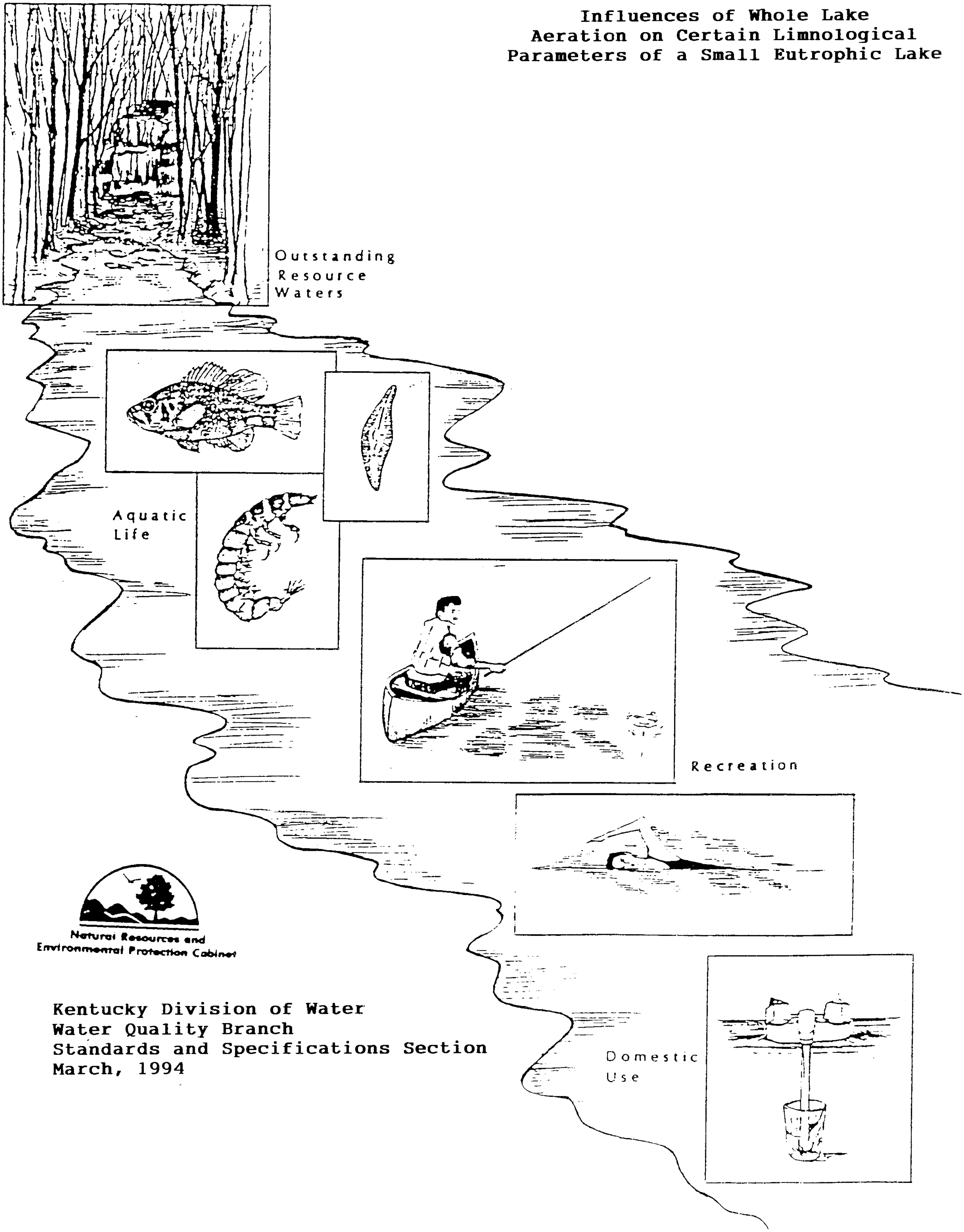
Influences of Whole Lake Aeration on Certain Limnological Parameters of a Small Eutrophic Lake



Natural Resources and
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Kentucky Division of Water
Water Quality Branch
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Kentucky Department for Environmental Protection
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Introduction

In November 1990, the Division of Fisheries of the Kentucky Department of Fish and Wildlife Resources (KDFWR) contacted the Kentucky Division of Water (KDOW) to request assistance in monitoring its Lower Game Farm Lake to determine the practical usage and benefits of artificial destratification and aeration. The problems that were occurring prior to aeration were clinograde dissolved oxygen profiles (concentrations which slope from high levels in the epilimnion to low levels in the hypolimnion), low reproductive rate of largemouth bass, and problematic growths of aquatic vascular plants and filamentous algae.

The KDFWR Division of Fisheries had several objectives to accomplish by the physical disruption of the water column. These objectives were to destratify the water column during the summer months, improve quality and quantity of benthic macroinvertebrates, establish a beneficial plankton bloom, recycle nutrients from the bottom sediments, increase fish growth, and reduce the aquatic vascular plant and filamentous algae problems.

A variety of lake restoration techniques have been utilized to reverse the process of eutrophication. These techniques limit fertility and sedimentation or attempt to control the consequences of premature aging of a lake. Some of the lake restoration techniques that have been used are: 1) curbing nutrient influx; 2) accelerating in-lake nutrient outflow and/or preventing the recycling of these nutrients; 3) manipulating lake habitats using management techniques such as chemical controls, aeration, dredging, and sediment consolidation (Dunst et al., 1974).

Lake aeration is typically used to eliminate thermal stratification and density barriers by increasing circulation within the lake. This movement oxygenates the bottom waters and leads to general increases in the rates of decomposition of bottom sediments and organic material in the water column. The increase in dissolved oxygen and the subsequent changes in the redox reactions involving metals such as iron, manganese, and aluminum affect the availability of nitrogen and phosphorus by regulating release from the sediments (Cowell et al.,1987). Oxygenation reduces phosphorus release and prevents the build up of ammonia in bottom waters.

Cowell et al. (1987) studied the effects of a multiple inversion aeration system upon the limnology of a small sinkhole lake in Florida. It was successful in eliminating many of the undesirable effects of eutrophication (e.g. oxygen depletion, blue-green algal blooms, and low benthic diversity) but did not change the trophic state. Wielgosz (1983) studied artificial destratification and its effects on zoobenthos and trophic state in a Polish reservoir. Before aeration, Chaoborus flavicans was the dominant species. After aeration and destratification, C. flavicans decreased in numbers rapidly while chironomidae and oligochaeta appeared in the open water zone. An increase in the densities of the chironomids, Chironomus plumosus and C. thummi, was also observed. The trophic status of the lake shifted biologically from polytrophic (Chaoborus sp. dominated) to eutrophic (Chaoborus-mesoplumosus type) as defined by Gizinski (1967). Steinberg (1983) found that artificial destratification of a small polytrophic and meromictic lake in Germany almost doubled the viable biomass of algae (expressed as chlorophyll-a) in the water column. This increase was not paralleled by an increase in primary production because of the self-shading effect of the algae. Light, therefore, became the limiting factor in both the destratified and the stratified lake. Destratification of this lake resulted in a permanent decrease in cyanophytes caused probably by elevated concentrations of several reduced chemical compounds (oxides of methane and bivalent iron and manganese). The reduced compounds were caused by the destruction of the monimolimnion (layer of water that does not normally destratify because of chemical composition) during aeration of the lake. The cyanophytes were replaced by various species of coccal and tetrasporal chlorophytes, centric diatoms, and small cryptophytes. Weiss et al. (1973) destratified a water supply impoundment in

North Carolina. Effectiveness of the destratification was distinctly evident in temperature distribution in the epilimnion and hypolimnion. Both areas exhibited approximately the same temperatures in all seasons during destratification. On the average when the lake was stratified, the hypolimnion was 10 degrees cooler than the surface water, whereas in the two subsequent years of destratification the temperature was only 1-2 degrees cooler at the bottom than the surface. Striking changes in numbers and population characteristics of the phytoplanktonic organisms were clearly evident. Benthic forms also shifted from species tolerant of micro-aerophyllic conditions to species that required higher levels of oxygen. Also, a more even distribution of organic material occurred as the lake became more homogeneous. The total period of observation was too short to establish clear changes in characteristics of fish populations, but it was evident that fishing efforts (based on the time it took to catch a fish) decreased and the number of fish caught per man hour increased because fish were attracted to the air bubbles.

Description of the Study Area

The Lower Game Farm Lake is located in Franklin County approximately one mile west of Frankfort, Kentucky. It is located on the same property on which the offices of Kentucky Department of Fish and Wildlife Resources are located. A map is provided (Figure 8) showing study area and sampling site. The Lower Game Farm Lake was constructed in 1951 and was opened to public fishing in 1952. It has a total of three surface acres with a mean depth of 5 feet. The maximum depth of the lake is 10 feet near the dam. The only inflows that the lake receives are the outflow from the Upper Game Farm Lake and rainfall runoff.

Methods

Approximate biweekly sampling was conducted from April 22, 1991 through September 27, 1991 to determine pre-aeration conditions. Biweekly sampling was conducted from April 30, 1992 through October 6, 1992 to monitor changes that were occurring during aeration.

Physical-Chemical Parameters

On each sampling date, the maximum depth was established by using a D & D Electronics FR-300 Dive Ray hand held depth finder. Euphotic zone depth was determined by using a Protomatic photometer. Subsurface ambient light was measured in foot candles and the probe was lowered to where 1% of the ambient light remained. The euphotic zone measurement was used to collect composite samples for chlorophyll-a analysis. The composite sample was collected by using a 3-liter non-metallic Kemmerer water sampler. Vertical profiles for dissolved oxygen, pH, conductivity, and temperature were measured at the surface and one-meter intervals to the bottom by using a Hydrolab Surveyor II field meter. Secchi depth was measured by establishing the point of disappearance of an 8-inch diameter alternating black and white painted metallic disk.

Chlorophyll-a

Chlorophyll-a determinations were made by using standardized procedures listed in Standard Methods for the Examination of Water and Wastewater 18th edition (1993). The collected composite sample was mixed by agitation, and a 50- or 100-milliliter aliquot was removed from the composite sample by a volumetric pipette. The aliquot was then vacuum filtered through a Whatman GF/C glass fiber filter on site. Duplicate samples were filtered for purposes of quality assurance. Both filters were placed in a black 35 mm film vial separated by aluminum foil to prevent the filters from sticking together when frozen. The vial was then placed in a whirlpack bag to prevent ice meltwater from entering the sample. The chlorophyll-a samples were then transported on ice to the KDOW biological laboratory in Frankfort and frozen until analyzed.

When ready for analyses, the filters were thawed and thoroughly ground in 90% acetone. The supernatant and ground glass-fiber filter were then transferred to a 15-milliliter calibrated Nalgene centrifuge tube and diluted to 10 milliliters with 90% acetone. The Nalgene tube was then capped and refrigerated for a period of approximately 24 hours to allow a complete extraction of chlorophyll pigments from the glass-fiber filter. The tubes were then centrifuged at 675 g for 20 minutes to clarify the solution. Following the centrifuging of the vials, an aliquot of the supernatant was transferred to a glass cuvette. The fluorescence was then measured before and after acidification with 2N hydrochloric acid by a Turner Designs Model 10 fluorometer.

Trophic Status

Trophic state indices (TSI's) were calculated using Carlson's method (1977). The procedure uses three separate univariate indices of trophic state (Secchi disk, chlorophyll-a, and phosphorus). The two parameters used in the calculations were Secchi disk and chlorophyll-a.

Statistical Analyses

A statistical analysis of selected data was computed by using a standardized unpaired two-tailed Wilcoxon Rank Sum Test (Mann-Whitney Median Analysis Test). This technique was used to determine if the values for chlorophyll-a, Secchi depth, and euphotic zone depth differed significantly between the pre-aeration and aeration periods. The confidence level interval was 95% ($p < .05$) for all analyses. A Student-Neuman Kuels' test was used for comparisons of the annual means of conductivity and pH for pre-aeration (1991) and aeration (1992) periods. A nonparametric t-test was used also for dissolved oxygen and temperature for comparison purposes.

Results

Vertical Physical-Chemical Parameter Profiles

During the 1991 pre-aeration sampling period, temperature and dissolved oxygen profiles (Figures 4 and 5) followed normal stratification patterns that are characteristic of eutrophic lakes. Temperature differences between the epilimnion and the hypolimnion (Figure 4) ranged from 0.5°C in May and late September to between 5° and 7°C during stratification. Dissolved oxygen concentrations exhibited clinograde vertical profiles. Saturation usually exceeded 90% in the epilimnion, but the hypolimnion exhibited concentrations of dissolved oxygen less than 0.7 mg/l during this pre-aeration period. Anoxic hypolimnetic conditions continued throughout the growing season until water temperatures became isothermic and disrupted the vertical stratification. This allowed subsequent reoxygenation of the hypolimnion by wind mixing. In concert with the dissolved oxygen, the pH values (Figure 6) showed stratification profiles that are characteristic of a eutrophic condition. Epilimnetic pH was normally above 7.8 while hypolimnetic pH values dropped below 7.0 in 1991. The mean value for pH in 1991 was 7.2, with an epilimnetic maximum of 8.3 in June and a hypolimnetic minimum of 6.6 in July and August. Conductivity showed characteristic profiles of a eutrophic lake (Figure 7). Epilimnetic conductivities were approximately 200 uS/cm less than the hypolimnetic readings under stratified conditions. The conductivity mean value for 1991 was 273 uS/cm, with a hypolimnetic maximum of 483 uS/cm in July and an epilimnetic minimum value of 190 uS/cm also in July.

Aeration of the Lower Game Farm Lake began in April and continued until October, 1992. During this period, there were no differences in the vertical profiles for any of the physical-chemical parameters (Figures 4, 5, 6, and 7). The dissolved oxygen profile in the first week of September showed a minor clinograde stratification when the aeration system malfunctioned. When the malfunction was corrected by KDFWR personnel, the hypolimnetic dissolved oxygen increased to previous levels. The mean value for pH in 1992 was 7.8, with a maximum of 8.6 in May and June and a minimum of 7.0 in June. The conductivity mean value for 1992 was 261 uS/cm with a maximum of 293 uS/cm in October and a minimum of 227 uS/cm in May.

Influence of Aeration on Physical-Chemical Parameters

Maximums, minimums, and means are presented in Table 1 to show the data for all physical-chemical parameters for both 1991 and 1992. Aeration produced extreme changes in only two of these parameters. Dissolved oxygen and pH both increased significantly ($p < .0001$) in 1992. Other parameters that were measured were not significantly affected by aeration when the differences in water column means were compared ($p > .05$). However, bottom temperatures and conductivities, when compared to the surface, showed significant differences between years because of the effect of destratification which allowed total mixing of the lake in 1992.

Aeration, other than breaking up thermal stratification, had a minimal effect on seasonal temperature patterns. The maximum daily temperature for 1991 was 30.4°C and for 1992 was 27.8°C. Minimum daily values were 14.4°C in 1991 and 16.5°C in 1992. The growing season means for both 1991 and 1992 were 22.9°C and 23.0°C, respectively. Figure 4 shows the temperature ranges for the surface and bottom waters in 1991 and 1992.

Aeration produced a marked influence on the dissolved oxygen concentration (Figure 5). During the 1991 pre-aeration sampling period, daily surface concentrations ranged from 10.2 to 4.1 mg/l. Daily concentrations associated with the hypolimnion were low and ranged from 3.6 to 0.1 mg/l during the period of thermal stratification. Differences in the dissolved oxygen concentrations between the surface and the bottom decreased significantly commensurate with the start-up of aeration in 1992. The concentrations at both depths were equivalent throughout the aeration period with the exception of the period of equipment malfunction (Figure 5, Sampling Period 8). The mean concentrations for 1991 and 1992 were 3.8 and 6.7 mg/l, respectively.

The pH values of the Lower Game Farm Lake exhibited a significant increase following the start-up of the aeration system (Table 6). During the pre-aeration year (1991), daily maximums for the surface ranged from 7.0 to 8.3 with daily minimums at the bottom from 6.6 to 7.1. During aeration, daily maximums ranged from 6.9 to 8.6 at the surface and from 7.0 to 8.6 at the bottom. The seasonal mean pH increased significantly ($p < .0001$) from a pre-aeration (1991) value of 7.2 to a value of 7.8 for 1992 (aeration period).

Aeration produced a small but insignificant increase ($p > .05$) in Secchi disk transparency (Figure 3). Mean transparency was 3.0 feet in 1991 and 3.5 feet in 1992.

Conductivity in Lower Game Farm Lake in 1991 ranged from a daily maximum of 483 uS/cm to a daily minimum of 190 uS/cm (Table 1). In 1992, conductivity values ranged from a daily maximum of 293 uS/cm to a daily minimum of 227 uS/cm. The seasonal means for 1991 and 1992 were 274 and 281 uS/cm, respectively, and were not significantly different ($p > .05$). Elevated conductivities occurred in the hypolimnion in 1991 during stratification. Conductivities were lower in 1992 and not elevated compared to the epilimnion.

Influence of Aeration on Phytoplankton

There were no significant differences (p >.05) in the means of chlorophyll-a concentrations between 1991 and 1992 (Figure 1). Although no significance was determined, aeration appeared to reduce the frequency of chlorophyll-a peaks greater than 60 ug/l. There were two such peaks for the sampling periods in 1991 and none occurred in 1992. The maximum peak value for chlorophyll-a was reduced from 71.0 ug/l in 1991 to 44.7 ug/l in 1992. The means for chlorophyll-a for 1991 and 1992 were 31.0 ug/l and 22.8 ug/l, respectively.

Trophic State Index

The seasonal mean was used to calculate the univariate indices of trophic state. Chlorophyll-a concentrations and Secchi disk depths were applied to determine and compare trophic state indices (TSI). Aeration was shown to have little effect on the average TSI values. Values for 1991 and 1992 were 60 and 58, respectively, using the chlorophyll-a formula. Secchi disk values were also used as a check to compliment the chlorophyll-a values in determining the TSI. TSI values using Secchi depths were 57 in 1991 and 61 in 1992. There were no significant differences (p >.05) for either chlorophyll-a or Secchi disk TSI values for 1991 and 1992. The TSI values indicated that the Lower Game Farm was eutrophic in both 1991 and 1992 and that aeration had no effect on trophic status.

Conclusions

The aeration system employed by KDFWR for the Lower Game Farm Lake successfully eliminated hypolimnetic oxygen depletion, which was one of the most undesirable features of eutrophication in the lake. Aeration also appeared to eliminate the frequency of chlorophyll-a peaks greater than 60 ug/l (hyper-eutrophication).

By increasing the dissolved oxygen throughout the water column, the useable habitat available for fish increased from approximately a 3-foot depth below the surface to the complete volume of the lake. This increase in useable habitat may or may not be beneficial to growth of larval fish since the refuge areas for zooplankton to evade predation (where lower dissolved oxygen occurs) are also decreased. A study by Wright and Shapiro (1990) stated that decreasing thickness of refuge areas for large-bodied cladocerans correlated well with the declines in the populations of these organisms. The loss in refuge availability increases competition because of other zooplanktivorous fish and reduces the amount of available food sources for larval and juvenile fish. This reduction in populations of large-bodied cladocerans caused by the reduction of the refuge areas may be compensated for by an increase in benthic macroinvertebrates caused by the increase in dissolved oxygen throughout the water column. Various authors have substantiated that by increasing the dissolved oxygen, a similar increase in more desirable benthic organisms will occur (Cowell et al. 1987, Weiss and Breedlove 1973).

Three parameters (dissolved oxygen, pH and bottom conductivity) showed significant changes from 1991 to 1992. Further changes may occur if aeration is continued. Cowell et al. (1987) and Weiss and Breedlove (1973) stated that for a lake to exhibit desirable changes in other chemical characteristics and trophic state, aeration may be necessary for several years.

Table 1: Maximum, Minimum and Mean Values for All Collected Parameters for Lower Game Farm Lake

	1991			1992		
	MAX	**MIN**	**MEAN**	**MAX**	**MIN**	**MEAN**
Temperature (°C)	30.4	14.4	22.9	27.8	16.5	23.0
Conductivity (uS/cm)	483	190	274	293	227	261
Dissolved Oxygen (mg/l)	10.2	0.1	3.8	11.8	4.3	6.7
pH (S.U.)	8.3	6.6	7.2	8.6	6.9	7.8
Euphotic zone (meters)	2.6	1.4	2.0	2.9	1.2	2.3
Secchi Disk (feet)	6.0	1.2	3.0	6.6	2.2	3.5
Chlorophyll-a (ug/l)	71.0	5.1	31.0	44.7	2.4	22.8
*TSI (chlorophyll-a)	72	47	61	68	39	58
*TSI (Secchi disk)	69	46	57	69	54	61

* 0 - 40	Oligotrophic
41 - 50	Mesotrophic
51 - 100	Eutrophic

Figure 1: Chlorophyll-a Data of Lower Game Farm Lake

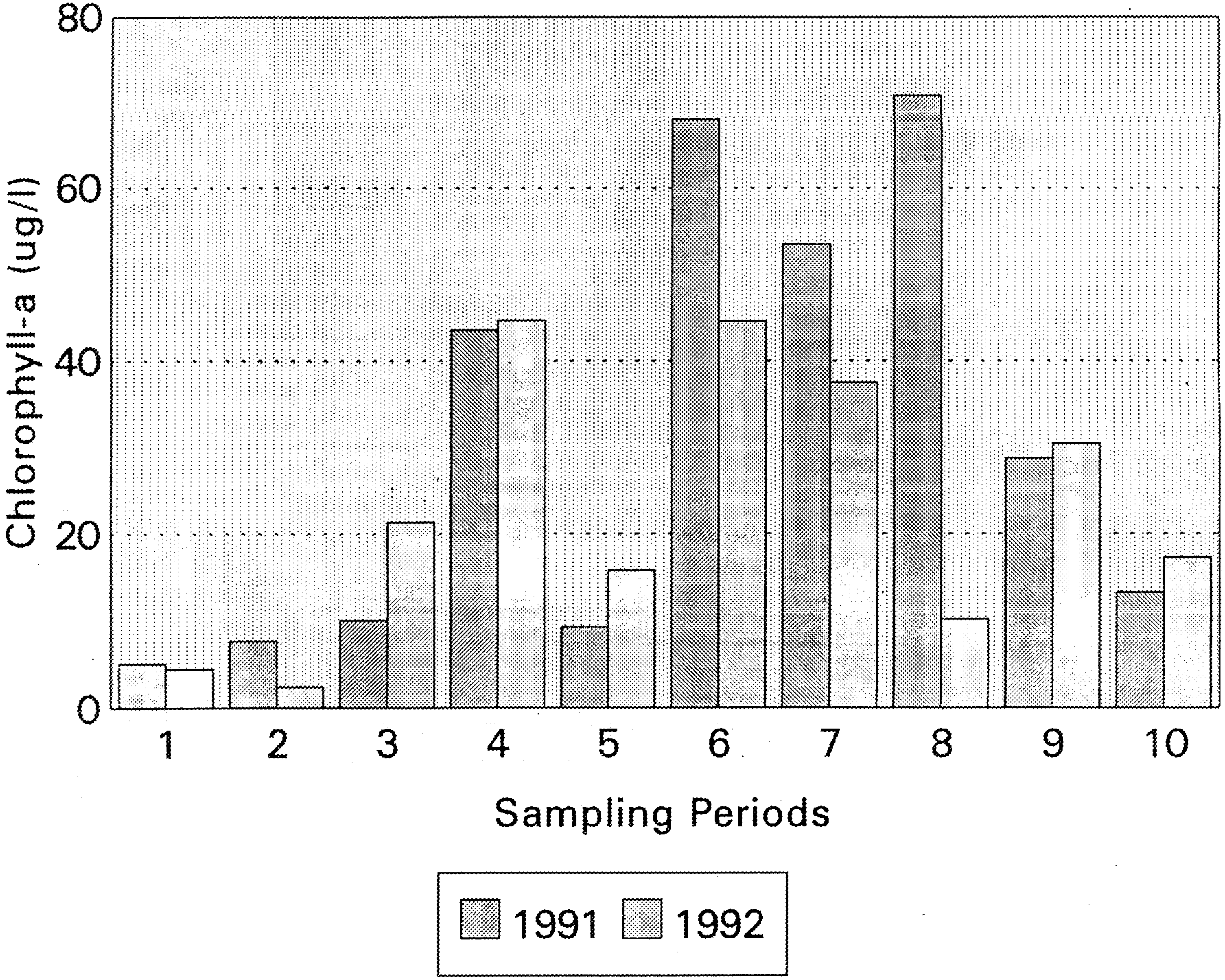


Figure 2: Euphotic Zone Depth Data of Lower Game Farm Lake

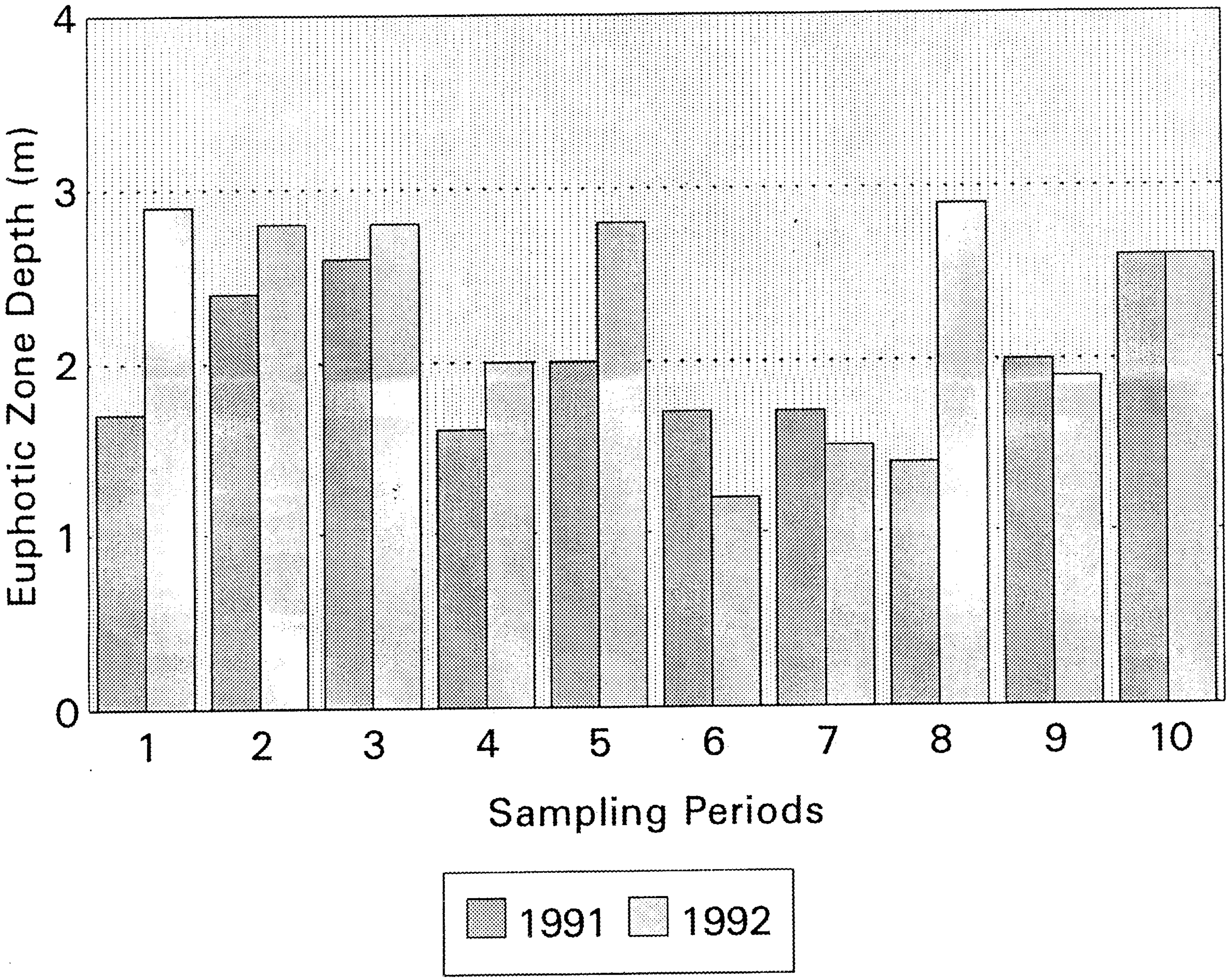


Figure 3: Secchi Depth Data of Lower Game Farm Lake

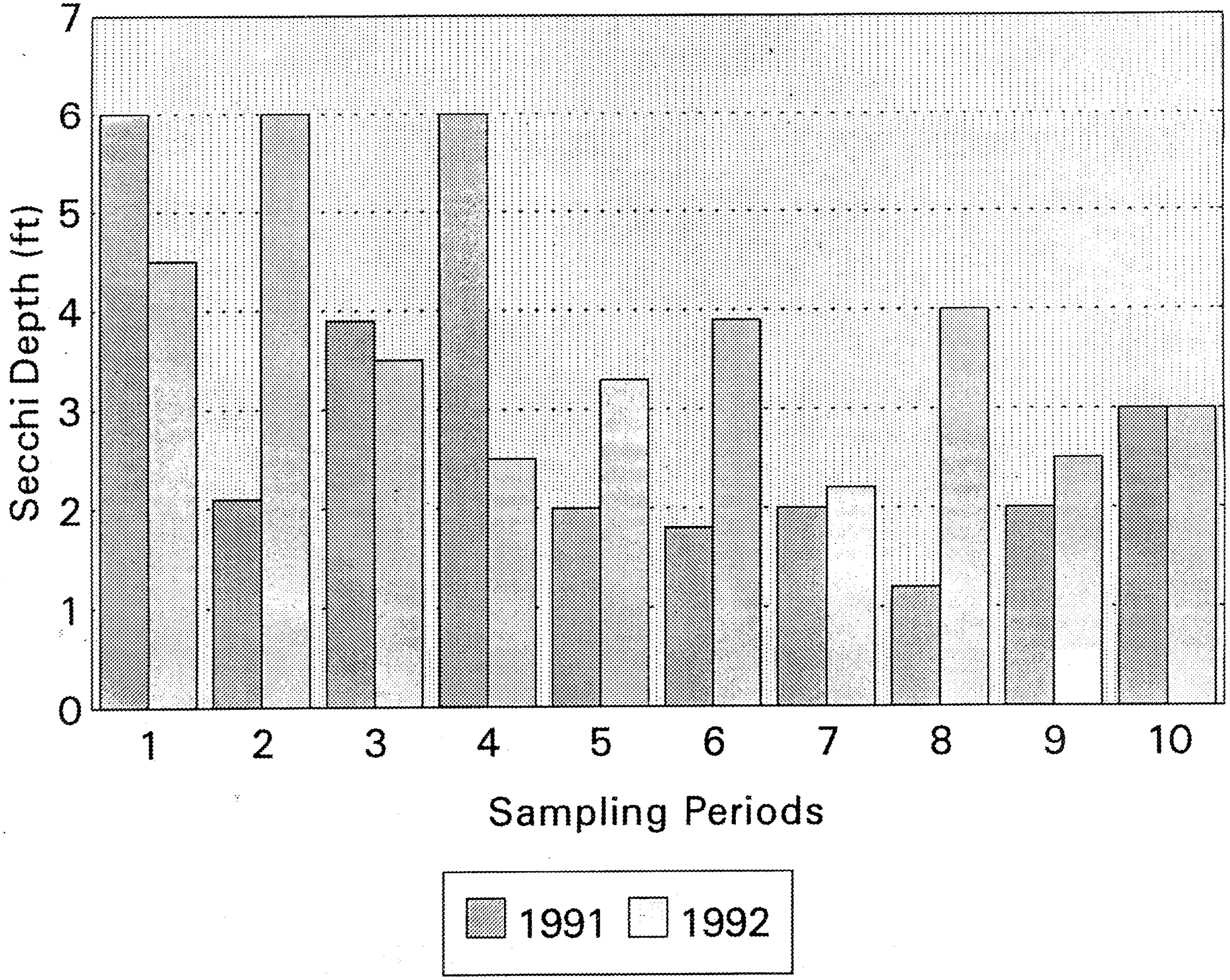


Figure 4: Temperature Profiles of Lower Game Farm Lake

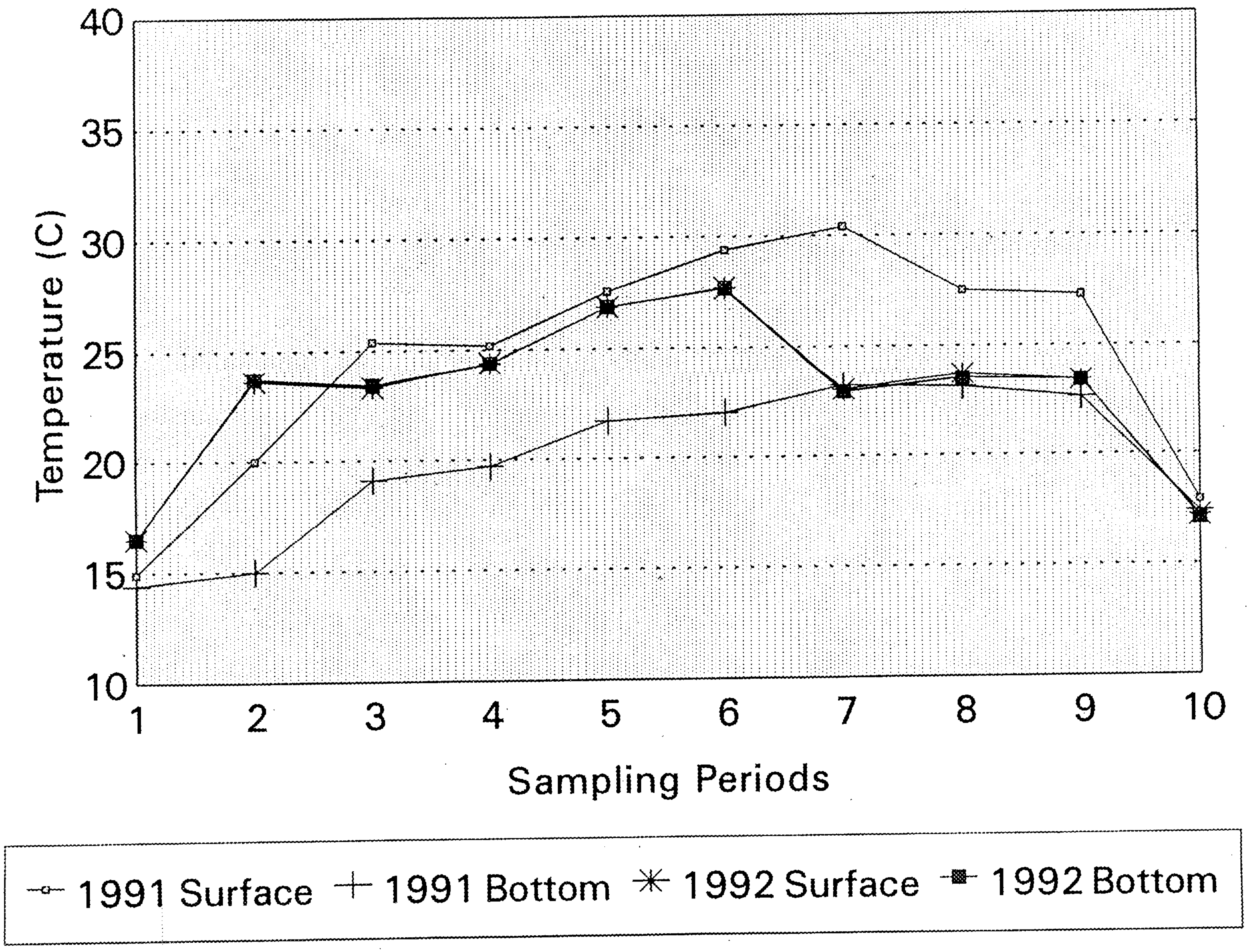


Figure 5: Dissolved Oxygen Profiles of Lower Game Farm Lake

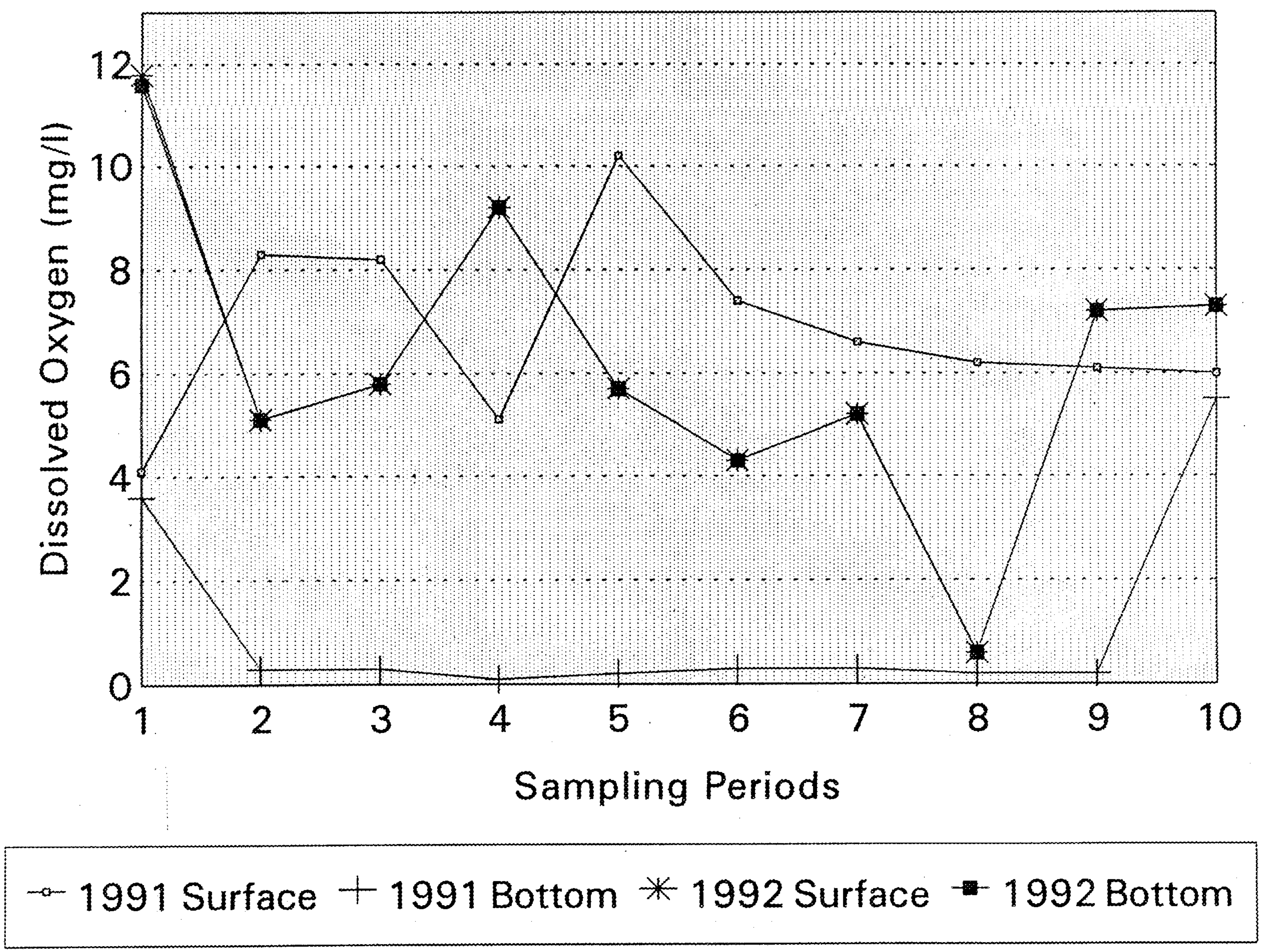


Figure 6: pH Profiles of Lower Game Farm Lake

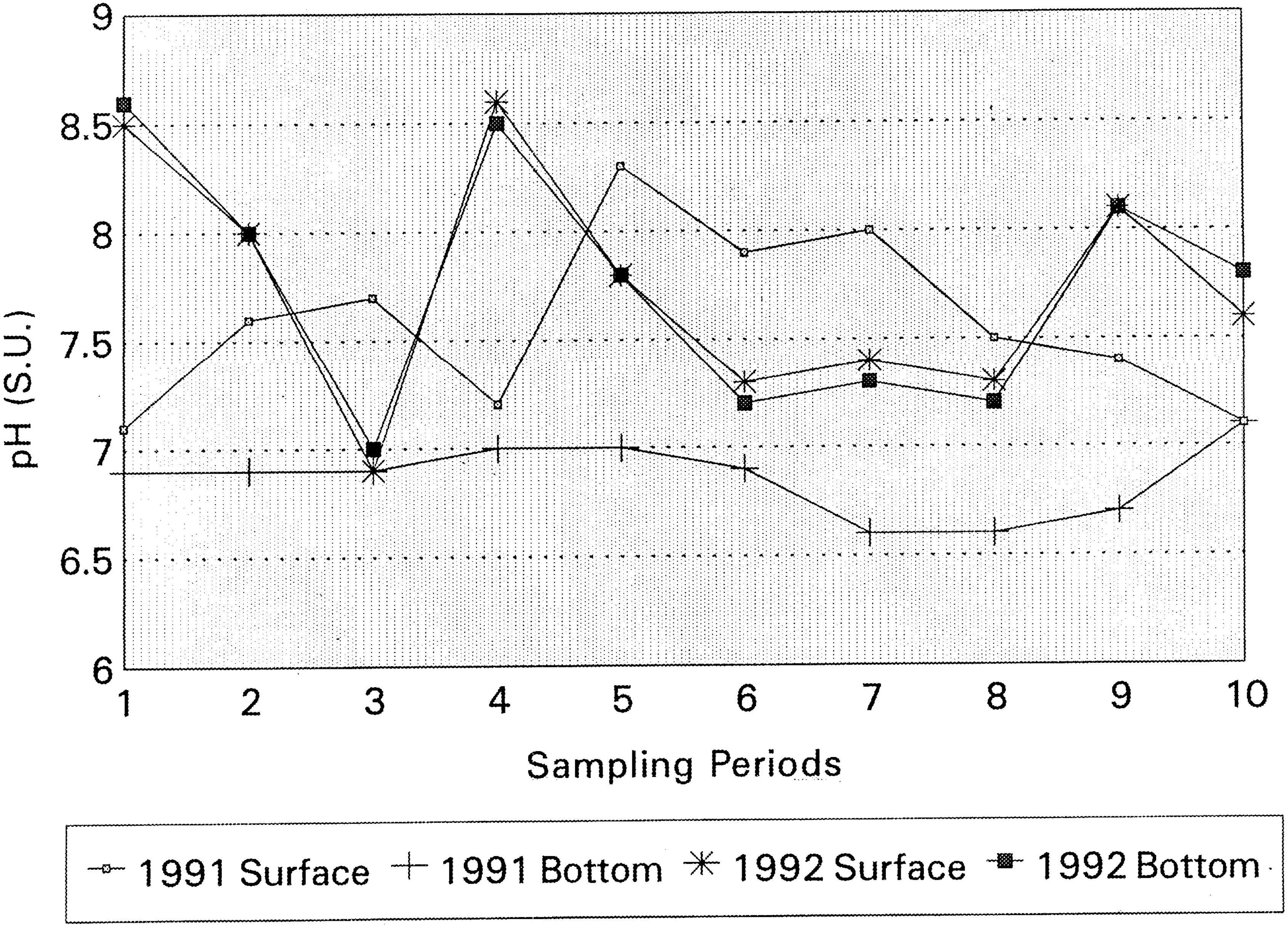


Figure 7: Conductivity Profiles of Lower Game Farm Lake

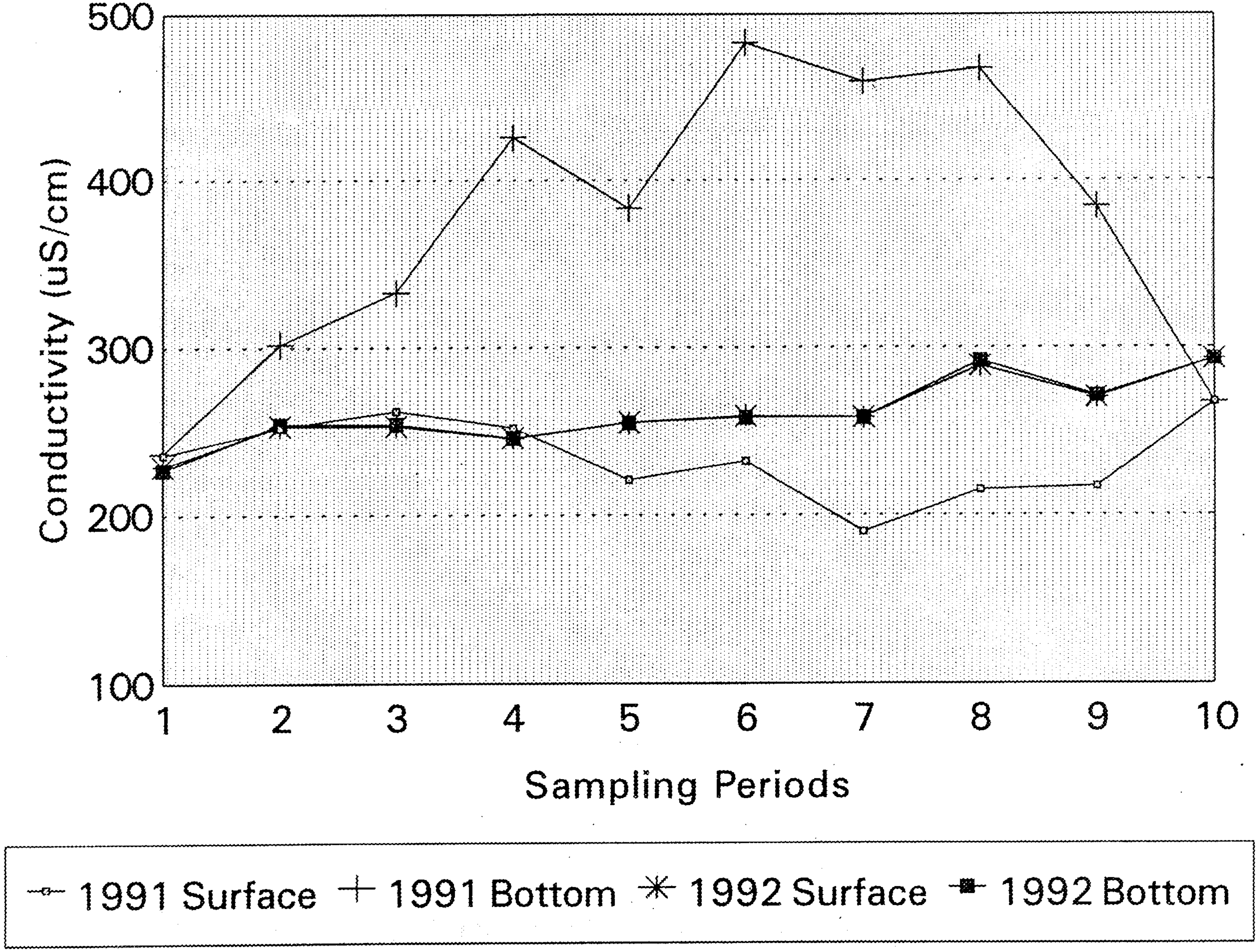
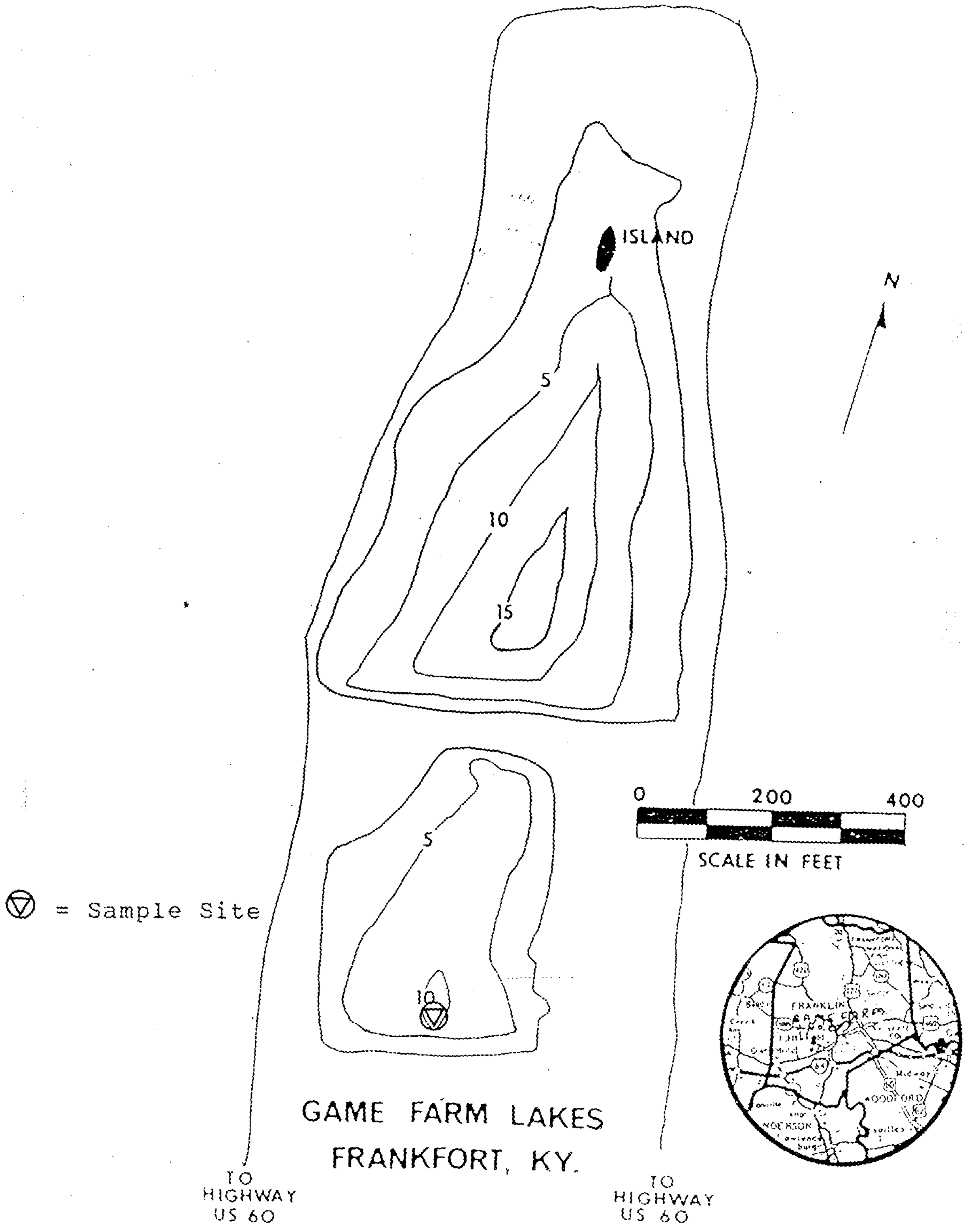


Figure 8: Map of Study Area Showing Sample Site



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