used and the temperature was maintained at 25°C. After one day, the lead concentration of the water rose to 5.0 ppb and remained constant at that level for three days. Control experiments showed no uptake or introduction of lead by the container. We conclude that the sediment contains exchangeable lead and is, therefore, a potential source of lead in the lake water.

Further evidence that the release of lead from the sediment may be influencing the observed lead concentrations comes from the fact that the summer data show an interesting correlation between the outlet lead concentration and lake volume (Figures 12 and 13). In Figure 12, the outlet lead concentration curve shows the same behavior as the volume curve except that it is shifted in time. In Figure 13, both curves again show similar behavior, with no shift in time. One possible explanation for this behavior is that as the volume of the lake increases, new sediment on the shoreline from which lead has not been leached comes into contact with the water, and migration of lead from the sediment occurs.

Another possibility is that biotic processes closely associated with lake volume and/or time of the year may be influencing the lead concentration. This is suggested by the fact that the correlation between the outlet lead concentration and volume occurs only in summer, and not in fall or spring (Figures 4 and 5). Of course, the lack of correlation may be due to changed flow conditions as well.

SUMMARY. The lead concentration of Turlock Lake water measured at the inlet, outlet and boat dock fluctuates during the year, and the behavior at each station is different. Comparison of lead concentrations measured at the inlet and outlet shows that the lead concentration increases as the water passes through the lake. Treatment of the inlet and outlet data, using a simple plug-flow model, leads to an apparent correlation between the increase in lead concentration and motorboat usage. The correlation may be misleading, however, for several reasons. Calculations show that the increase in lead concentration is much too large to be attributable entirely to motorboat usage. Secondly, a strong correlation exists between the summer outlet lead concentrations and lake volume. Finally, while it would be expected that a reduction in the lake volume by a factor of two together with a constant number of boats should cause a general doubling in the lead concentration, no such behavior is evident. Rather, the lead concentrations are very much the same, and behave as if governed by solubility equilibria and/or kinetic limitations.

The mechanism linking lake volume and lead concentration is unclear but is likely to involve migration of lead from the sediment, which contains exchangeable lead, and/or biotic processes. No definite conclusion can be drawn at this point as to the source of lead in Turlock Lake. Further studies are being conducted on the role of the sediment in controlling concentrations of dissolved lead.

The lead concentrations measured at the boat dock, the area of most intense boat traffic, show a correlation with the number of boats launched during the summer months. The correlation is better, and higher lead concentrations occur, during periods of low lake volume.

Acknowledgments. We are especially grateful to Warren F. Brandle, Robert W. Crothers, James G. Mortensen, Terry L. Nordman and Robert D. Swanson for collecting water samples and performing some of the analyses. We wish to thank too, the Turlock Irrigation District, especially Mr. Leroy H. Kennedy and Mr. Chris Kiriakou who patiently answered all of our questions concerning Turlock Lake and provided us with daily records of Lake conditions. We are also grateful to the California Department of Parks and Recreation for its cooperation, and to the Rangers at Turlock Lake State Park for making available to us their daily records of boat launchings. We are also very pleased to acknowledge the financial assistance of the Water Resources Center (Project W-531 (A-064-CAL)).

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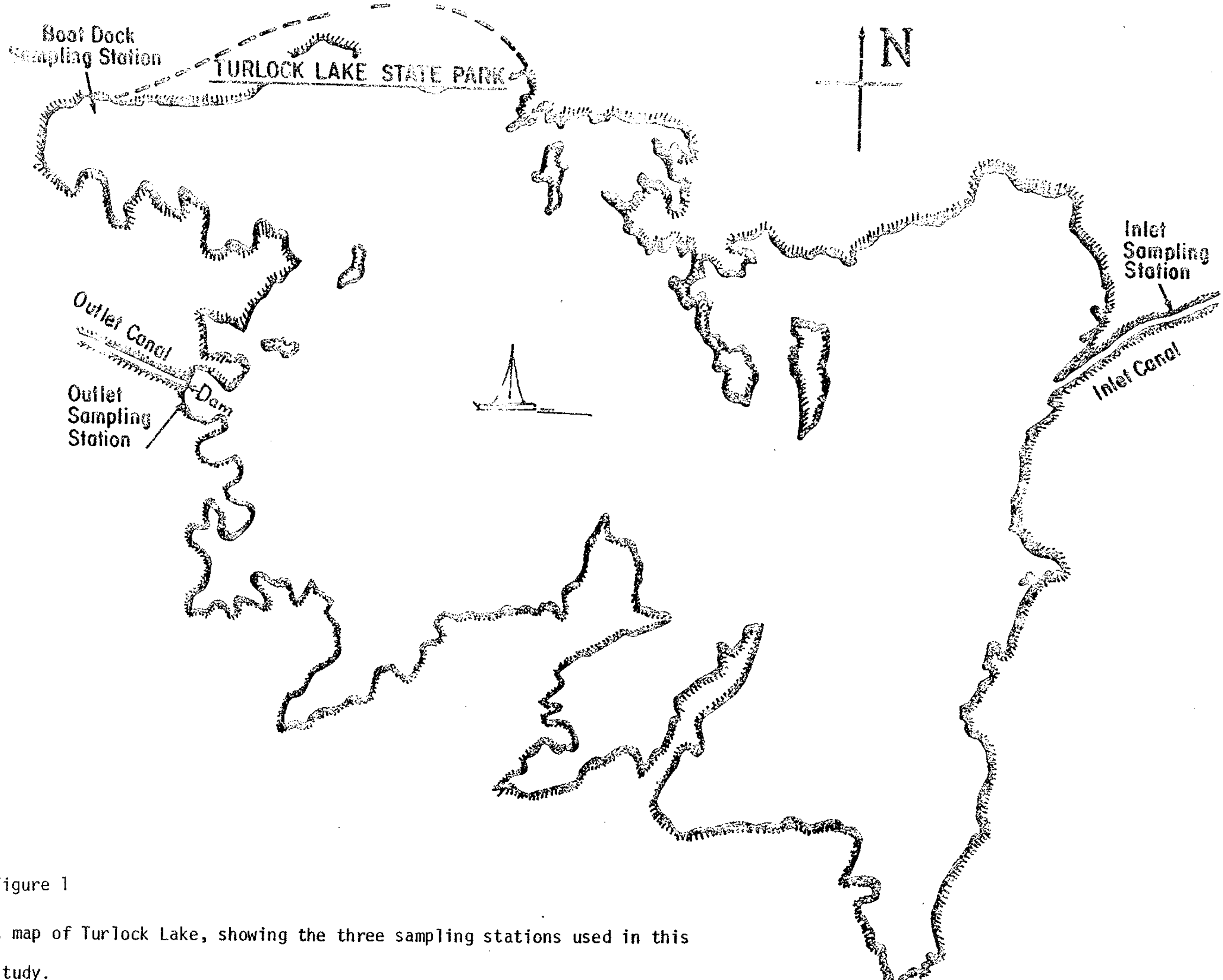


Figure 1

A map of Turlock Lake, showing the three sampling stations used in this study.

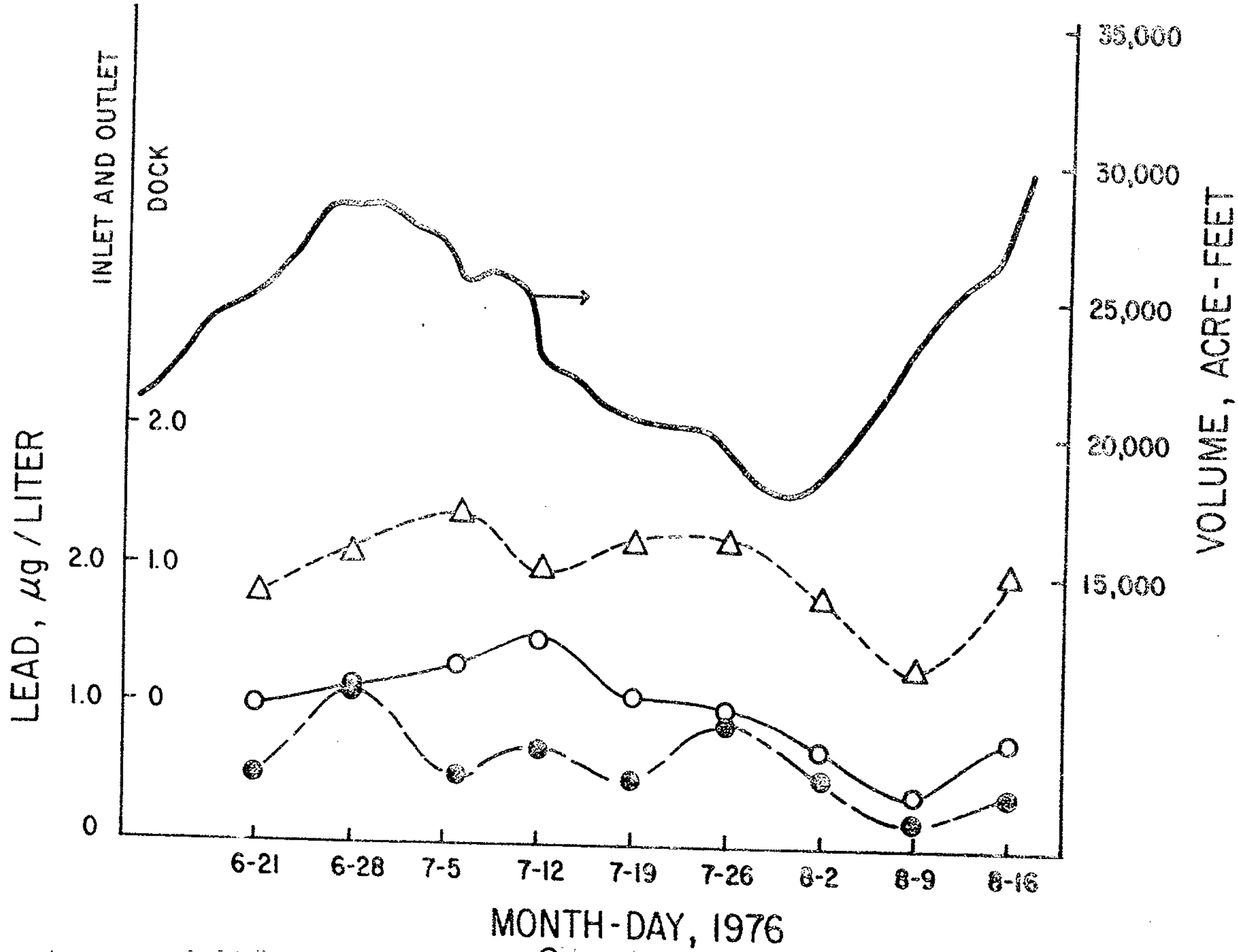


Figure 2

Lead concentrations and lake volume during summer 1976. ○, lead concentration at outlet; ●, lead concentration at inlet; △lead

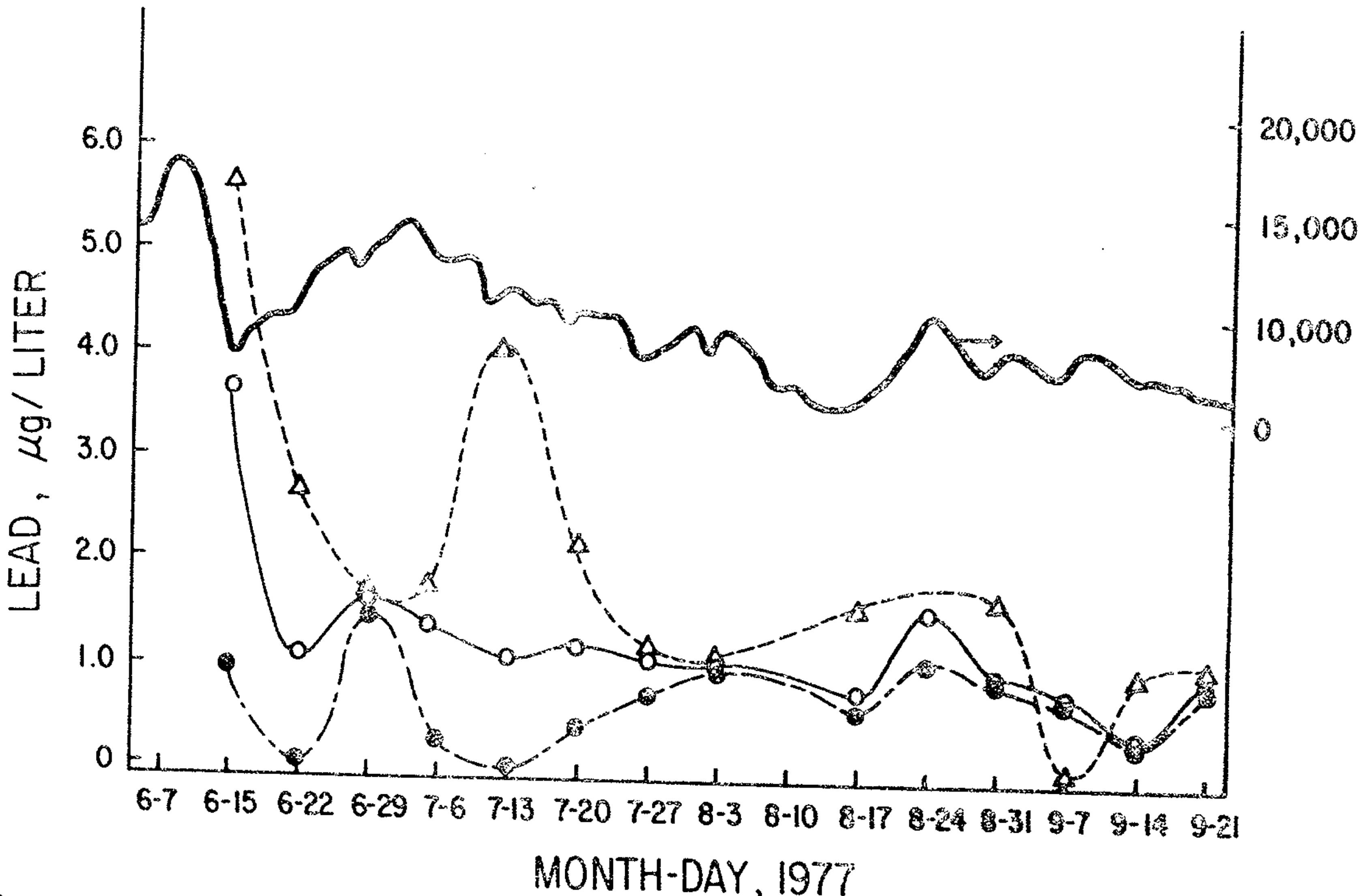


Figure 3

Lead concentrations and lake volume during summer 1977. ○, outlet concentration; ●, inlet concentration; △, boat dock concentration. Heavy line shows lake volume.

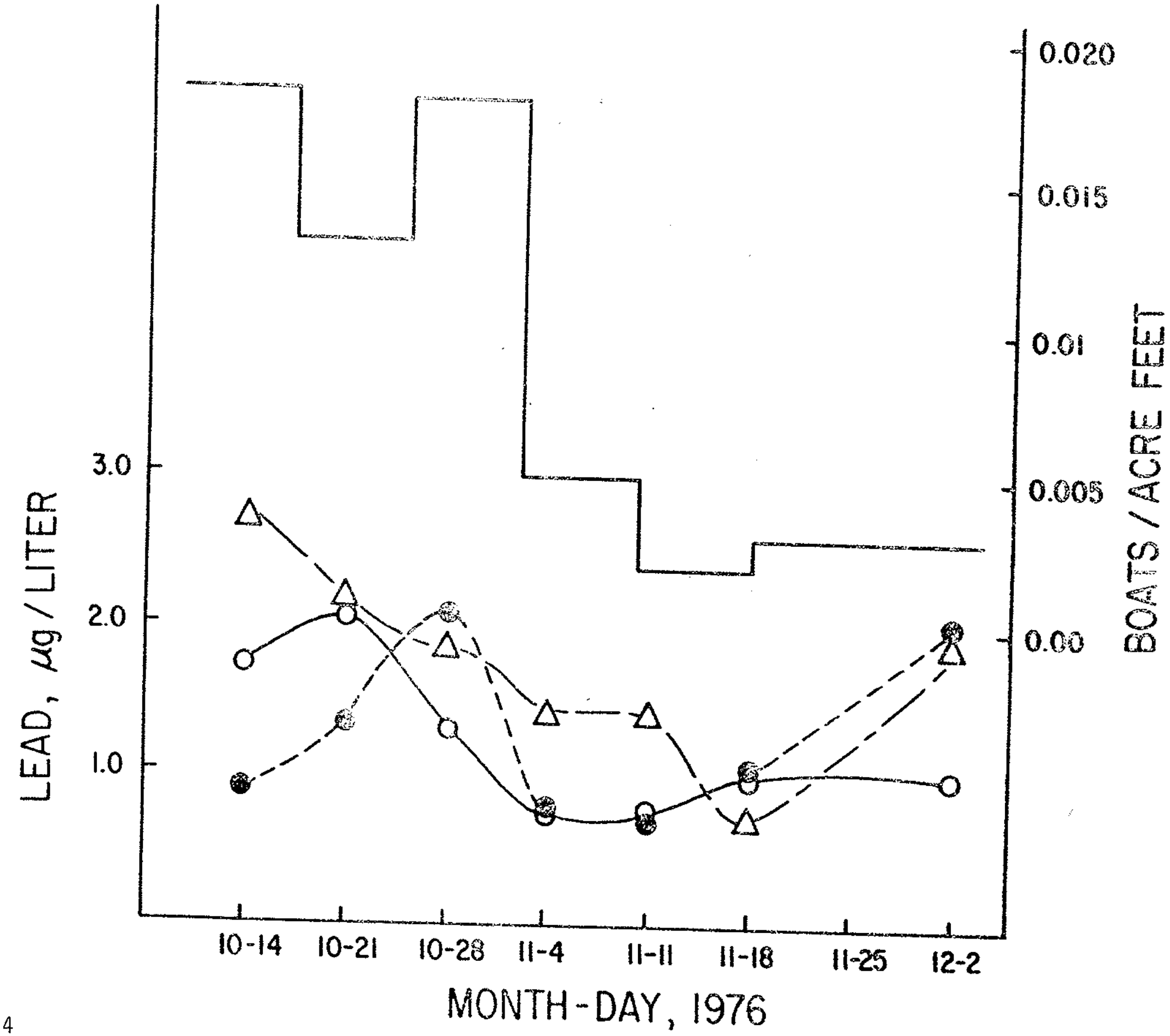


Figure 4

Lead concentrations and boats per-unit-volume during fall 1976. ○, outlet concentration; ●, inlet concentration; △, boat dock concentration.

This histogram shows the number of boats per-acre-foot in the lake.

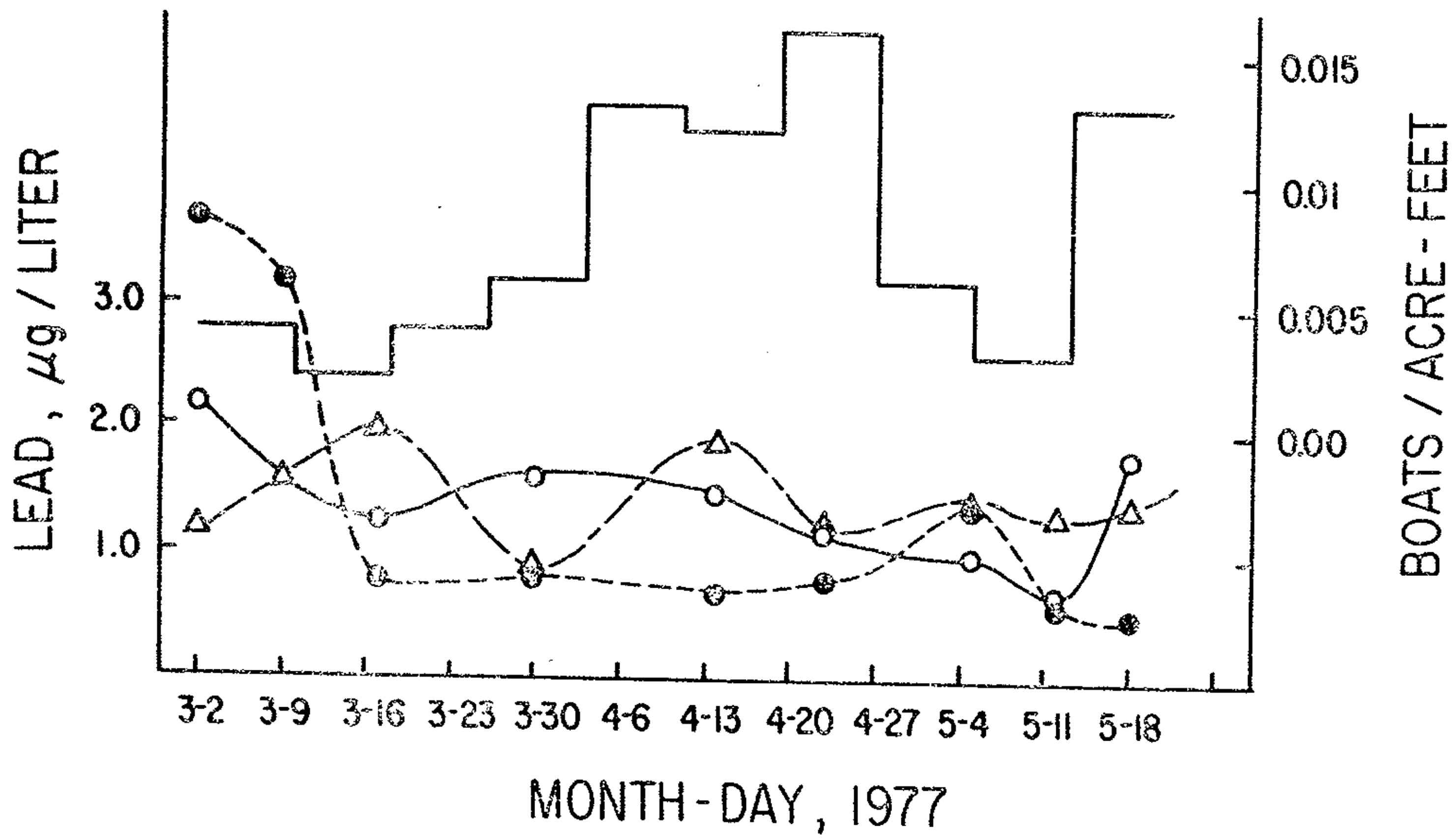


Figure 5

Lead concentrations and boats per-unit-volume during spring 1977. ○, outlet concentration; ●, inlet concentration; △, boat dock concentration. The histogram shows the number of boats per-acre-foot in the lake.

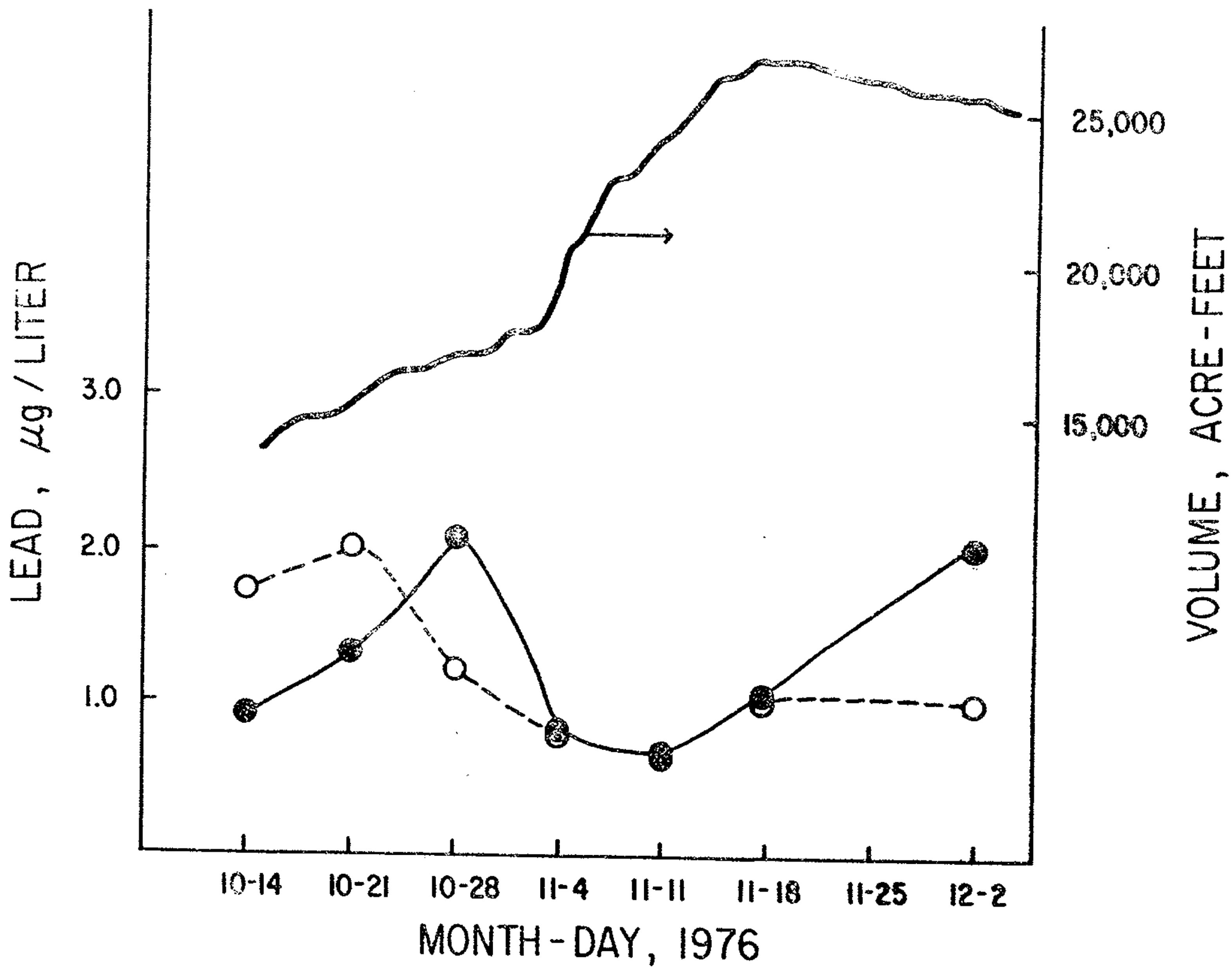


Figure 6

Lead concentrations and lake volume during fall 1976. ○, outlet concentration; ●, inlet concentration. Heavy line shows lake volume.

During this entire period, no water was released from the lake.

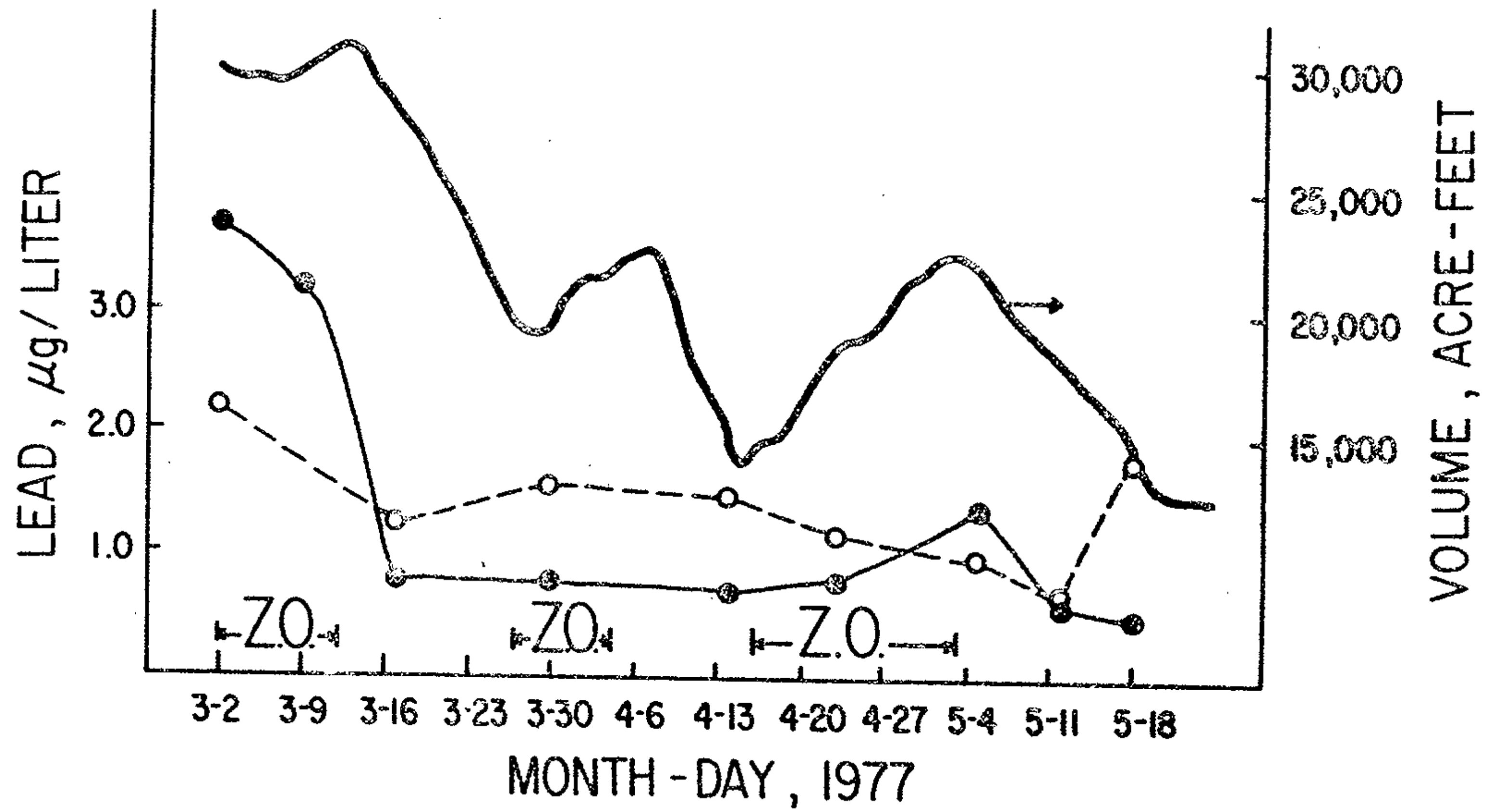


Figure 7

Lead concentrations and lake volume during spring 1977. ○, outlet concentration; ●, inlet concentration. Heavy line shows lake volume. The intervals labelled "Z.O." are periods of zero outflow from the lake.

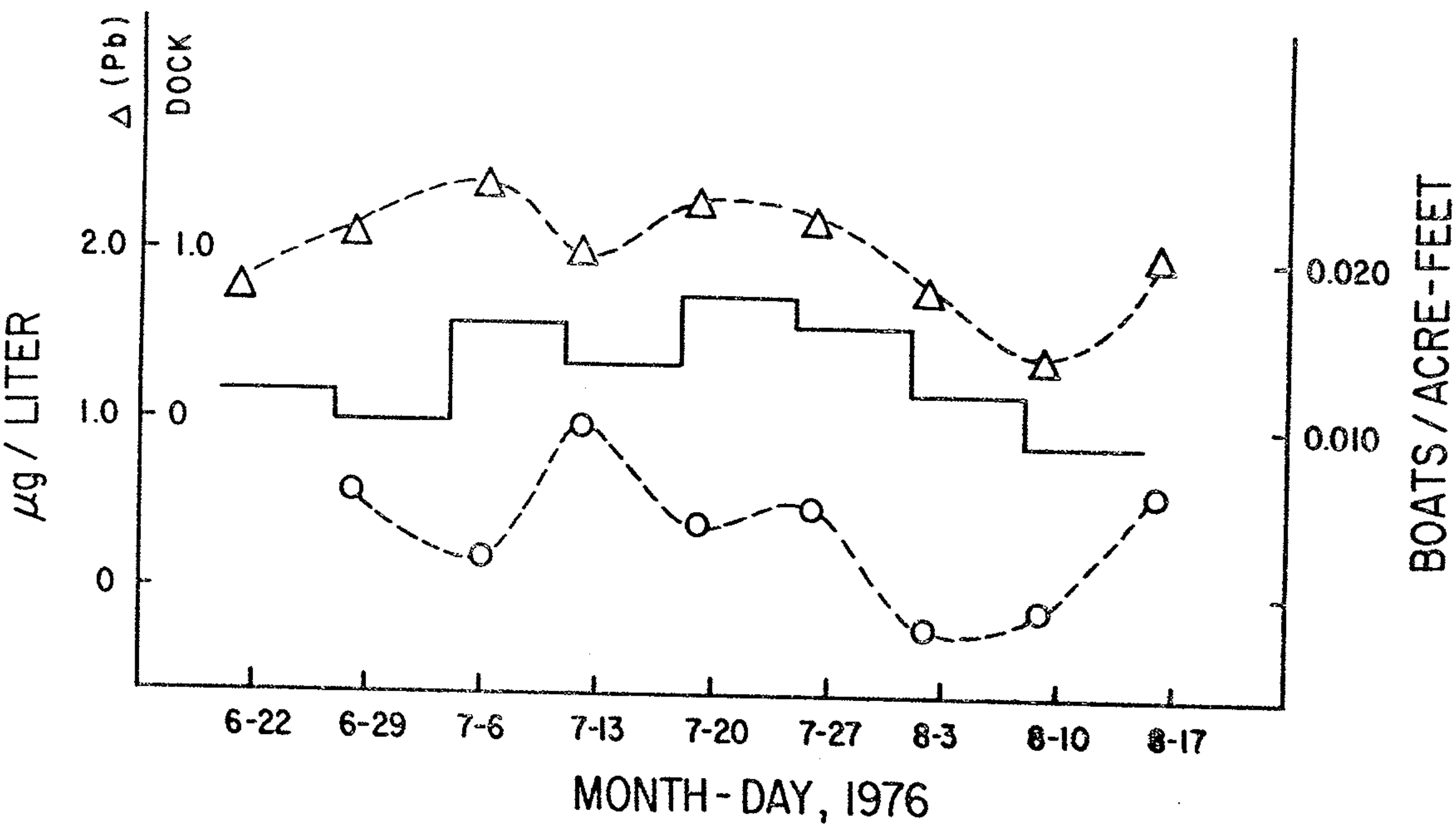


Figure 8

A comparison of Δ(Pb) and the lead concentration at the boat dock with the number of boats per-unit-volume during summer 1976. △, boat dock lead concentration; ○, Δ(Pb) values from plug-flow model. The histogram shows the number of boats per-unit-volume.

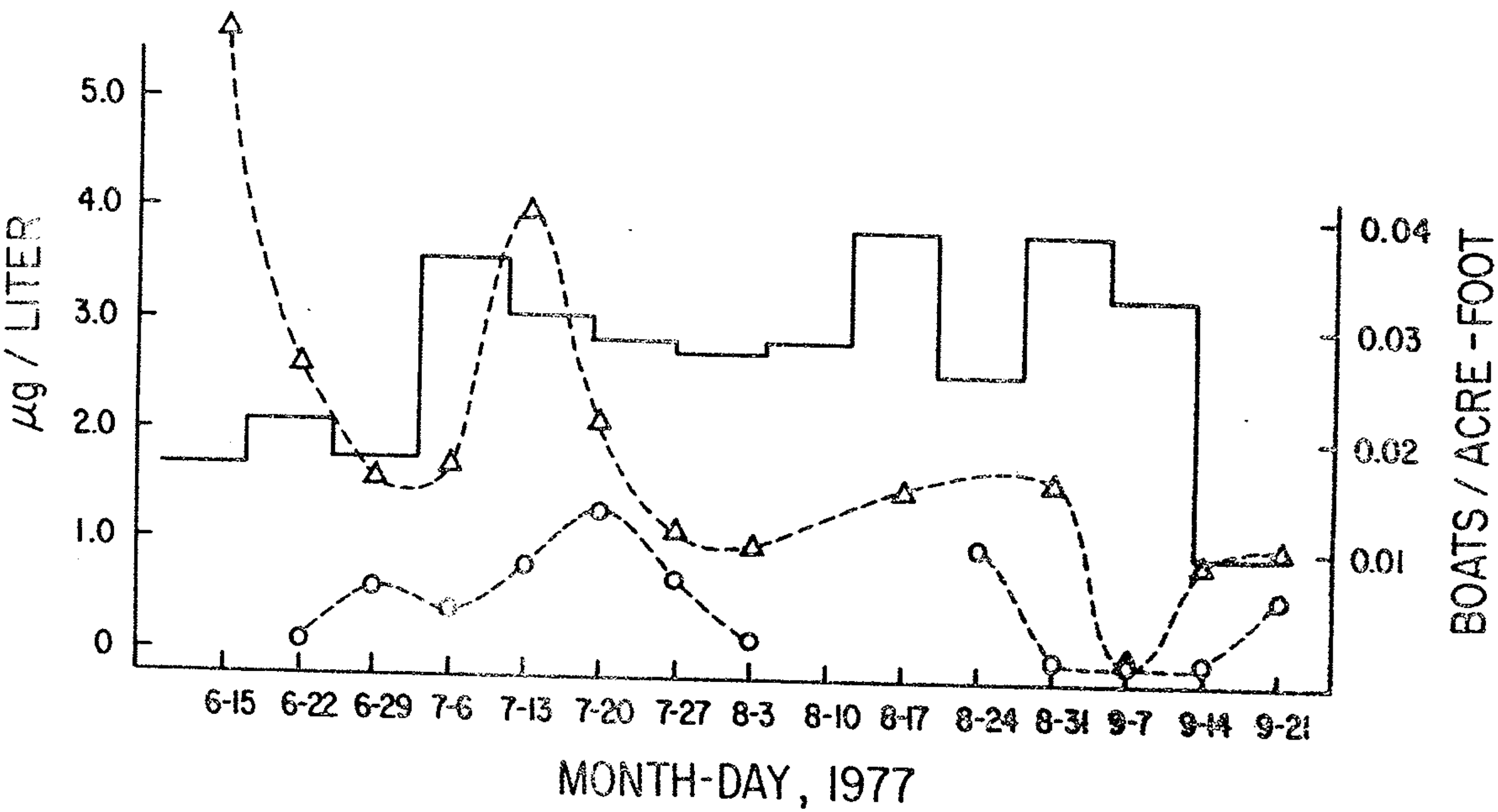


Figure 9

A comparison of Δ(Pb) and the lead concentration at the boat dock with the number of boats per-unit-volume during summer 1977. △, boat dock lead concentration; ○, Δ(Pb) values from plug-flow model. The histogram shows the number of boats per-unit-volume.

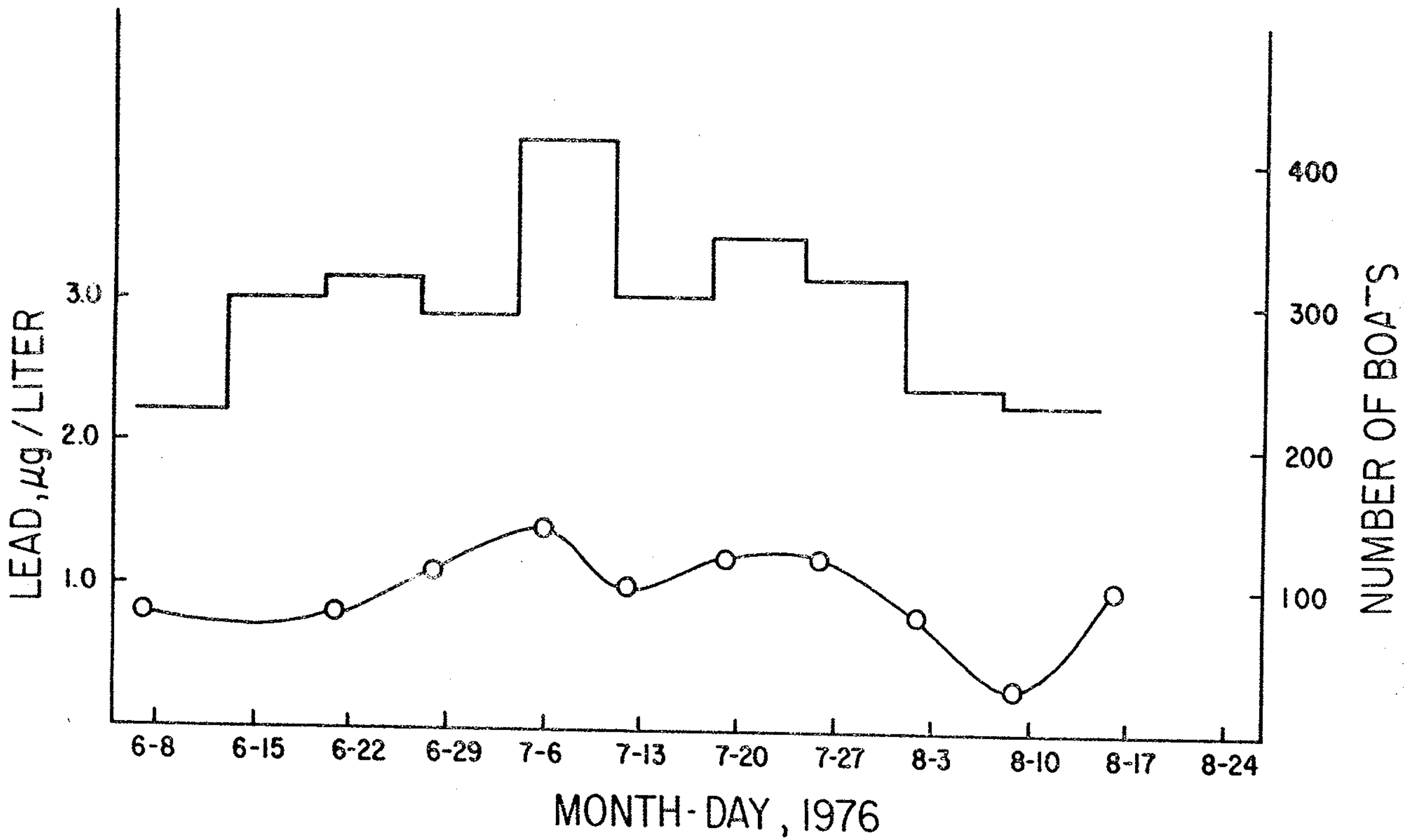


Figure 10

A comparison of the lead concentration at the boat dock, (circles), and the total number of boats launched, (histogram), during summer 1976.

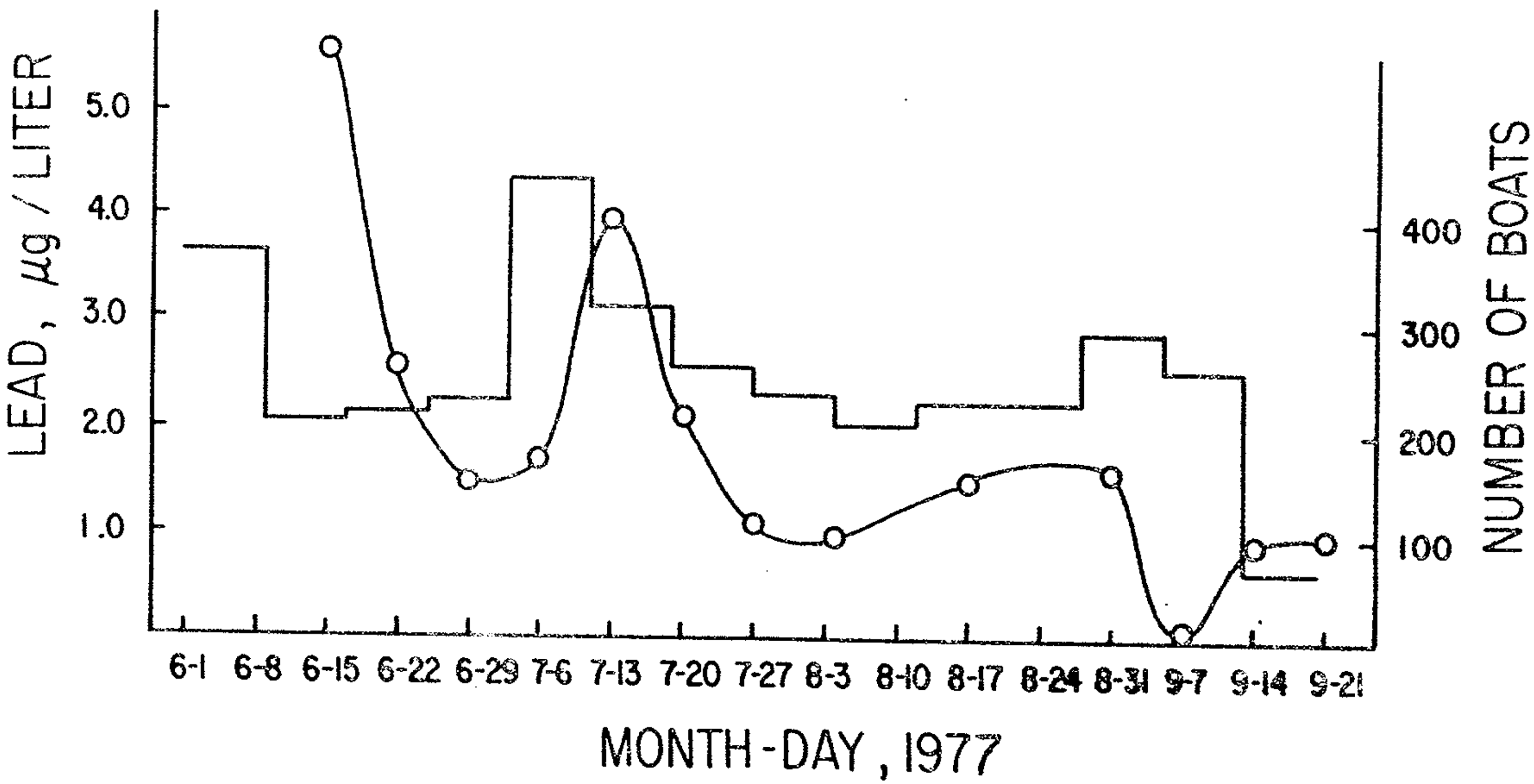


Figure 11

A comparison of the lead concentration at the boat dock, (circles), and the total number of boats launched, (histogram), during the summer 1977.

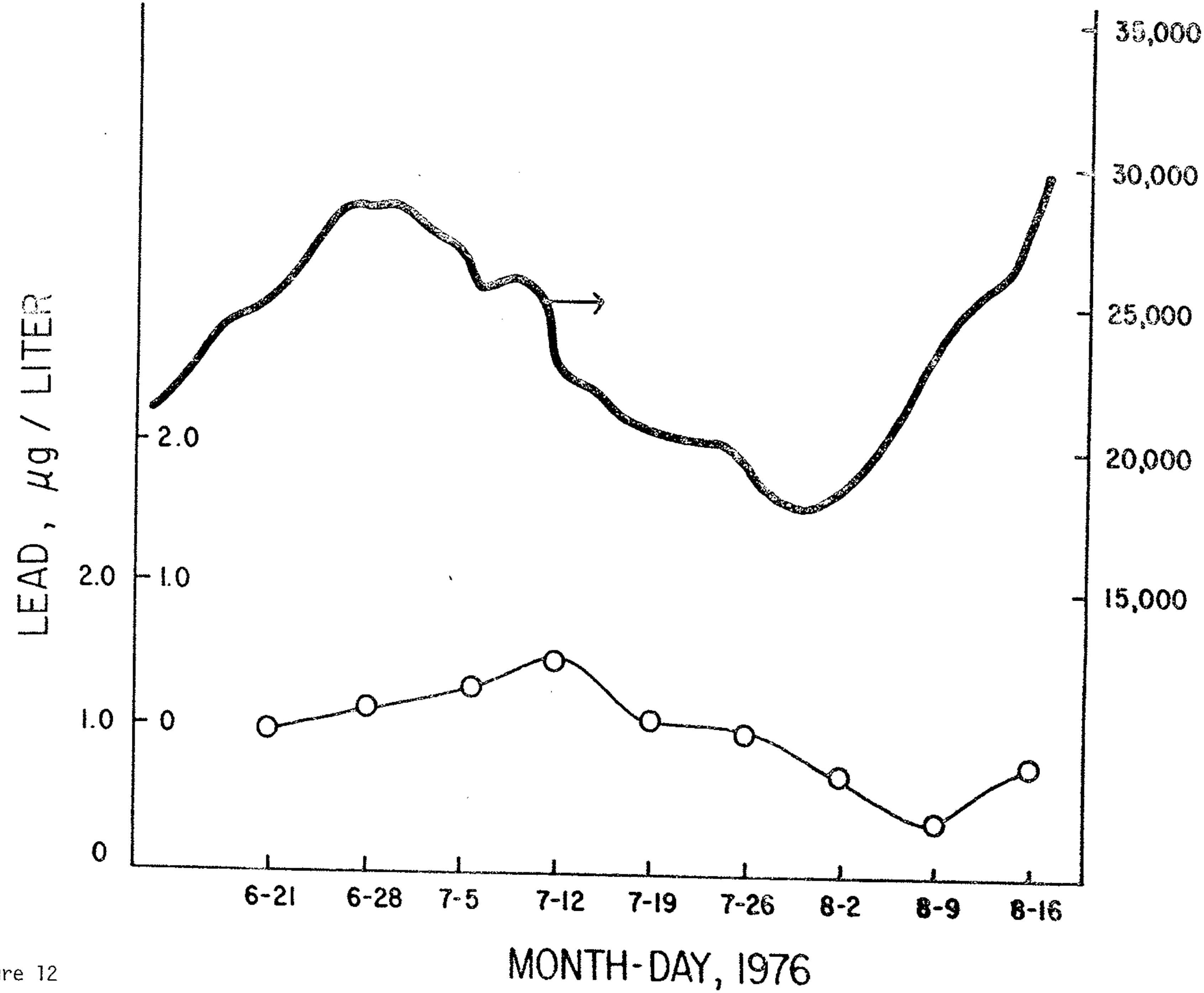


Figure 12

A comparison of the outlet lead concentration, (circles), and the lake volume (heavy line) during summer 1976. A correlation exists, although

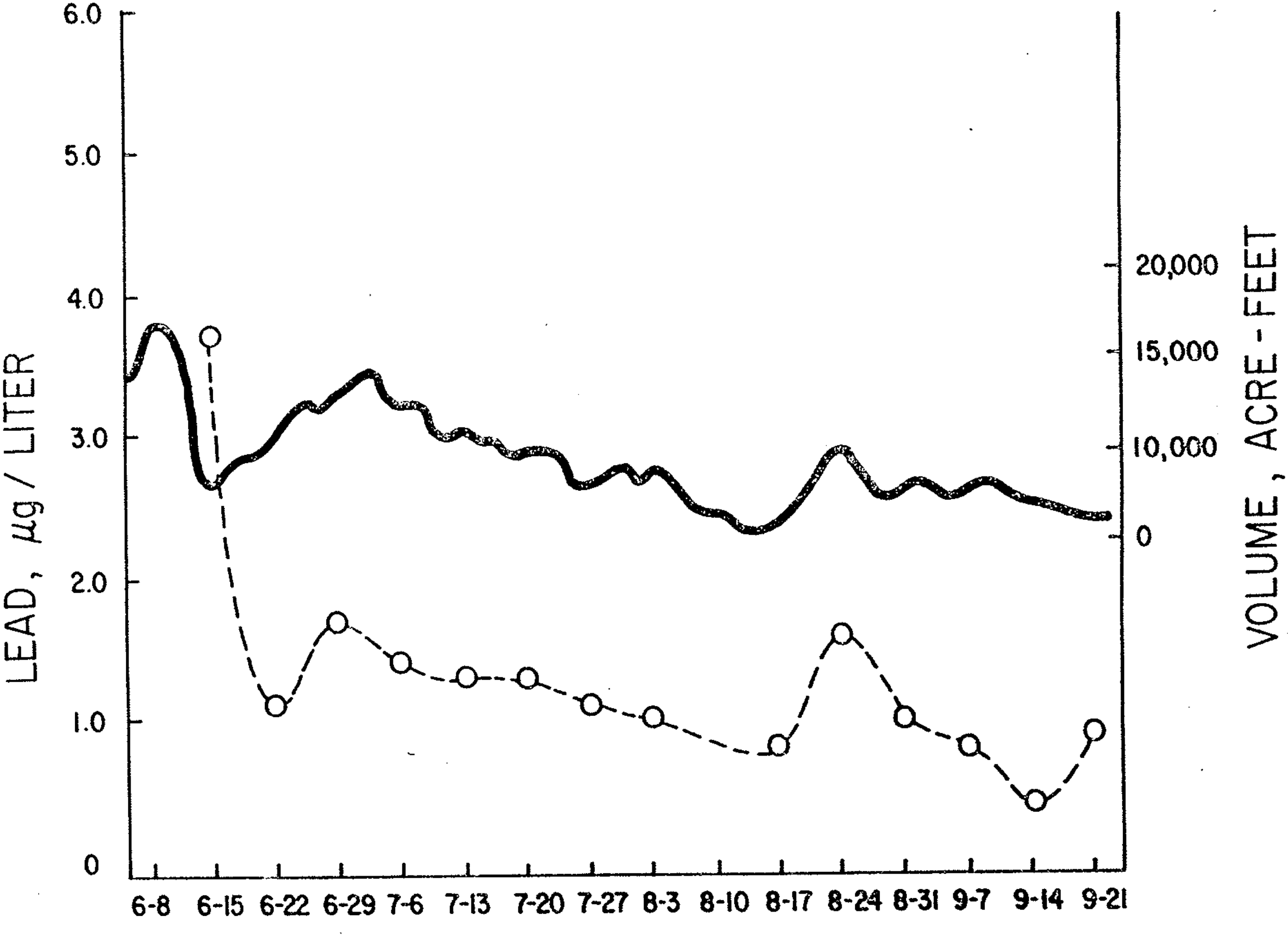


Figure 13

A comparison of the outlet lead concentration, (circles), and the lake volume, (heavy line), during summer 1977.