LIVING LAKES PROGRAM

FINAL REPORT

CURLEW POND

Prepared for:

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1.0 INTRODUCTION

1.1 Overview

Living Lakes, Inc. (LLI) was established in December, 1985, as a not-for-profit organization to design and implement an aquatic liming and fish restoration program for acidified waters. The basic goal of the program was to develop and demonstrate cost-effective technologies for neutralizing acidic surface waters so that restored waters once again could support valuable and important fisheries.

Although much debate has occurred in the past on the exact nature and cause of surface water acidification, the LLI Program was designed to address the restoration of acidified water regardless of the source of acidity. The program was based upon knowledge gained from aquatic liming operations in Great Britain, Norway, and Sweden, as well as liming activities in the United States.

Since its inception, LLI objectives have included the implementation of a field demonstration program designed to identify, treat and monitor a family of candidate lakes and streams impacted by acidification and the transfer of viable technologies to resource managers responsible for maintaining productive fisheries. Over the past six years, this effort has resulted in the treatment of 39 lakes and 13 streams in the northeastern, mid-atlantic and upper mid-west regions of the United States. Knowledge gained through follow-up water quality and biological monitoring was subsequently used to develop guideline criteria for determining the feasibility of surface water liming.

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As 1992 marks the end of the LLI Program, a final objective is to summarize and transfer information and experiences gained to responsible resource managers. This includes the preparation and distribution to each participating organization a history of liming activities on their lake(s), historical water quality, a summary of monitoring activities results, and a qualitative fisheries overview. This report, when accompanied by a newly released liming manual, *A Practical Guide to Managing Acidic Surface Waters and Their Fisheries* (1 copy enclosed), will provide each management agency with all information needed to mitigate the acidity in their lake(s).

Additionally, the Conservation Fund through The Freshwater Institute has agreed to disseminate LLI technical information to major conservation groups.

1.2 Purpose of Report

This report summarizes major LLI activities completed on Curlew Pond for the period July, 1986, through December, 1991. The results of these activities represent an overview of pond response to treatment with limestone materials. The principal objectives are to:

- summarize liming activities completed on the pond,
- describe the results of post-treatment water quality monitoring,
- document the results of annual qualitative fishery surveys, and
- provide summary information on major program conclusions.

These objectives are discussed in the following three sections of this report, with supplemental monitoring data provided in Appendix A. Section 2.0 presents site characterization information including a description of pond, targeted management objectives and an overview of the LLI monitoring program. Section 3.0 summarizes major field activities completed on the pond. Information presented includes a description of pond liming operations, water quality monitoring activities and fishery survey results. Finally, Section 4.0 provides a summary of program results with direct applicability to Curlew Pond.

2.0 SITE CHARACTERIZATION

2.1 Pond Description

Curlew Pond is a 17.5 ha kettle pond located in the Town of Plymouth, Plymouth County, Massachusetts. It is a highly valued community attraction with recreational amenities featuring swimming, sun bathing, fishing, and boating. The pond is administered by the Plymouth Conservation Commission with assistance from the Massachusetts Division of Fish and Wildlife.

Curlew Pond is classified as a groundwater seepage pond with surface water inflows limited to major storm events. Key physical features include a maximum depth of 10 m, mean depth of 5.5 m and volume of approximately 959,170 m^3. The combination of these factors results in an estimated hydraulic retention time of about 1.7 years. Pond outflow is limited entirely to evaporative losses and seepage into adjacent groundwaters.

Water quality at Curlew Pond has historically been good with the exception of depressed pH and elevated lead levels (19 ug/l in 1986; EPA Freshwater Chronic Criteria is 3.2 ug/l).

2.2 Management Objectives

The LLI Program established two treatment scenarios for the restoration of acidified lakes. The first, termed mitigative liming, is used to restore or renovate self-sustaining, put-and-take, or put-grow-and-take fisheries. This management strategy is used in ponds displaying a pH of $\leq$ 6.0 and an Acid Neutralizing Capacity (ANC) of $\leq$ 10 ueq/l. The second strategy, maintenance liming, is used to protect unique or important biological populations (e.g. fisheries) in mildly acidic ponds considered especially susceptible to acidification. The threshold criteria used to implement this strategy includes a pH $\leq$ 6.5 and an ANC $\leq$ 100 ueq/l.

Application of these criteria to Curlew Pond resulted in the adoption of a maintenance liming strategy for the waterbody. Selection was based on initial pH values as low as 6.08, with corresponding ANCs averaging 16 ueq/l. Implementation of the maintenance liming alternative would target pH and ANC increases to 7.0 standard units and 200 ueq/l, respectively. Water quality improvements above maintenance liming thresholds would thus ensure continued use as a self-sustaining bass fishery. This management objective was subsequently discussed with and approved by the Massachusetts Division of Fish and Wildlife.

2.3 Monitoring Program

The LLI monitoring program for Curlew Pond included two basic elements -- a periodic water quality monitoring component and an annual fishery survey. The principal objectives were to collect the information needed to establish pre-treatment baseline conditions, calculate required limestone dosages, assess post-treatment changes in water quality and qualitatively evaluate the effects of liming on resident fish communities.

All water quality monitoring was conducted at three established locations (Index Station, Station 2, Station 3; Figure 1). These locations coincided with the deepest area of each sub-basin and best typified pond-wide water quality.

Initial pre- and post-treatment monitoring included a full suite analyses for 23 water quality parameters. Thereafter, a reduced suite of 8 parameters was monitored during routine site visits. Sample collection and analysis followed rigorous LLI protocols, thus assuring high quality results. The parameters included in each analytical scenario are listed in Table 1.

Over the course of the LLI Program, Curlew Pond was monitored on numerous occasions. At a minimum, the site was sampled twice a year -- once immediately following spring ice-out, and again in late summer during peak periods of biological productivity. A third monitoring visit was completed during ice-over conditions in the winter following initial treatment (1986-1987). A final sample was collected following retreatment in the fall of 1991.

In addition to water quality monitoring, a fishery survey was conducted during each year of the program (1986 - 1990). The primary purpose of this component was to collect the data needed to qualitatively assess population changes most likely to occur in response to acidification. The main objective of the survey was to capture and release a minimum of 30 representatives of each designated target species. In Curlew Pond the designated target species included smallmouth and largemouth bass.

TABLE 1
LIVING LAKES ANALYTICAL PARAMETERS

Full Suite

pH	Dissolved Organic Carbon
Acid Neutralizing Capacity (ANC)	Nitrate
Conductivity	Sulfate
Cadmium	Dissolved Inorganic Carbon
Calcium	Chlorine
Iron	Fluorine
Lead	Potassium
Zinc	Magnesium
Aluminum (Total Dissolved)	Sodium
Phosphorus (Total)	Ammonia
Nitrogen (Total)	Silca
Manganese	

Reduced Suite

pH	Conductivity
Calcium	Phosphorus (Total)
Aluminum (Total dissolved)	Nitrogen (Total)
Acid Neutralizing Capacity (ANC)	Dissolved Inorganic Carbon

3.0 SUMMARY OF FIELD ACTIVITIES

The following three sections highlight major field activities completed on Curlew Pond for the period May, 1986, the month of initial inclusion in the LLI Program, through program culmination in December, 1991.

Summary information provided includes an overview of pond liming operations, water quality monitoring activities and fishery survey results. A complete listing of all LLI water quality data collected for the pond is provided in Appendix A.

3.1 Liming Operations at Curlew Pond

Over the course of the LLI Program, Curlew Pond was treated twice with limestone materials. The initial application occurred on June 27, 1986, with the second treatment completed in mid-July, 1991. The amount (dose) and grade of limestone utilized was derived from pre-defined water quality objectives and the unique chemical and physical characteristics of the pond. The water quality objectives established for the pond included an ANC greater than 100 ueq/l and a weighted pH above 6.5 standard units (maintenance liming criteria). Both treatments successfully attained these water quality targets.

Prior to each treatment, LLI secured all required regulatory permits and approvals. This process was facilitated through preparation and submission of a pre-treatment plan containing details of the proposed activity. Key plan components included a background description, statement of purpose, pre- and post-treatment water quality projections, dosage calculations, application technique and tentative treatment schedule. A computer model termed DeAcid was used to calculate the required dosage and project post-treatment water quality response for each of the two treatment events completed on Curlew Pond.

During the initial treatment, 12.9 tonnes of high calcium carbonate limestone was applied to the pond surface via helicopter. This process included partitioning of the pond into three treatment zones to compensate for variations in depth and ensure application of the prescribed limestone dosage. The treatment zones, their depth, area and dosage are detailed below:

Zone	Mean Depth (m)	Surface Area (ha)	Applied Dose (tonnes)
1	5.7	7.5	6.3
2	6.1	6.5	5.2
3	3.9	3.5	1.4

Of the total dose applied, approximately 12.5 tonnes (97%) was used to neutralize the water column, with remaining 0.4 tonnes applied to the pond bottom sediments. This equated to an area-weighted sediment dose of 0.007 tonnes/hectare. The limestone used in the application had a median particle diameter of 14 microns, and displayed a calcium content in excess of 95%. It arrived on-site in bulk form, was pre-mixed into a slurry and subsequently dispersed over each buoyed zone by helicopter.

The second liming was completed over the period July 18-19, 1991. A much less expensive boat-mounted slurry box technique was used in the retreatment process. Based on a better understanding of pond water quality following initial treatment, a higher sediment dose was applied in the second treatment (0.34 tonnes/hectares). An additional change included an increase in the average size of the limestone material utilized. This was included to prolong the reacidification interval to the extent possible. Incorporation of these changes resulted in a revised limestone dose of 15.2 tonnes. The application process followed a two zone approach. Rather than dose each zone independently, Zone 1 (depth > 5.0 m) was initially treated with 7.6 tonnes, with the remaining 7.6 tonnes uniformly distributed over the entire pond surface. This approach reduced treatment time and ensured application of the proper sediment dose to Zone 2. At the rate applied, reacidification to pH 6.2 was estimated at approximately 6 years.

3.2 Water Quality Monitoring

Review of historic water quality data indicated that prior to 1986, Curlew Pond was mildly acidic displaying pH values of from 4.9 - 6.9 standard units (su). ANC (alkalinity) levels for the same period varied from 0 - 38 ueq/l thereby indicating susceptibility to acidification (low buffering capacity). With the exception of slightly elevated lead levels, the remaining water quality indicators displayed no apparent anomalies.

In June, 1986, LLI initiated a water quality monitoring program on Curlew Pond. The principal objectives of this program were to:

- establish pre-treatment baseline water quality conditions,
- collect data needed to evaluate treatment effectiveness, and
- document changes in water quality during the reacidification phase.

Over the next five years, periodic visits were made to support each of the above targeted objectives.

As previously noted, samples were analyzed for either a full or reduced suite of parameters (Table 1). Collection depths were contingent upon water column temperature at the time of sampling. Typically however, two sets of samples were collected during each site visit -- one at a depth of 1.5 meters, with the second set obtained near the pond bottom. In addition, a portable meter was used to record temperature, pH, conductivity and dissolved oxygen levels at one meter depth intervals in the water column. All sampling was confined to three stations (Index Station, Station 2, Station 3) located at the deepest point in each sub-basin of the pond (Figure 1).

Pretreatment sampling (full suite parameters) was completed in early June, 1986. Analytical results were in basic concurrence with historic water quality conditions. The primary indicators of acidity -- pH, ANC and Calcium -- were found at levels supporting a classification of mildly acidic. No other parameters, save lead, displayed concentrations in excess of those found in natural waters. Based upon these results, an initial limestone dose was calculated and applied to the pond in June, 1986. Follow-up monitoring was subsequently completed on July 28, 1986. A comparison of pre- and post-treatment water quality conditions is provided below.

	Pre-Treatment (June 11, 1986)	LLI Treatment Targets	Post-Treatment (July 28, 1986)
pH (su)	6.1	> 7.0	7.5
ANC (ueq/l)	15.9	>200.0	264.1
Ca (mg/l)	0.9	> 2.0	5.7

As shown above, the liming successfully attained post-treatment water quality targets established for the pond. No statistically significant change was observed in any of the other 20 parameters included in the monitoring program. This observation was in concurrence with previous studies reporting that liming will, in general, increase only levels of ANC, Ca, pH, conductivity and DIC (dissolved inorganic carbon). Metals, although typically observed to decrease following liming, showed no significant changes in Curlew

Pond. This was primarily due to the fact that the pond was only mildly acidic prior to liming, and that most metals were present in concentrations at or below detection limits.

During the reacidification period (1987 - 1991) the pond was monitored at least twice a year for a reduced suite of eight parameters (Table 1). This semi-annual monitoring was conducted at ice-out and again during late summer, normally prior to fall turnover. In August, 1990, sampling results indicated that pH and ANC values had dropped below LLI threshold reliming criteria. To ensure continued maintenance of water quality suitable for a self-sustaining bass fishery, the pond was retreated with limestone in mid July, 1991. Observed pre- and post-treatment changes in water quality associated with this activity are summarized as follows:

	Pre-Treatment (Aug. 2, 1990)	LLI Treatment Targets	Post-Treatment (Aug. 22, 1991)
pH (su)	6.3	> 7.0	7.4
ANC (ueq/l)	20.0	>200.0	366.0
Ca (mg/l)	1.5	> 2.0	8.1

As evidenced above, the retreatment was successful in attaining the LLI treatment targets prescribed for the pond. Modelling projections indicate that Curlew Pond should maintain adequate water quality, i.e., pH > 6.2, ANC > 100 ueq/l and Ca > 2.0 mg/l, for approximately six years.

3.2.1 Summary Results

Results of the five year monitoring program on Curlew Pond can best be summarized in terms of seven water quality variables deemed critical to an applied liming program. Of these variables, three -- transparency (secchi depth), temperature and dissolved oxygen -- are basic to any fishery management endeavor. The remaining four -- pH, ANC, Ca and

Al -- regulate the effects of acidification on fish and are thus, instrumental in developing any viable remediation alternative. For a full listing of all analytical results, the reader is referred to Appendix A.

Transparency

Secchi Disk readings are useful as a means of comparing the visibility of different waters. In effect, they provide a measure of the depth to which light penetrates into the pond. Factors affecting secchi depth include water color, algal biomass and suspended particulate matter. When obtained during periods of maximum productivity (typically late summer) secchi readings correlate well with algal production, and hence, can provide useful information on the trophic condition of the waterbody. Figure 2 shows the mid-summer secchi depth for the period July, 1986, through August, 1991. Secchi readings averaged approximately 5.5 meters over this interval, varying in depth from a minimum of 4.5 meters in 1987 and 1988 to a maximum of 8.5 meters in July, 1986. Given these results, pond water transparency can be considered good to excellent.

Temperature

As is typical of many deep kettle lakes and ponds, Curlew Pond thermally stratifies during warm weather periods. Simply put, thermal stratification is the development of three temperature layers in the water column -- an upper layer called the epilimnion, middle layer termed the mesolimnion, and lower layer called the hypolimnion. From a fishery management perspective, this phenomenon is important as very little mixing occurs between each strata. Oxygen levels in the bottom layer may become depleted, thus precluding use of these areas by fish and other aquatic inhabitants.

A typical summer temperature profile for Curlew Pond is presented in Figure 3. Under average conditions, the pond displays a surface to bottom temperature change of approximately 13°C, with each of the three thermal layers clearly in evidence. The epilimnion (surface) layer penetrates to a depth of about 4.5 meters, with thermal transition (mesolimnion) occurring between 4.5 and 6 meters. Thus, the hypolimnion includes all remaining pond areas greater than 6 meters in depth.

Dissolved Oxygen

The availability of adequate concentrations of dissolved oxygen (D.O.) is essential for the maintenance of any resident biological community. Typically, most North American game fish species require a minimum of 3 mg/l D.O. to sustain life. In ponds displaying thermal stratification, D.O. levels in the hypolimnion may drop below this minimum as a result of organic decomposition. Because thermal stratification restricts D.O. replenishment, fish may be unable to use deepwater areas during warm weather periods.

Mid-summer monitoring results for Curlew Pond are graphically depicted in Figure 4. As shown, D.O. concentrations were uniformly above the 3.0 mg/l criteria throughout the water column. During 1989 this zone extended upward in the water column to include pond areas at depths greater than 8 meters. Although the duration of low oxygen concentrations at depth in the hypolimnion was not seasonally ascertained, total water column mixing in the fall probably re-supplied these areas with adequate levels of D.O. This is supported by the observance of uniform surface-to-bottom D.O. concentrations immediately after ice-out in the spring.

pH, ANC, Calcium

Of the 23 analytical and 4 water column variables included in the monitoring program, three -- pH, ANC and calcium -- are most crucial in evaluating changes in water quality as a result of liming. A fourth parameter, aluminum, is also included due to its potential toxicity to fish in acidified systems. This parameter is discussed in the next section.

Numerous reports confirm that at pH levels below 6.5, many fish species begin to show stress. Concurrent to this process, the ability of a pond to mitigate acidity (ANC) also declines. This is reflected in subsequent lowering of calcium concentrations, typically the most dominant parameter in determining ANC. At calcium concentrations below 2.0 mg/l, physiological stress can occur in many fish species and other aquatic organisms.

Water quality targets of pH > 6.5, ANC > 100 ueq/l, and calcium concentration above 2.0 mg/l are considered adequate for protection of most fish species. These limits served as the threshold for all LLI liming activities.

Monitoring results for pH, ANC and calcium observed in Curlew Pond are graphically displayed in Figures 5, 6 and 7, respectively. LLI treatment targets for all 3 parameters were successfully attained following each liming activity. Data on both hypolimnetic and epilimnetic samples are included for illustrative purposes.

Results of the monitoring program indicate that reacidification is occurring in Curlew Pond. Following initial treatment, reacidification to program reliming thresholds took approximately two to four years (pH and ANC). Corresponding calcium levels remained above 2.0 mg/l throughout this period.

Dosage adjustments made in the second liming should further delay the reacidification process. Model projections indicate that use of a larger sized material and increasing the sediment dose should extend this process by several years. Initial post-treatment monitoring results appear to support this prediction. Follow-up water quality monitoring is, however, recommended to track the actual reacidification process.

Aluminum

As ponds acidify, the solubility of many potentially toxic metals increases. With a corresponding reduction in ANC, this generally results in higher concentrations of dissolved metals. Of these metals, aluminum is readily supplied from contributing groundwater and/or watershed sources and can be toxic to fish in relatively low concentrations.

Previous investigations report that toxic stress in fish can occur as concentrations of inorganic monomeric aluminum increase above 5 ug/l. In the LLI program, concentrations of total dissolved aluminum above 60 ug/l (0.06 mg/l) required collection and analysis of the more toxic monomeric forms. In Curlew Pond both aluminum species were collected and analyzed. Monitoring results for total dissolved aluminum are presented in Figure 8.

The observed trends in aluminum concentrations are difficult to interpret. Although there appears to be a reduction in aluminum levels with time, the data are highly variable and prevent any definitive conclusion. At no time was total aluminum found to exceed the 60 ug/l criteria established by LLI. Although monomeric levels were found at concentrations in excess of 5 ug/l, no toxic stress was observed in the resident fish population. This may be explained by the relatively high concentrations of calcium present through the duration of the program.

3.3 Fisheries Survey

3.3.1 Fisheries Data Collection Methods

To qualitatively evaluate the fish population present in each program lake, a combination of several collection methods was employed. These methods included: South Dakota trap nets, gill nets, seines, and electrofishing techniques. Each gear type has a specific pond area in which it is most efficient for collection of a particular segment of the population.

Trap nets are most efficient for capturing juvenile and adult fish in the littoral (near-shore) zone. Gill nets are utilized to capture adults in the pelagic (deep) areas of the waterbody. Seines are used to collect mostly young-of-the-year species frequenting near-shore areas. Electrofishing is used to capture fish from a variety of pond habitats. The concurrent use of these gear types thus enables a sampling team to collect representative species from most pond habitats.

3.3.2. Fishery Sampling Results

Throughout the LLI Program, an annual fishery survey was conducted on Curlew Pond. In addition, a pre-treatment survey was completed in 1986. The principal objective of this survey was to collect quantitative information on the target and non-target species found in the pond. To accomplish this objective, an attempt was made to collect a minimum of 30 adult bass and trout species per site visit. Information recorded included species type, length, weight and, when possible, sex. In addition, scale samples were collected and archived for future reference. Information recorded for non-target species was limited to species name, size class and number collected. Survey results for the target species (bass) are tabulated in Table 2.

Survey results indicate that Curlew Pond presently contains self-sustaining populations of both largemouth bass (Micropterus salmoides) and smallmouth bass (Micropterus dolomieni).

Qualitative information collected for both bass species indicate that at least two year-classes were present during each year the pond was surveyed. With the exception of 1986 and 1990, there was a trend toward fewer smallmouth bass and more largemouth bass.

TABLE 2
QUALITATIVE FISH SURVEY RESULTS: TARGET SPECIES
1986–1990
CURLEW POND, MASSACHUSETTS

			Young–of–the–Year (2)			Juveniles/Adults			
YEAR	TARGET SPECIES (1)	TOTAL NUMBER SAMPLED	NUMBER SAMPLED	AVERAGE WEIGHT (g)	AVERAGE LENGTH (mm)	NUMBER SAMPLED	AVERAGE WEIGHT (g)	AVERAGE LENGTH (mm)	NUMBER OF YEAR CLASSES PRESENT
1986	LMB	85	72	3	60	13	432	281	3
1987	SMB	20	0	3	58	11	234	243	3
	LMB	2	9	0	0	2	22	123	2
1988	SMB	10	1	8	90	9	191	194	2
	LMB	47	29	5	73	18	193	201	2
1989	SMB	7	0	0	0	7	189	241	2
	LMB	39	1	3	71	38	241	245	4
1990	SMB	5	1	12	96	4	71	179	2

(1) SMB = Smallmouth bass
LMB = Largemouth bass

(2) Young–of–the–year size classification based on fish < 100 mm in length (all species) at the time of sampling. (J. Bergin, W. Hubert, personal communication, 1989)

Finally, although the survey results must be interpreted with caution, the average length and weight of young-of-the-year captured appeared to increase over the four years following the initial liming. While data limitations preclude an exact determination for this apparent increase, water quality improvements attributable to liming could be a major factor.

Listed below are the non-target species captured during the annual survey. The presence of these additional species offer a well rounded diversity to Curlew Pond, and in addition, provide an excellent forage base for adult target species.

Common Name	Scientific Name
Pumpkinseed	Ledomis gibbosus
Bluegill	Ledomis macrochirus
Yellow Perch	Perca flavescens
Banded Killifish	Fundulus diaphanus
Chain Pickerel	Esox niger
Brown Bullhead	Ictalurus nebulosus
Black Crappie	Pomoxis nigromaculatus
White Perch	Morone americana

4.0 SUMMARY AND CONCLUSIONS

Over its six-year tenure, the LLI Program has successfully demonstrated that liming acidified waters is an effective, quick and economical technique for improving water quality to levels suitable for the support of viable fish populations. Additional major conclusions of the program are identified as follows:

- Calcium carbonate (limestone) is an effective material for neutralizing acidified waters.

- The slurry box dosing device is the most economical way to apply limestone to ponds with surface areas under 40 hectares. For ponds over 40 hectares, application by specialized barge is recommended.

- The DeAcid model is relatively accurate for determining limestone dosages, for predicting post-treatment water quality response, and estimating rates of reacidification in treated systems.

- Pond liming generally increases pH, ANC, Calcium and DIC in surface waters.

- The solubilities of many potentially toxic metals generally decrease as a result of liming.

- The addition of limestone generally results in a positive response in fish and other aquatic biota.

With the exception of a noticeable change in post-treatment metals concentrations, the conclusions outlined above are all applicable to Curlew Pond. The non-appreciable reduction in metals is most probably due to the fact that the pond was only mildly acidic prior to liming and that the metals present were at concentrations near their analytical detection limits. In summary, the overall objective of providing a water quality suitable for the maintenance of a recreational fishery in Curlew Pond has been successfully attained.

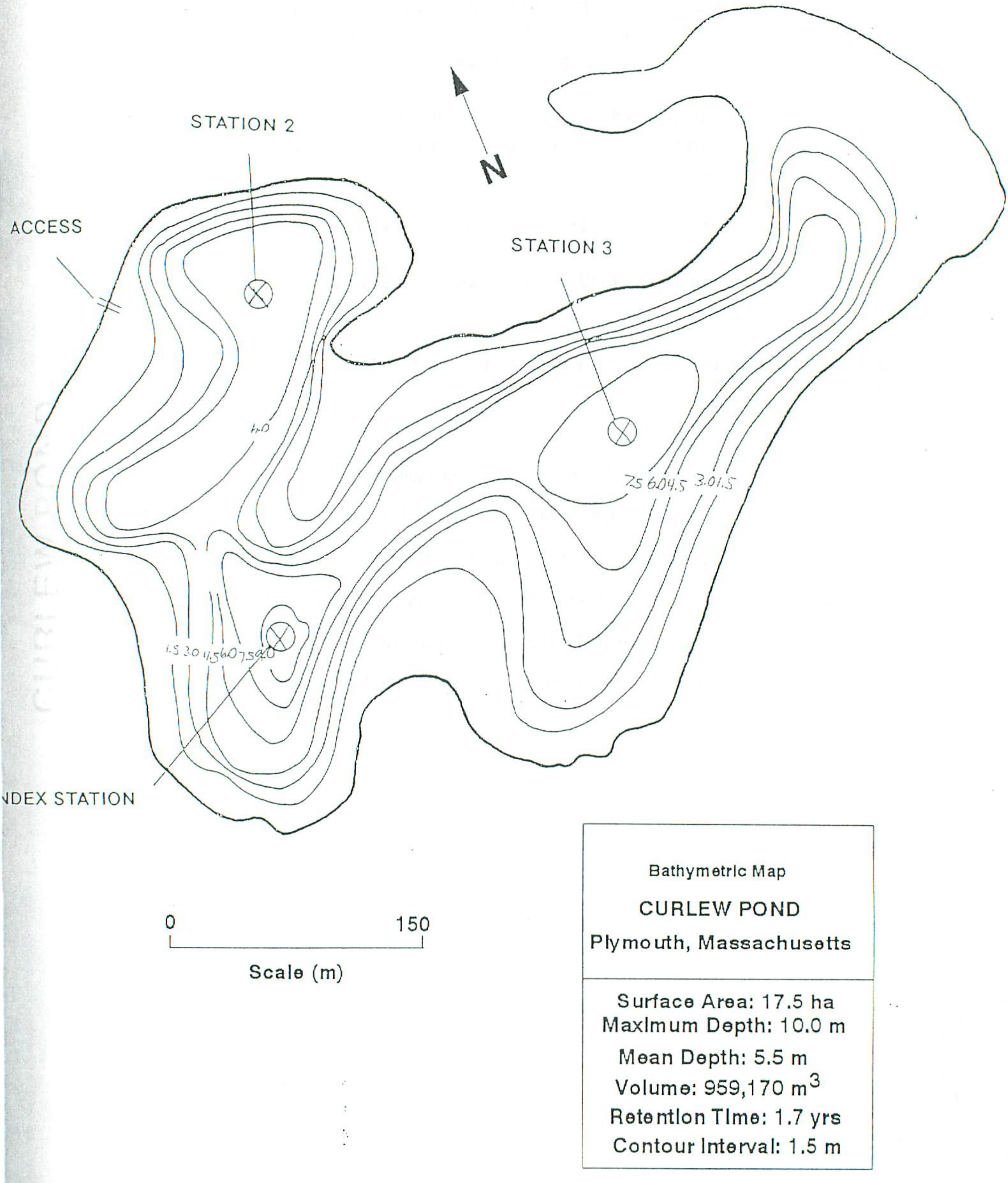

STATION 2
N
ACCESS
STATION 3
NDEX STATION
0
150
Scale (m)
Bathymetric Map
CURLEW POND
Plymouth, Massachusetts
Surface Area: 17.5 ha
Maximum Depth: 10.0 m
Mean Depth: 5.5 m
Volume: 959,170 m3
Retention Time: 1.7 yrs
Contour Interval: 1.5 m

FIGURE 1

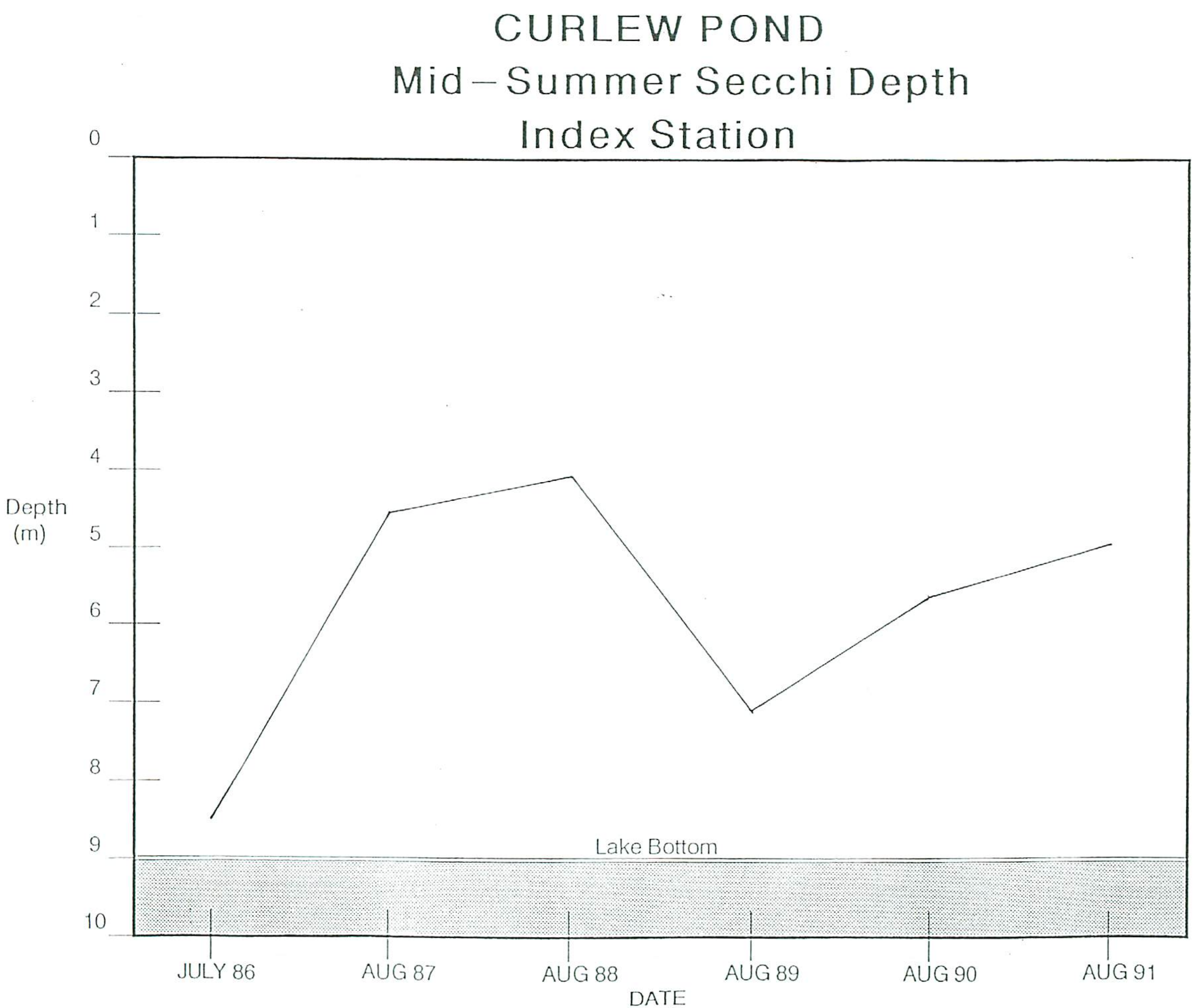

CURLEW POND
Mid – Summer Secchi Depth
Index Station
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
Lake Bottom
JULY 86
AUG 87
AUG 88
AUG 89
AUG 90
AUG 91
DATE

FIGURE 2

Typical Summer Temperature Profile
Index Station: 1988

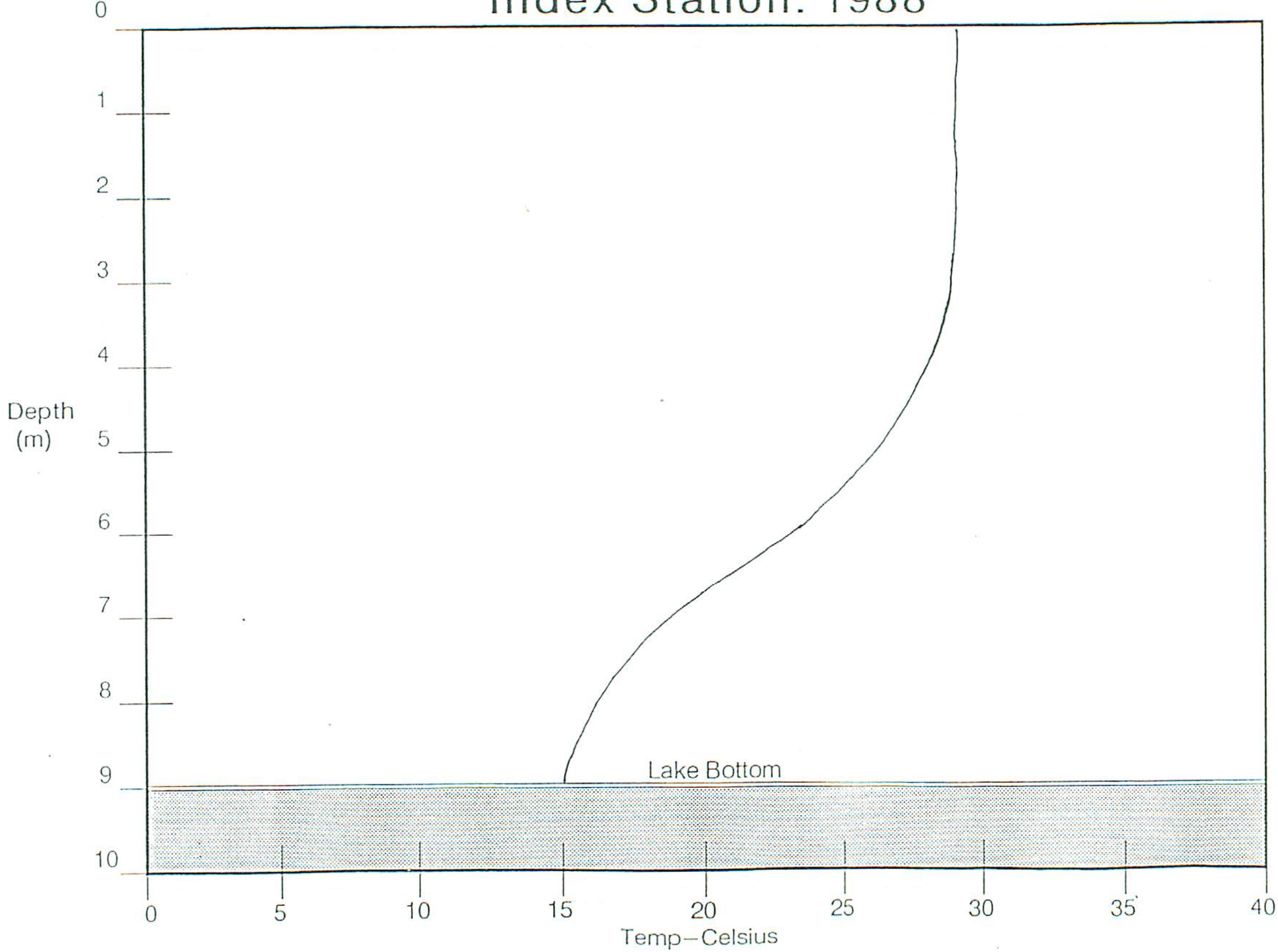


FIGURE 3

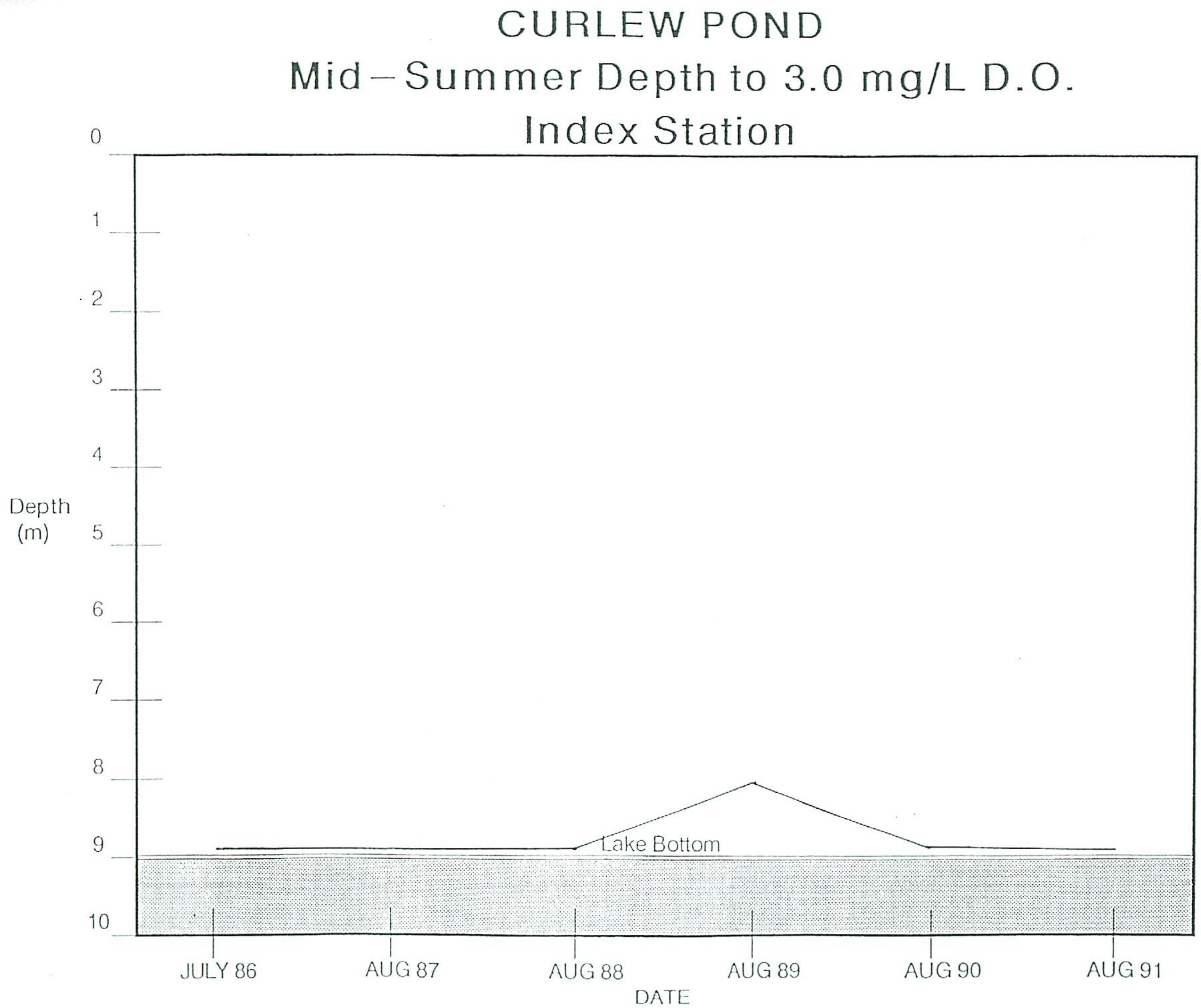
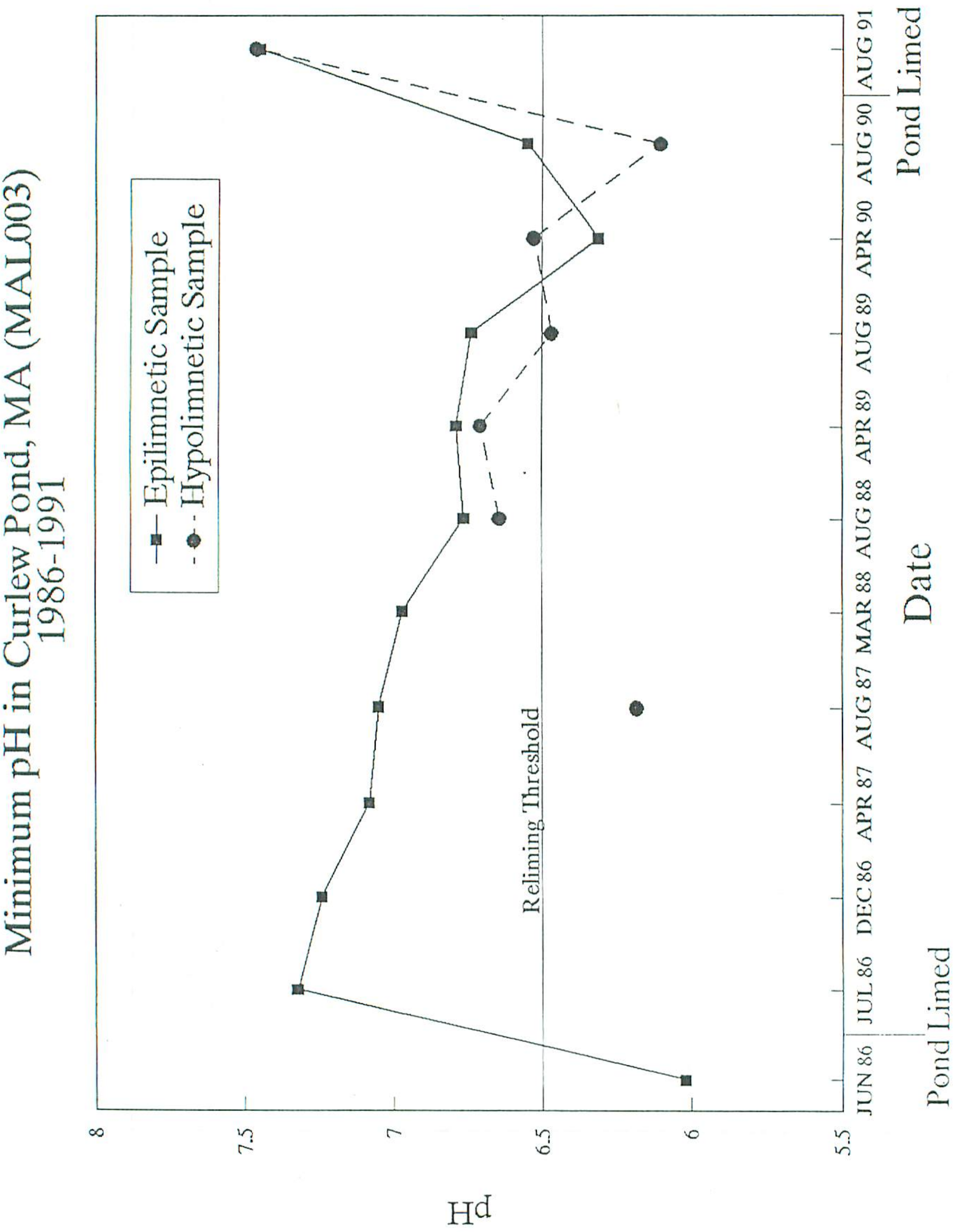

CURLEW POND
Mid – Summer Depth to 3.0 mg/L D.O.
Index Station
Depth
(m)
0
1
2
3
4
5
6
7
8
9
10
Lake Bottom
JULY 86
AUG 87
AUG 88
AUG 89
AUG 90
AUG 91
DATE

FIGURE 4



Minimum pH in Curlew Pond, MA (MAL003)
1986-1991
Epilimnetic Sample
Hypolimnetic Sample
Reliming Threshold
pH
8
7.5
7
6.5
6
5.5
JUN 86
JUL 86
DEC 86
APR 87
AUG 87
MAR 88
AUG 88
APR 89
AUG 89
APR 90
AUG 90
AUG 91
Pond Limed
Pond Limed
Date

FIGURE 5

Mean ANC for Curlew Pond, MA (MAL003)
1986-1991

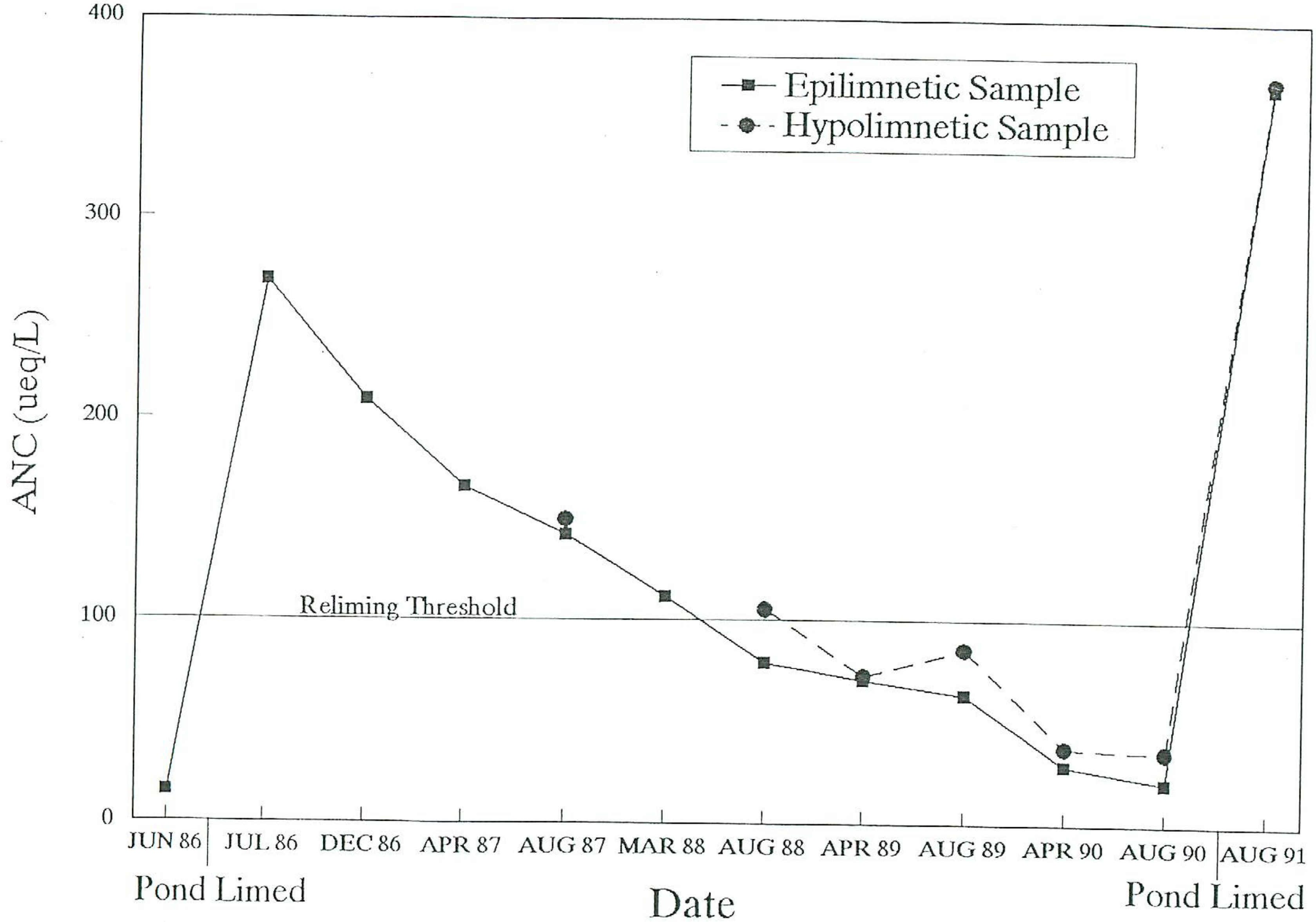


FIGURE 6

Mean Calcium Levels in Curlew Pond, MA (MAL005)
1986-1991

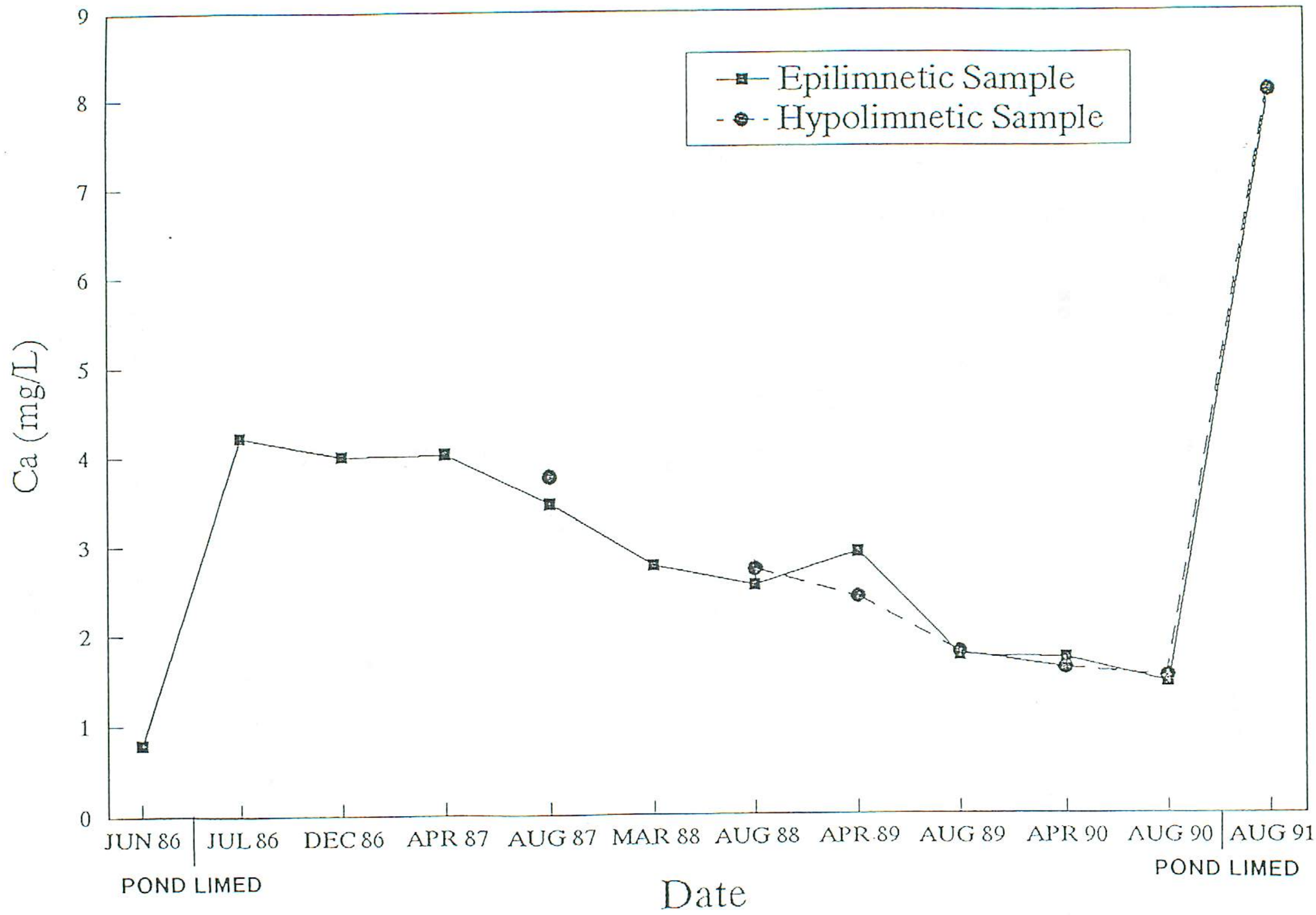


FIGURE 7

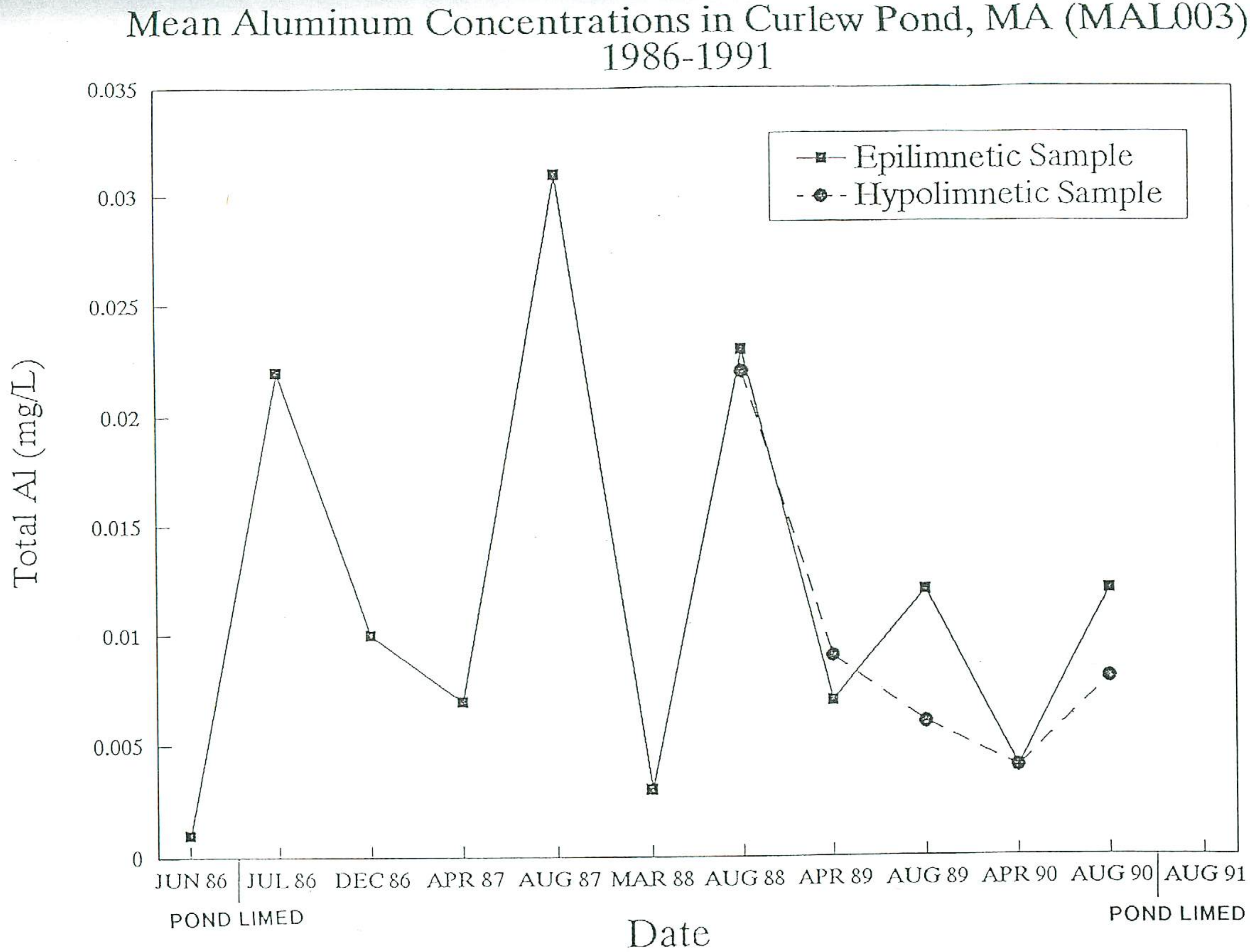

Mean Aluminum Concentrations in Curlew Pond, MA (MAL003)
1986-1991
Epilimnetic Sample
Hypolimnetic Sample
Total Al (mg/L)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
JUN 86
JUL 86
DEC 86
APR 87
AUG 87
MAR 88
AUG 88
APR 89
AUG 89
APR 90
AUG 90
AUG 91
POND LIMED
POND LIMED
Date

FIGURE 8

LIVING LAKES, INC.

WATER QUALITY MONITORING DATA

age No. 1
/03/92

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Index Station - Routine Parameters

mple ate	Sample Depth (M)	Field D.O. (mg/L)	Lab pH	Lab Cond. (us/cm)	ANC GRAN (ueq/L)	Ca (mg/L)	Ca (ueq/L)
/11/86	1.0	9.00	6.080	38.000	15.900	0.908	45.31
/28/86	1.0	7.65	7.490	61.300	264.100	5.711	284.98
/04/86	1.0	13.09	7.500	55.900	210.200	4.753	237.17
/16/87	1.5	11.73	7.070	50.000	167.700	3.790	189.12
/31/87	1.5	8.61	6.930	48.500	164.200	3.277	163.52
/31/87	8.5	0.08	6.180	51.600	149.800	3.822	190.72
/24/88	1.5	13.18	6.970	44.400	113.330	2.770	138.22
/10/88	1.5	7.86	6.920	44.130	77.540	2.530	126.25
/10/88	7.0	8.33	6.590	44.000	105.030	2.710	135.23
/13/89	1.5	11.57	6.760	41.570	63.260	2.220	110.78
/13/89	7.5	11.18	6.760	41.060	71.070	2.270	113.27
/10/89	1.5	7.91	6.710	43.670	76.580	1.760	87.82
/10/89	7.0	7.94	6.800	44.720	91.820	1.800	89.82
/05/90	1.5	13.59	6.310	38.560	6.350	1.720	85.83
/05/90	8.7	13.41	6.500	38.700	6.320	1.630	81.34
/02/90	1.5	9.83	6.550	39.010	13.400	1.430	71.36
/02/90	7.0	7.94	6.100	38.740	35.500	1.510	75.35
/22/91	1.5	7.93	7.440	*	366.000	8.140	406.19
/22/91	8.0	7.56	7.460	*	370.000	8.070	402.69

* = No Data Collected
0.000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Index Station - Routine Parameters

ample ate	Sample Depth (M)	Total Al (mg/L)	Monomeric Al (mg/L)	NO3-N (mg/L)	SO4 (mg/L)	NH3-N (mg/L)	F (mg/L)
/11/86	1.0	0.000	*	0.018	7.580	0.074	0.011
/28/86	1.0	0.031	*	0.011	5.200	*	*
/04/86	1.0	0.009	*	0.053	5.024	0.000	0.020
/16/87	1.5	0.008	*	*	*	*	*
/31/87	1.5	0.041	*	*	*	*	*
/31/87	8.5	0.009	*	*	*	*	*
/24/88	1.5	0.006	0.000	0.000	0.000	0.000	0.000
/10/88	1.5	0.014	0.000	0.000	0.000	0.000	0.000
/10/88	7.0	0.000	0.000	0.000	0.000	0.000	0.000
/13/89	1.5	0.008	*	*	*	*	*
/13/89	7.5	0.009	*	*	*	*	*
/10/89	1.5	0.009	0.006	0.000	5.130	0.000	0.010
/10/89	7.0	0.007	0.003	0.000	4.650	*	*
/05/90	1.5	0.004	*	*	*	*	*
/05/90	8.7	0.004	*	*	*	*	*
/02/90	1.5	0.012	0.000	0.000	5.350	0.000	0.025
/02/90	7.0	*	*	*	*	*	*
/22/91	1.5	*	*	*	*	*	*
/22/91	8.0	*	*	*	*	*	*

* = No Data Collected
0.000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Index Station - Routine Parameters

ample Date	Sample Depth (M)	DOC (mg/L)	DIC (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Na (mg/L)	K (mg/L)
5/11/86	1.0	1.530	0.307	0.106	0.006	3.730	0.498
7/28/86	1.0	1.610	3.355	0.000	0.003	*	*
2/04/86	1.0	3.010	2.561	0.234	0.010	4.994	0.485
/16/87	1.5	2.080	2.017	*	*	*	*
/31/87	1.5	4.470	1.739	0.177	0.011	*	*
/31/87	8.5	2.640	5.245	0.223	0.017	*	*
/24/88	1.5	0.000	0.000	0.150	0.009	*	*
/10/88	1.5	0.000	0.000	0.450	0.009	0.000	0.000
/10/88	7.0	0.000	0.000	0.440	0.015	0.000	0.000
/13/89	1.5	*	0.990	0.150	0.012	*	*
/13/89	7.5	*	1.080	0.160	0.030	*	*
/10/89	1.5	2.700	0.630	0.000	0.000	*	*
/10/89	7.0	2.890	1.280	0.000	0.000	4.380	0.430
/05/90	1.5	*	0.830	0.240	0.006	*	*
/05/90	8.7	*	0.840	0.240	0.011	*	*
/02/90	1.5	2.960	0.590	0.240	0.002	4.130	0.450
/02/90	7.0	2.370	1.450	0.200	0.000	0.000	0.000
/22/91	1.5	*	*	*	*	*	*
/22/91	8.0	*	*	*	*	*	*

* = No Data Collected
0.000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Index Station - Routine Parameters

Sample Date	Sample Depth	Cl (mg/L)
06/11/86	1.0	8.320
07/28/86	1.0	*
12/04/86	1.0	6.570
04/16/87	1.5	*
08/31/87	1.5	*
08/31/87	8.5	*
03/24/88	1.5	*
08/10/88	1.5	*
08/10/88	7.0	*
04/13/89	1.5	*
04/13/89	7.5	*
08/10/89	1.5	8.040
08/10/89	7.0	*
04/05/90	1.5	*
04/05/90	8.7	*
08/02/90	1.5	6.060
08/02/90	7.0	*
08/22/91	1.5	*
08/22/91	8.0	*

* = No Data Collected
0.000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Index Station - Metals

mple ate	Sample Depth	Pb (mg/L)	Zn (mg/L)	Cd (mg/L)	Fe (mg/L)	Mn (mg/L)	Mg (mg/L)
/11/86	1.0	0.006	0.005	0.000	0.003	0.001	0.726
/28/86	1.0	0.016	0.007	0.000	0.009	0.000	*
/04/86	1.0	0.019	0.002	0.000	0.012	0.000	0.820
/16/87	1.5	*	*	*	*	*	*
/31/87	1.5	*	*	*	*	*	*
/31/87	8.5	*	*	*	*	*	*
/24/88	1.5	0.000	0.000	0.000	0.000	0.000	0.000
/10/88	1.5	0.000	0.000	0.000	0.000	0.000	0.000
/10/88	7.0	0.000	0.000	0.000	0.000	0.000	0.000
/13/89	1.5	*	*	*	*	*	*
/13/89	7.5	*	*	*	*	*	*
/10/89	1.5	0.000	0.000	0.000	0.010	0.000	0.740
/10/89	7.0	0.001	0.000	0.000	0.090	0.000	*
/05/90	1.5	*	*	*	*	*	*
/05/90	8.7	*	*	*	*	*	*
/02/90	1.5	0.000	0.000	0.000	0.000	0.000	0.720
/02/90	7.0	0.000	0.000	0.000	0.000	0.000	0.730
/22/91	1.5	*	*	*	*	*	*
/22/91	8.0	*	*	*	*	*	*

* = No Data Collected
0.000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 2 - Routine Parameters

Sample Date	Sample Depth (M)	Field D.O. (mg/L)	Lab pH	Lab Cond. (us/cm)	ANC GRAN (ueq/L)	Ca (mg/L)	Ca (ueq/L)
06/11/86	1.0	9.05	5.980	38.300	17.600	0.912	45.51
06/11/86	1.5	0.00	5.960	37.900	17.400	0.906	45.21
07/28/86	1.0	0.00	7.570	60.700	262.900	5.718	285.33
07/28/86	1.0	0.00	7.510	60.700	259.900	5.650	281.94
12/04/86	1.0	13.46	7.020	54.400	210.800	4.709	234.98
12/04/86	1.0	0.00	7.200	55.600	210.300	4.705	234.78
04/16/87	1.5	12.37	7.080	50.600	169.500	3.781	188.67
04/16/87	1.5	0.00	6.960	50.100	163.300	3.744	186.83
08/31/87	1.5	8.89	7.050	50.200	136.200	3.289	164.12
08/31/87	1.5	0.00	7.110	49.200	129.500	3.266	162.97
03/24/88	1.5	13.22	6.950	45.100	110.260	2.740	136.73
08/10/88	1.5	7.71	6.920	44.690	66.720	2.510	125.25
08/10/88	5.5	8.63	6.300	43.220	97.770	2.480	123.75
04/13/89	1.5	11.21	6.800	42.960	82.790	2.090	104.29
04/13/89	5.5	10.85	6.690	41.270	88.930	2.110	105.29
08/10/89	1.5	7.90	6.710	42.840	53.470	1.670	83.33
08/10/89	5.5	7.81	6.660	43.030	50.660	1.810	90.32

* = No Data Collected
0.000 = Below Analytical Detection Limits

e No. 1
03/92

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 2 - Routine Parameters

mple te	Sample Depth (M)	Total Al (mg/L)	Monomeric Al (mg/L)	NO3-N (mg/L)	SO4 (mg/L)	NH3-N (mg/L)	F (mg/L)
.1/86	1.0	0.004	*	0.022	6.951	*	*
.1/86	1.5	0.000	*	0.021	5.985	*	*
8/86	1.0	0.035	*	0.012	5.160	0.011	0.019
8/86	1.0	0.037	*	0.012	5.240	*	*
4/86	1.0	0.011	*	0.077	4.800	*	*
4/86	1.0	0.012	*	0.082	4.848	*	*
6/87	1.5	0.008	*	*	*	*	*
6/87	1.5	0.008	*	*	*	*	*
1/87	1.5	0.036	*	*	*	*	*
1/87	1.5	0.038	*	*	*	*	*
4/88	1.5	0.000	*	*	*	*	*
0/88	1.5	0.013	*	*	*	*	*
0/88	5.5	0.000	*	*	*	*	*
3/89	1.5	0.008	*	*	*	*	*
3/89	5.5	0.009	*	*	*	*	*
0/89	1.5	0.004	0.058	0.000	4.890	*	*
0/89	5.5	0.009	0.024	0.000	5.360	*	*

= No Data Collected
000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 2 - Routine Parameters

nple ite	Sample Depth (M)	DOC (mg/L)	DIC (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Na (mg/L)	K (mg/L)
11/86	1.0	1.450	0.366	0.087	0.005	*	*
11/86	1.5	1.500	0.325	0.090	0.004	*	*
28/86	1.0	1.540	3.240	0.000	0.004	4.330	0.518
28/86	1.0	1.480	3.142	0.062	0.003	*	*
04/86	1.0	3.290	2.400	0.229	0.009	*	*
04/86	1.0	3.820	2.479	0.229	0.010	*	*
16/87	1.5	2.070	2.134	*	*	*	*
16/87	1.5	2.160	2.102	*	*	*	*
31/87	1.5	4.410	1.653	0.155	0.012	*	*
31/87	1.5	4.360	1.726	0.198	0.008	*	*
24/88	1.5	0.000	0.000	0.140	0.006	*	*
10/88	1.5	0.000	0.000	0.390	0.009	*	*
10/88	5.5	0.000	0.000	0.490	0.014	*	*
13/89	1.5	*	1.070	0.170	0.004	*	*
13/89	5.5		1.160	0.160	0.009	*	*
10/89	1.5	3.040	0.710	0.000	0.000	*	*
10/89	5.5	3.050	0.740	0.000	0.000	*	*

= No Data Collected
.000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 2 - Routine Parameters

ple te	Sample Depth	Cl (mg/L)
11/86	1.0	*
.1/86	1.5	*
28/86	1.0	6.600
28/86	1.0	*
04/86	1.0	*
04/86	1.0	*
6/87	1.5	*
6/87	1.5	*
1/87	1.5	*
1/87	1.5	*
4/88	1.5	*
0/88	1.5	*
0/88	5.5	*
3/89	1.5	*
3/89	5.5	*
0/89	1.5	*
0/89	5.5	*

= No Data Collected
000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 2 - Metals

mple ate	Sample Depth	Pb (mg/L)	Zn (mg/L)	Cd (mg/L)	Fe (mg/L)	Mn (mg/L)	Mg (mg/L)
/11/86	1.0	0.006	0.005	0.000	0.011	0.003	*
/11/86	1.5	0.003	0.005	0.000	0.006	0.001	*
/28/86	1.0	0.017	0.012	0.000	0.011	0.000	0.796
/28/86	1.0	0.020	0.008	0.000	0.010	0.000	*
/04/86	1.0	0.014	0.002	0.000	0.011	0.000	*
/04/86	1.0	0.009	0.002	0.000	0.008	0.000	*
/16/87	1.5	*	*	*	*	*	*
/16/87	1.5	*	*	*	*	*	*
/31/87	8.5	*	*	*	*	*	*
/31/87	1.5	*	*	*	*	*	*
/31/87	1.5	*	*	*	*	*	*
/24/88	1.5	*	*	*	*	*	*
/10/88	7.0	*	*	*	*	*	*
/10/88	1.5	*	*	*	*	*	*
/13/89	7.5	*	*	*	*	*	*
/13/89	1.5	*	*	*	*	*	*
/10/89	7.0	0.001	0.000	0.000	0.090	0.000	
/10/89	1.5	0.000	0.000	0.000	0.020	0.000	
/05/90	8.7	*	*	*	*	*	*
/02/90	7.0	*	*	*	*	*	*

* = No Data Collected
0.000 = Below Analytical Detection Limits

No. 1
3/92

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 3 - Routine Parameters

.e e	Sample Depth (M)	Field D.O. (mg/L)	Lab pH	Lab Cond. (us/cm)	ANC GRAN (ueq/L)	Ca (mg/L)	Ca (ueq/L)
:/88	1.5	13.27	6.990	46.000	106.440	2.790	139.22
)/88	1.5	7.78	6.920	45.080	88.630	2.540	126.75
)/88	6.0	8.31	6.690	45.600	88.030	2.640	131.74
:/89	1.5	11.09	6.810	42.320	74.400	2.110	105.29
./89	6.0	10.99	6.770	41.850	84.080	2.050	102.30
)/89	1.5	7.93	6.790	42.120	44.110	1.760	87.82
)/89	6.0	7.87	6.680	42.250	45.590	1.760	87.82

= No Data Collected
000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 3 - Routine Parameters

;ample)ate	Sample Depth (M)	Total Al (mg/L)	Monomeric Al (mg/L)	NO3-N (mg/L)	SO4 (mg/L)	NH3-N (mg/L)	F (mg/L)
/24/88	1.5	0.005	*	*	*	*	*
/10/88	1.5	0.024	*	*	*	*	*
/10/88	6.0	0.002	*	*	*	*	*
/13/89	1.5	0.010	*	*	*	*	*
/13/89	6.0	0.009	*	*	*	*	*
'10/89	1.5	0.015	0.009	0.000	5.460	*	*
'10/89	6.0	0.009	0.005	0.000	5.150	*	*

= No Data Collected
000 = Below Analytical Detection Limits

No. 1
/92

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 3 - Routine Parameters

e	Sample Depth (M)	DOC (mg/L)	DIC (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Na (mg/L)	K (mg/L)
/88	1.5	0.000	0.000	0.180	0.014	0.000	0.000
/88	1.5	0.000	0.000	0.420	0.005	0.000	0.000
/88	6.0	0.000	0.000	0.400	0.006	0.000	0.000
/89	1.5	*	1.030	0.160	0.028	*	*
/89	6.0	*	1.010	0.170	0.000	*	*
/89	1.5	2.580	0.600	0.000	0.000	*	*
/89	6.0	2.780	0.660	0.000	0.000	*	*

= No Data Collected
)00 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 3 - Routine Parameters

ɔle :e	Sample Depth	Cl (mg/L)
ↄ4/88	1.5	*
.0/88	1.5	*
.0/88	6.0	*
.3/89	1.5	*
.3/89	6.0	*
.0/89	1.5	*
.0/89	6.0	*

= No Data Collected
ⅰ.000 = Below Analytical Detection Limits

LIVING LAKES CHEMISTRY DATABASE
CURLEW POND
Station 3 - Metals

e	Sample Depth	Pb (mg/L)	Zn (mg/L)	Cd (mg/L)	Fe (mg/L)	Mn (mg/L)	Mg (mg/L)
/88	1.5	*	*	*	*	*	*
/88	1.5	*	*	*	*	*	*
/88	6.0	*	*	*	*	*	*
/89	1.5	*	*	*	*	*	*
/89	6.0	*	*	*	*	*	*
/89	1.5	*	*	*	*	*	*
/89	6.0	*	*	*	*	*	*

No Data Collected
00 = Below Analytical Detection Limits