Appendix C

Report of the Leelanau Watershed Council

Water Quality Monitoring Program
(1990 to 1995)

Leelanau Conservancy

REPORT OF THE

LEELANAU WATERSHED COUNCIL

WATER QUALITY MONITORING PROGRAM

(A Synthesis of Data from 1990 to 1995)

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SUMMARY

Data collections from 1990 to the present have permitted "trophic status" determinations for the major lakes of Leelanau County (Leelanau, Glen, Little Traverse, Lime, and Cedar). Trophic status is a reflection of the nutritional state, or the ability of the lake to support plant growth. Lakes are classified as oligotrophic, mesotrophic, or eutrophic. Oligotrophic lakes have limited ability to sustain plant growth (low production) and therefore are relatively free of nuisance aquatic plants, high in dissolved oxygen levels throughout the year, and usually contain fairly clear water. Eutrophic lakes support abundant plant growth (high production) and thus exhibit extensive weed populations, reduced oxygen levels (particularly during late summer), and murky water. Mesotrophic lakes fall in between. Because trophic status is a continuum rather than a yes or no condition, there is no single or absolute way to classify a lake.

A common method used to quantify trophic status employs the calculation of a Trophic Status Index (TSI). TSI values are determined by using concentrations of the nutrient phosphorous, concentrations of the green plant pigment chlorophyll-a, and water clarity as measured with a secchi disk.

TSI values calculated from data collected in County lakes indicate that Glen Lake and Lake Leelanau are oligotrophic. Cedar, Lime, and Little Traverse Lakes are marginally oligotrophic as some parameters fall just within the mesotrophic range.

As of yet, there are no detectable trends in water quality in any of the lakes based on the short six year monitoring period. Overall, the water quality of County lakes is very good.

The monitoring program has compiled a scientifically acceptable and comprehensive benchmark set of data for each lake, more than just TSI determination data. These data include an array of physical and chemical parameters on both the lakes and major tributary streams, species-specific phytoplankton (algae) analyses for each lake, and nutrient budget calculations for Lime and Little Traverse lakes. An earlier MDNR/EPA/Glen Lake Association supported study conducted by myself, produced a nutrient budget for Glen Lake.

The monitoring program will:

1) continue the annual, routine collection of water column profile data (temperature, dissolved oxygen, pH, etc.), and nutrient and chlorophyll-a concentration data.

2) continue to develop and evaluate a nutrient budget for each lake, and recommend any potential remedial activity where data indicate it may be necessary.

3) continue to inform both visitors and County residents of the water quality conditions of our lakes and of their role in influencing those conditions.

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PREFACE

This cumulative report is a nice representation of the true value and potential of our monitoring program. In effect, the whole report can be viewed as a single data point, or a baseline block of data reflecting the state of our water quality in the early to mid 1990s. Having such a dataset should prove to be invaluable as time passes. Even if the program ended today, it would afford the ability to objectively compare the water quality at some future point to that of today, i.e., another four to five year block of data collected in a scientifically sound and comparable manner at any time in the future. That alone is a milestone. However, by continuing to maintain our core program of data collection, we can actively monitor (as opposed to an occasional static assessment when time and resources permit) and witness the development (or lack of development) of trends, whether potentially harmful or beneficial, and act accordingly from a resource management position. We must keep in mind that the practical value of the entire dataset increases in a disproportionately large manner relative to our steady annual level of investment as we continue.

I would like to extend appreciation to all of the individuals who have made the this program successful, either by generous financial, physical, and/or philosophical support. Your contributions are, and will continue to be, the foundation of the program. Bingham Township, Leland Township, Leelanau County and the Michigan Department of Environmental Quality have also been very supportive and I hope that these cooperative efforts will continue as well. And although he will not be pleased at being singled out, I must give special thanks to Walt Nielsen for everything from data entry, report preparation, collection of stream data, careful insight into data interpretation, etc. Thanks Walt!

INTRODUCTION

Whenever discussing water quality and this program, I feel compelled to offer a definition of water quality and then explain how it is monitored. The underlying limnology (study of freshwater systems) need not be re-examined or even understood, however, understanding some basic concepts is important as they form the philosophical cornerstone of the program. I apologize to those who may recognize some of this text from earlier reports, however, it should be repeated each year either for review or to introduce newcomers to the program.

First, what is 'water quality'? I suspect there are as many interpretations or definitions as there are users of the term. Therefore, I offer the following working definition: **Water quality reflects the composition of water as affected by the sum of natural processes and man's cultural activities, expressed in terms of measurable quantities and related to intended water usage.** That is, water bodies integrate all of the forces acting upon them, whether natural (such as direct precipitation, sunlight, etc.) or unnatural (septic leakage, fertilizer runoff, etc.). By measuring scientifically accepted variables (such as dissolved oxygen, phosphorus, etc.) whose values can be compared with a set of standards, one can determine if the quality of the water body is acceptable for a given use (such as the public water supply versus recreational use).

Although water quality can be determined empirically (based on these numerous measurements), it is also a relative concept. Generally, the water quality of Leelanau County lakes is 'good', relative to most lakes in southern Michigan, while the water quality of lakes in southern Michigan is 'great' relative to a sewer lagoon.

So then how is water quality monitored? Based on our definition, the answer is obvious. If we can define it instantaneously by taking a set of measurements, it follows that continued measurements would monitor it over time, like annual check-ups monitor health. Therefore, the program's approach to monitoring our water quality involves the routine collection of data based on a comprehensive list of parameters collected with a frequency great enough to distinguish normal cyclical variations from true trends. The dataset provides a current baseline of values while trends in the data identify both desirable and undesirable conditions. And by doing this, we satisfy our ultimate program goal: to provide a continuous, scientifically valid, long-term record of measured indices of water quality to aid in objective and judicious management of the County's aquatic resources.

This objective has not changed. Nor should it ever change. The core program (our comprehensive list of parameters) may grow (or shrink), or increased effort may be diverted to a specific or temporary project, but the ultimate objective simply cannot change.

Before continuing, I would like to briefly summarize what specific water quality monitoring activities have already occurred in the County to place our program and effort into perspective. Prior to implementation of our water quality program, most work has involved single temperature /dissolved oxygen/water chemistry collections over depth (profiles) by the DNR, and the self-help secchi disc water visibility programs sponsored by the DNR and carried out by respective Lake Associations. Profiles were normally collected about mid summer, beginning around 1973, with maybe one or two follow up collections prior to 1990. Specifically, in North Lake Leelanau, two profiles were collected in 1978, and 2 in 1985. One profile was collected from Little Traverse Lake in 1980 and one in 1989, as well as one profile from Lime Lake each in 1978 and 1980. In Cedar Lake, one profile was obtained in 1975, one in 1979, and two in 1989. In south Lake Leelanau, one profile was collected in 1974 and two in 1978. And in Big Glen Lake, a profile was collected in 1973, one in 1980, one in 1984, and one in 1985. Good secchi depth data exist for some of the lakes, particularly Lake Leelanau, from the mid seventies through the eighties.

Most of the above datasets contain information that is useful, but limited. Profiles of temperature and dissolved oxygen and concurrent water chemistry were generally obtained mid-summer, well before peak stratification (as we now know). Also, some were not collected in the deepest basins, i.e., the 1978 profile in North Lake Leelanau only extended to 100 feet. Furthermore, the ability to measure extremely low levels of total phosphorus was not really refined at the time from a practical standpoint and consequently most values are listed as 0.001 mg/L (or 1.0 ug/L). Almost all of our observed total phosphorus determinations range from about 3 to 8 ug/L, and I can assure you that it is extremely unlikely that phosphorus concentrations have increased by that magnitude since the seventies.

Additionally, an extensive EPA/DNR/Glen Lake Association funded study of Glen Lake was completed by me in 1992. The project was a one year field study, primarily designed to facilitate the calculation of a phosphorus nutrient budget. It was completed on time and contains some excellent information. However, due to bureaucratic and other events out of my control, the final report is not yet available. It is anticipated that this report will be available this summer.

Our effort has picked up substantially where these programs left off. Table 1 summarizes the data collected through 1995. The 1996 data have been entered into the database, but are not formally included in this report.

Table 1. Number of individual monitoring program measurememts made in Leelanau County lakes (1990-1995).

Lake Station	Profiles	Total P	NOx	Chlor-a	Sechhi Disk	Bottom Sediment
Big Glen	47	194	194	16	36	1
Cedar	19	66	59	15	22	1
Lime	55	138	110	24	46	5
Little Glen	42	113	117	15	34	
Little Traverse	54	138	107	22	45	1
NLL Sta. 1	50	186	123	14	39	
NLL Sta 2	23	115	73		38	
SLL Sta. 3	46	110	73		37	
SLL Sta. 4	22	73	77		34	
SLL Sta. 5	49	134	88	16	39	
TOTALS	407	1267	1021	135	370	8

Profiles = Hydrolab measurements over depth: temperature, oxygen concentration, pH, conductivity, and oxidation-reduction potential
Total P = Total phosphorous
NOx = Nitrate (+nitrite) nitrogen
Chlor-a = Chlorophyll-a, a measure of the green pigment in plants (alga)
Secchi Disk = Measure of water clarity
Bottom Sediment = Samples of bottom sediment for total phosphorous concentration
NLL = North Lake Leelanau
SLL = South Lake Leelanau

Such studies are planned for all of our monitored lakes, and at this point, we have completed preliminary nutrient budgets for Lime Lake and Little Traverse Lake. A separate report detailing that work, and including a computer predictive model developed by Dr. Ray Canale, will be available shortly.

Also, we have completed a phytoplankton (essentially algae) survey of our program lakes. By examining species assemblages of phytoplanton, we not only obtain another instantaneous measure of the water quality, but we have also established an excellent biological benchmark for future comparisons. Species identification were made by Dr. Jan Stevenson at the University of Louisville and that report is available

A tremendous baseline dataset combining discharge and nutrient composition for some 25 County streams has also been compiled. This has been and continues to be funded by the DEQ (support for analytical fees) under the auspices of Mike Stifler in the Cadillac office, and a volunteer field technician team of eight people from local lake associations. These data will be extremely useful in the calculations and fine tunings of future nutrient budget assessments and will be provided in a separate report in the near future.

Prior to commenting on each lake, it should be noted that I collected all profile data and water samples. Prior to daily use, the Hydrolab was calibrated pursuant to the manufacturers recommendations and post-calibrated on occasion (being a two day sampling effort, the following morning often served as post-calibration as values rarely drifted significantly). All water chemistry analyses were conducted by the Battelle Great Lakes Laboratory in Traverse City, Michigan (now independent of Battelle and operating as Great Lakes Environmental Center). Field samples were collected with a 5 liter vertical Wildco water sampler and subsampled to an acid-washed and pre-acidified glass 250 ml bottle (supplied by GLEC). Sample bottles were maintained on ice (or refrigerated) prior to delivery. At least one sample per round was collected in triplicate for quality control purposes.

I would also like to re-emphasize how 'young' the program's dataset is. It takes time to detect trends. A few years of physical profile data and basic water chemistry do not comprise the perfect program or dataset capable of answering all questions on our County's water quality. **However**, one could spend many, many times over what we are spending and still not satisfactorily answer all questions. Thanks to a great deal of donated time and expertise, we are spending an extremely small amount of money to obtain some very valuable data that otherwise would not be collected. And as the dataset grows, so will our knowledge of each system.

I would also like to briefly introduce/review (as the case may be) a few basic limnological concepts pertinent to understanding my comments on the water quality data. Our program focuses on a number of inter-related physical and chemical parameters with levels of total phosphorus and dissolved oxygen perhaps the two most important. The reasons for this are simple.

The larger and deeper lakes in Leelanau County thermally stratify each summer. When stratified, a band of warm water remains near the surface (the epilimnion). Just beneath the epilimnion exists a narrower band of water which exhibits a sharp decrease in temperature (the metalimnion or thermocline). Below the metalimnion is a cold deep layer extending to the lake bottom (the hypolimnion). The colder, more dense hypolimnion generally does not interact with the warmer, less dense overlying water until fall when the surface water cools. Until this "fall overturn" occurs, oxygen can be depleted or eliminated from the bottom waters by oxygen-requiring decomposition of organic materials on the bottom. And decomposition rates

generally are related to the productivity of the overlying water, for the greater the biomass produced above, the greater the input of organic material to the sediments below. And when oxygen is greatly reduced or eliminated above the sediments, the rate at which phosphorus is released from the sediments can increase dramatically, and phosphorus is what ultimately fuels the productivity (often called the "limiting nutrient" because when it is no longer available growth stops regardless of the availability of all other nutrients). This situation is undesirable because it can become a significant nutrient pulse during the fall overturn when the water column completely mixes. This internal loading of phosphorus is not only difficult to quantify, but it is especially difficult to remedy. In effect, the lake fuels itself with nutrients from within, and as each lake transforms itself from a water mass to a land mass by filling in (eutrophication), this internal fuel becomes increasingly important.

During the winter, a reverse thermal stratification occurs where the coldest water is just below the ice and the warmest and most dense is just above the bottom (4 degrees centigrade). More importantly, when the ice forms, it prevents the water from mixing with and obtaining oxygen from the atmosphere. This means that bottom sediments can once again reduce or eliminate oxygen, possibly fueling the release of phosphorus and its subsequent input to the system when the lake mixes again in the spring. As a note, an extreme form of oxygen depletion in the winter is referred to as "winter-kill". This occurs in shallow basins (a small water volume relative to a large surface-area of bottom sediments) where ice forms early and becomes snow covered for the winter. The snow prevents light penetration which retards the photosynthetic production of oxygen (the only major oxygen source once ice prohibits atmospheric mixing). During a long winter season, sediments and organisms dependent on oxygen for respiration consume the entire quantity of available oxygen and when the ice goes, these organisms will be found dead. Fortunately, none of the larger lakes within Leelanau County are susceptible to this phenomenon because of their basin morphometries (shapes).

Due to space limitations and the importance of phosphorus and dissolved oxygen most of the following discussions on individual lake basins will focus on these parameters, as well as chlorophyll-a (the green pigment in algae), secchi disk depth, and to some extent nitrate nitrogen. Many summary figures are used for both my convenience and yours. All raw data are available in appendix form.

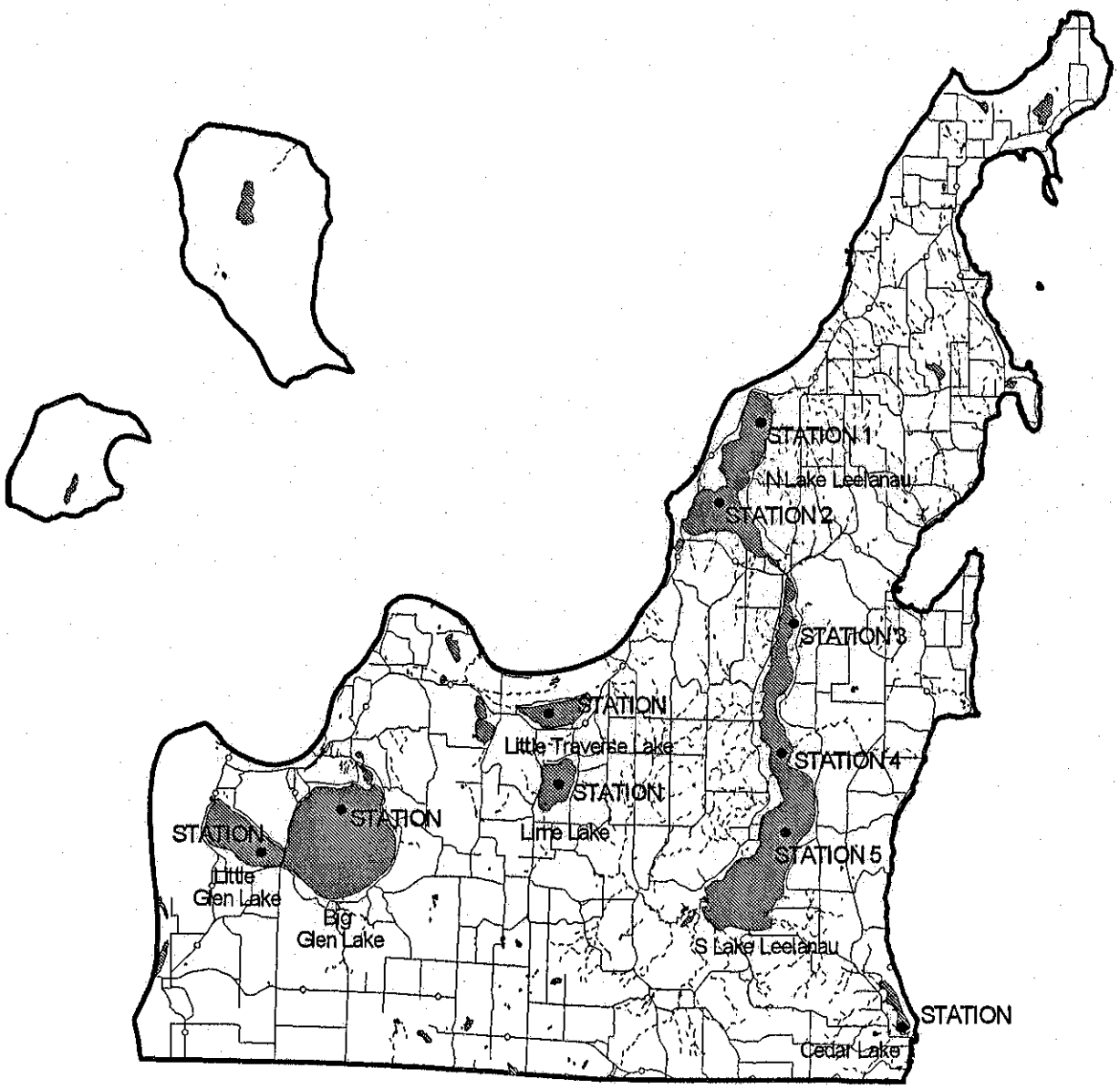
NORTH LAKE LEELANAU

Hydrolab profile data (depth in meters, temperature in degrees centigrade, dissolved oxygen in milligrams per liter, conductivity in millimhos per cm at 25 degrees centigrade, and oxidation/reduction potential: positive = oxidizing, negative = reducing environment), secchi disk visibility data, and water samples (primarily for total phosphorus, nitrate, and chlor-a analyses) have been collected 6-9 times per year at Station 1 (fig. 1). Early in the program Hydrolab profiles were obtained at Station 2, now only water samples and secchi depth are collected (see the Appendix for all raw profile and chemistry data for all lake stations). Water samples were collected each sampling at the surface, 10, 20, and 35 meters at Station 1, and at the surface, 10, and 25 meters at Station 2. Chlor-a samples were obtained by combining approximately 16-17 mls of water from a depth of twice the secchi depth, the secchi depth, and from the surface to form a 50 ml composite sample.

In UNDER 2 ppm LEADS TO INCREASED P RELEASE from Sediment

Hydrolab profile, nutrient chemistry, and secchi visibility data continue to indicate that North Lake Leelanau water quality is good, and likely unchanging. There may be some hypolimnetic phosphorus accumulation in both the summer and winter months at Station 1 (the deepest area in the basin and consequently the primary sampling location for North Lake Leelanau).

For 6 consecutive years, late summertime oxygen levels in the hypolimnion just above the lake bottom sediments were depressed, although no anoxia (a complete loss of oxygen) was recorded (the only deep-water station in the County not to exhibit a complete loss of oxygen in water just above the sediments during summer). Off-bottom oxygen depletions under the ice in late winter have also been observed (fig. 2). Conditions for accelerated phosphorus release are best when all oxygen has been depleted in overlying waters, however, release rates can increase in concentrations less than 2 mg/L of oxygen, and this may be occurring. Increases in total phosphorus concentrations in the hypolimnion (fig. 3) appear to correspond to periods of low dissolved oxygen (i.e., late summer and late under-ice). As with any dataset, the relationship is not perfect. Only in 1990 was an extended period of very low oxygen observed during the summer months. In subsequent years the oxygen concentrations diminish to about 2 mg/L, but do not exceed it. The extent of these reduced levels in the late summer periods affects a greater portion of the water column and therefore a greater surface area of the bottom sediments. Values range from about 2-4 mg/L at depths greater than 30 meters (this of course assumes that there is still some enhancement of release rates at these oxygen levels). Conversely, in the winter periods of low oxygen, which appear to be every year, the reduced concentrations only occur below a depth of 37 meters. This dramatically reduces the area of bottom which might contribute phosphorus under such conditions.



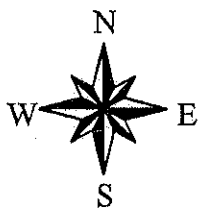


Figure 1. Station Locations

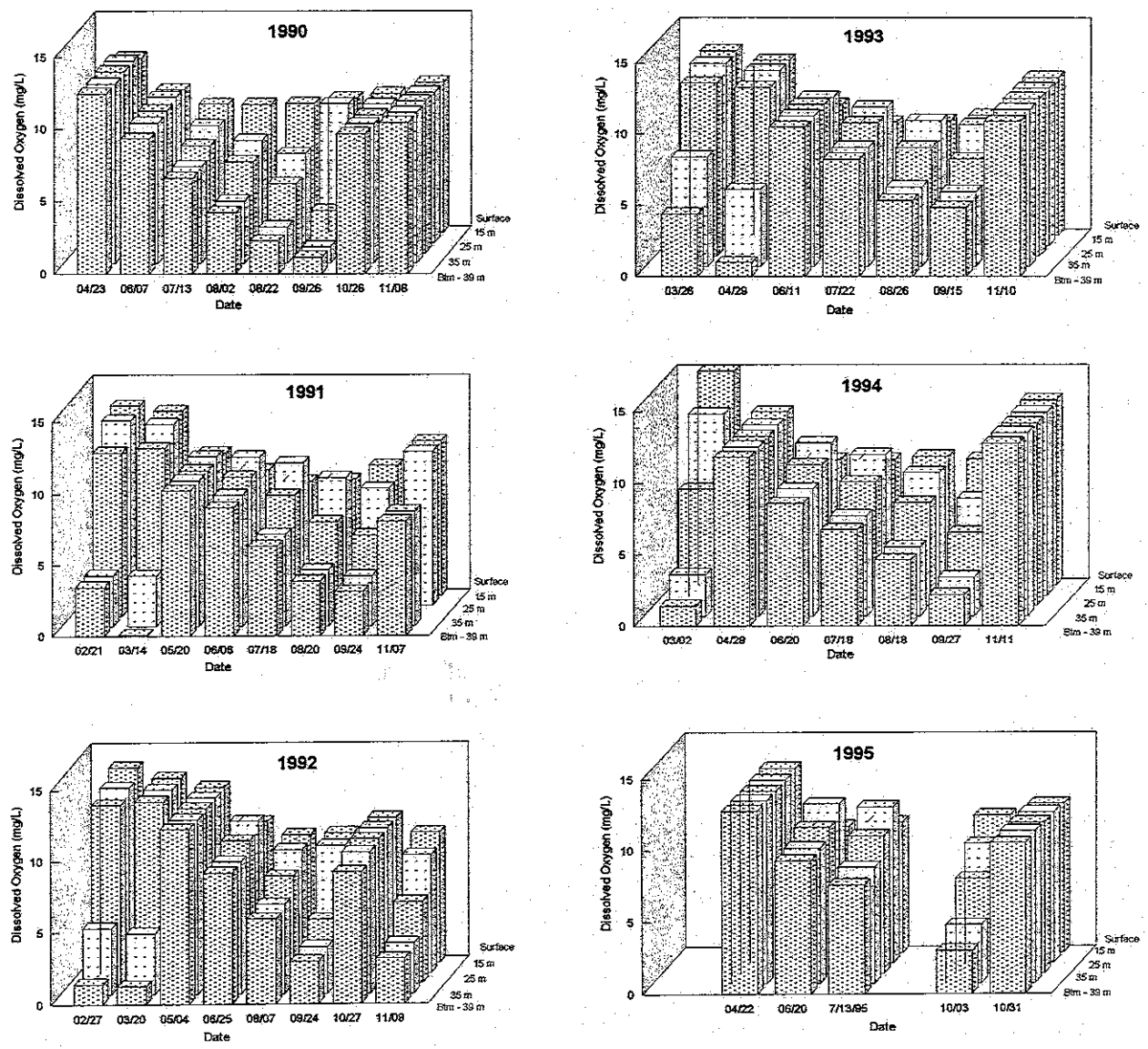


Figure 2. Dissolved oxygen concentrations (mg/L) at depths- the surface, 15 m, 25 m, 35 m, and the bottom, observed in North Lake Leelanau throughout each year, 1990 through 1995. Note consistent decrease of oxygen levels off bottom during late summer/early fall and late winter (ice) periods.

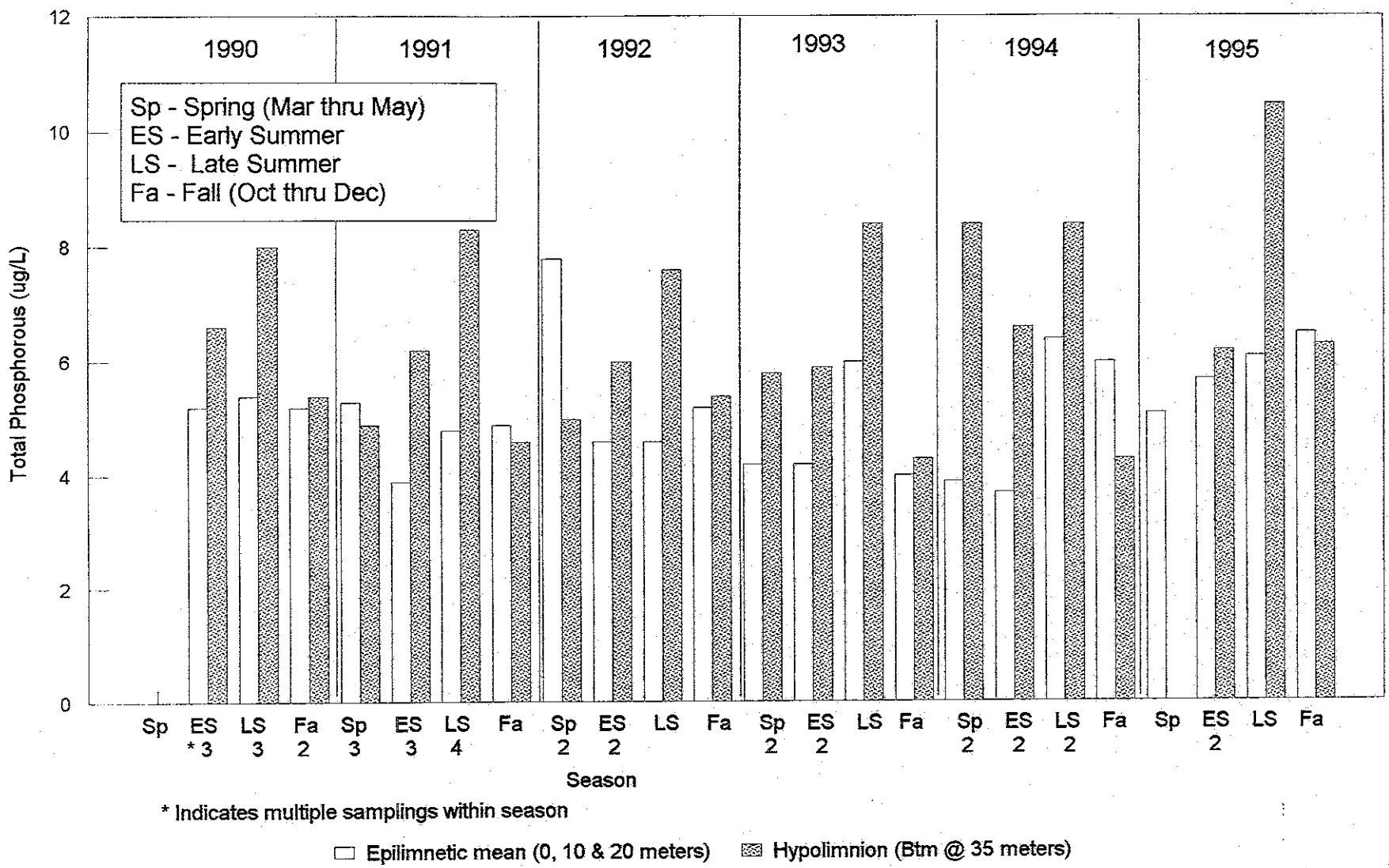


Figure 3. Seasonal (Spring, Early Summer, Late Summer, Fall) epilimnetic and hypolimnetic phosphorous concentrations observed 1990 through 1995 in North Lake Leelanau. Epilimnetic concentration is the mean value of the 0, 10 and 20 m concentrations, while the 35 m value represents the hypolimnion. In cases where multiple samples were collected during a season, values were averaged.

At this time it does appear that there is some internal input of phosphorus to North Lake Leelanau as evidenced by the consistent slightly higher total phosphorus readings above 6 mg/L in the hypolimnion during late summer. I suspect that the relative contribution of this source is small.

So what does this mean? At this point it gives insight into a potential phosphorus source/problem in the basin. As more pieces of the puzzle are empirically determined with nutrient budget work (such as wet and dry atmospheric deposition, groundwater-both natural and anthropogenic, surface water, etc.), the relative contribution of internal phosphorous loading from sediments can be assessed. Additionally, upon turnover in the fall, it is possible that a substantial portion of the phosphorus released to the hypolimnion is precipitated back to the sediments when mixed with oxygenated water. The percentage is difficult to determine, depending on the presence or absence of iron or hydrogen sulfide, and obviously the more that precipitates, the more positive the impact on the overall health of the lake.

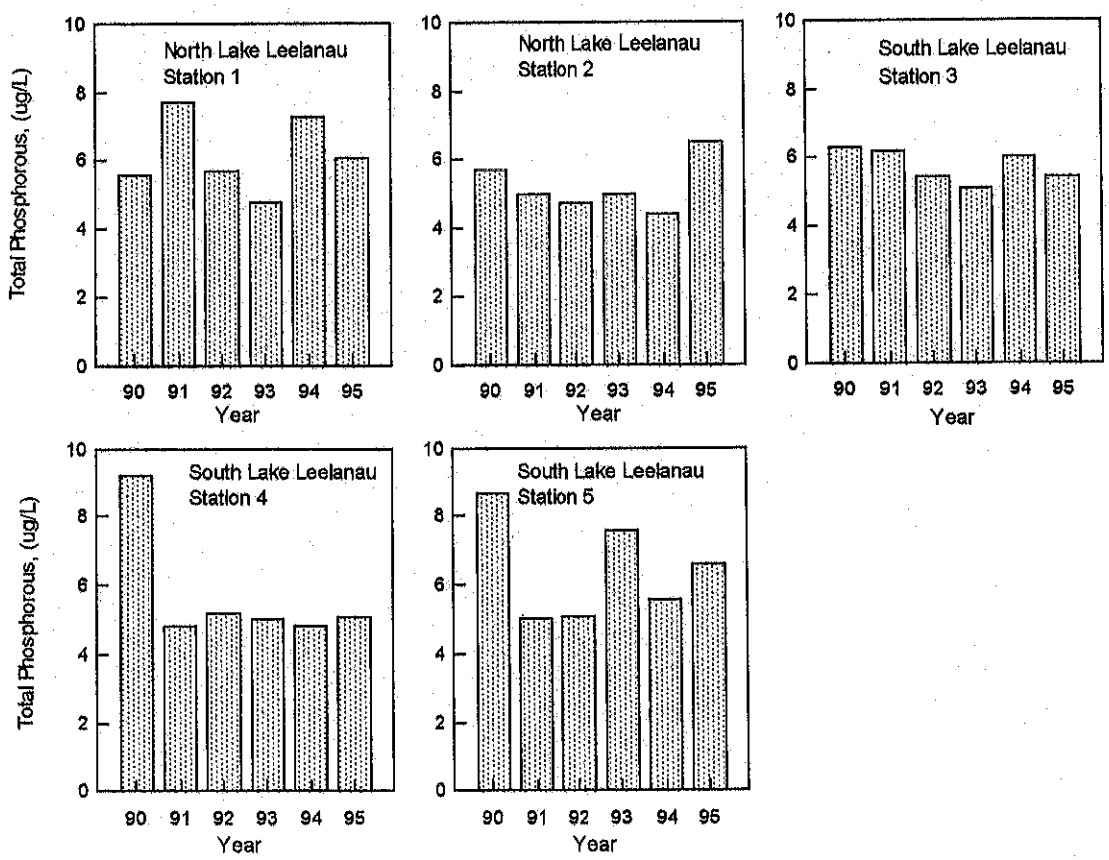


Figure 4. Overall annual mean phosphorous concentrations (ug/L) observed 1990 through 1995 at five Lake Leelanau Stations.

Having said all of this, it is important to point out that yearly average total phosphorus concentrations in the lake have all been consistent, and well within acceptable or oligotrophic standards (less than 8 ug/L)(fig. 4). Oligotrophic conditions are most desirable as they are indicative of low productivity, high water transparency, and general high water quality. While total phosphorus is only one index of water quality, it is not uncommon for highly productive lakes (eutrophic) to exhibit total phosphorus concentrations exceeding 100 ug/L.

Nitrate nitrogen concentrations have ranged from about 10 to 1000 ug/L, usually falling in the 200 to 400 ug/L range when averaged over depth. There appears to be a reduction in the epilimnion during late summer periods, although this phenomenon is not nearly as pronounced as in Big Glen Lake. It is hypothesized that this reduction is related to specific nutrient/species interactions. Possibly, one species gains a competitive advantage over others in extremely low phosphorus environments in the presence of nitrate nitrogen. I feel this warrants watching, for it may be nitrogen is playing a larger role in productivity in some of our lakes than traditionally thought. And if this turned out to be the case, it poses more challenging problems relative to phosphorus because of its higher motility and availability.

NO_3 200-400 ug/L
Range 10-1000

As stated earlier, productivity results in continued input of organic matter to the sediments which will require oxygen to decompose. Production is highest during the summer, although our measurements of chlor-a (the green photosynthetic pigment of algae) have not identified any pronounced summer increases (fig. 5). Values have ranged from 1-3 ug/L, well below the oligotrophic standard of 4.0 ug/L. At such low values, a peak increase or change in the summer time algal community may result in temporary chlor-a changes of only perhaps 0.5 to 1 ug/L, which we would likely miss without an increase in our sampling frequency.

Chlor a - 1-3 ug/L

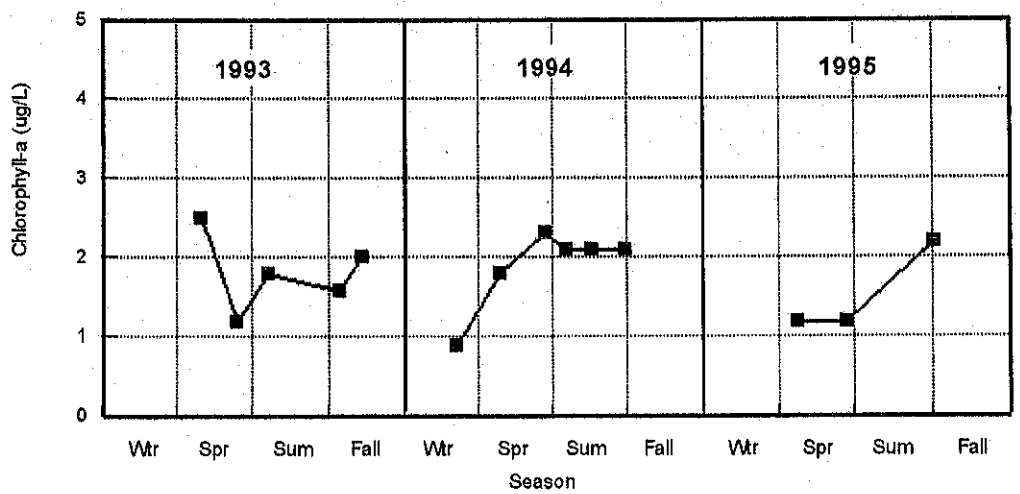


Figure 5. Seasonal chlorophyll-a concentrations (mg/L) observed 1993 through 1995 at North Lake Leelanau Station 1. Each value represents the mean of a sample composited from the surface, the depth of the secchi observation, and twice the secchi depth.

We have observed a decrease in water transparency throughout the lake as measured by the secchi disk visibility depth after summer commences. Season minimums and maximums have ranged between about 10 and 20 feet from 1990 to 1995 (fig. 6). The oligotrophic standard for this measure is greater than 16 feet. Because our lakes are relatively hardwater, calcium carbonate based systems, natural clouding or "whiting" occurs during peak photosynthetic periods and can result in a lowered secchi disk value, so this is not surprising.

Watch –
1) Dolicp standard for NO3
2) Process of 'whiting'?

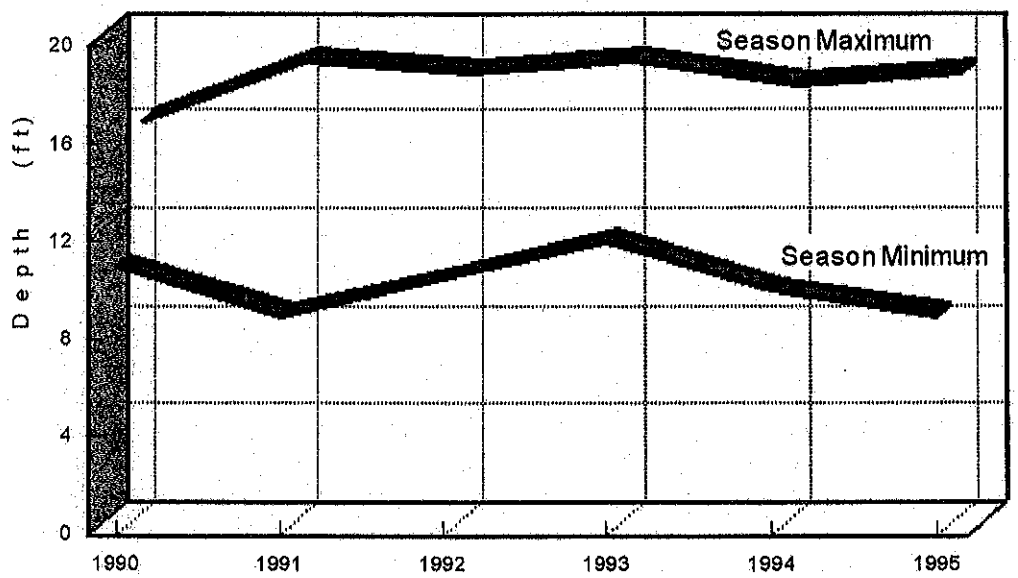


Figure 6. Seasonal maximum and minimum secchi disk observations (depth in feet) from 1990 through 1995 at North Lake Leelanau Station 1.

Using historical data from the DNR/Lake Association program it would appear that there has been a slight increase in the secchi depth since 1975 (Fig 7). Actually it appears that the increase occurred between 1975 and 1985 and has remained about the same between 1985 and 1995. It is conceivable that this apparent increase was due, at least in part, to the elimination of phosphorous in detergents.

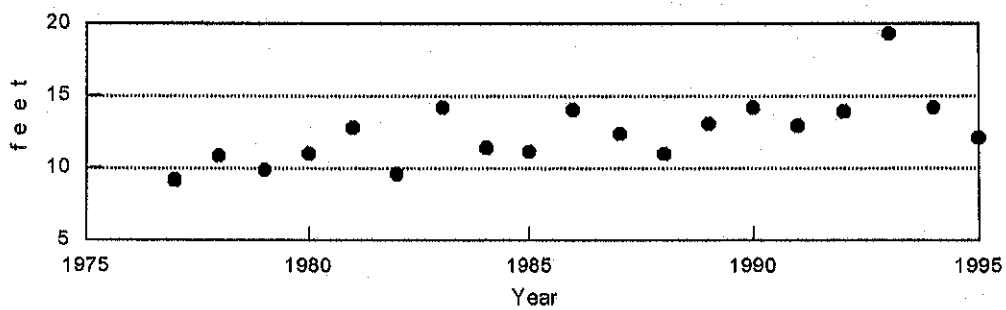


Figure 7. Mean secchi disk observations (depth in feet) from 1975 to 1995 for North Lake Leelanau as reported by DNR/Lake Association Self Help Program.

SOUTH LAKE LEELANAU

Hydrolab profile data, secchi disk transparency data, and water samples have been collected 6-9 times per year at stations 3-5 (fig. 1). Water samples were collected at the surface, 7, and 10 meters at Station 3, at the surface, 7, and 11 meters at Station 4, and at the surface, 10, and 18 meters at Station 5. Chlor-a concentrations have been determined at stations 3 and 5 using 50 ml composite samples beginning in 1993.

Like North Lake Leelanau, Hydrolab profile and water chemistry data indicate that South Lake Leelanau water quality is good. The relationship between dissolved oxygen and total phosphorus concentrations over depth is similar to that observed in the north basin. There has been severe off-bottom oxygen depletion at Station 5 prior to fall turnover over the past 6 seasons (fig. 8). Some winter oxygen depression occurs, however, not to the extent observed in the north basin, and near-bottom oxygen concentrations most likely remain sufficient enough as to not adversely influence water chemistry prior to ice-out. Although the relationship does not appear to be as clear, total phosphorus levels during summer periods in the hypolimnion seem to be slightly elevated (fig. 9). Late summer (and at other times as well) hypolimnetic values tend to be slightly higher than concurrent epilimnetic levels. Because periods of severely reduced oxygen generally develop in mid to late July and persist until mid to late September, and extend from a depth of 15 to 16 m to the bottom, this phenomenon may have a greater overall potential impact in the large southern basin as there is a considerable surface area of bottom sediments exposed to little or no dissolved oxygen below 15 meters.

I would also like to point out that each year has the potential to be somewhat different than any other individual year (again the reason for the long-term commitment) because of the weather. One summer may be long and hot with fairly calm weather and another may be short and cold and breezy. The former would provide conditions for an early and long-lasting stratification (ideal for phosphorus release) and the latter would tend to create a shorter period whereby phosphorus could enter the system. For example, Station 3, because of its relatively shallow depth, is particularly susceptible to wind-induced breakdown of the thermal structure in mid-summer. This occurred in 1991, and thermal stratification never really developed in 1992, a generally cold and windy summer. All of the south basin stations are more likely to be influenced in this way (because of their shallower depths), and as far as phosphorus release from the sediments is concerned, an early breakdown of the thermal structure is good, because it re-supplies oxygen to the water above the sediments.

During periods of late summer stratification at Station 3, hypolimnetic phosphorus concentrations were slightly elevated from 1990 to 1995, however, the data do not indicate that such concentrations are strictly unique to that time of the year and therefore those conditions.

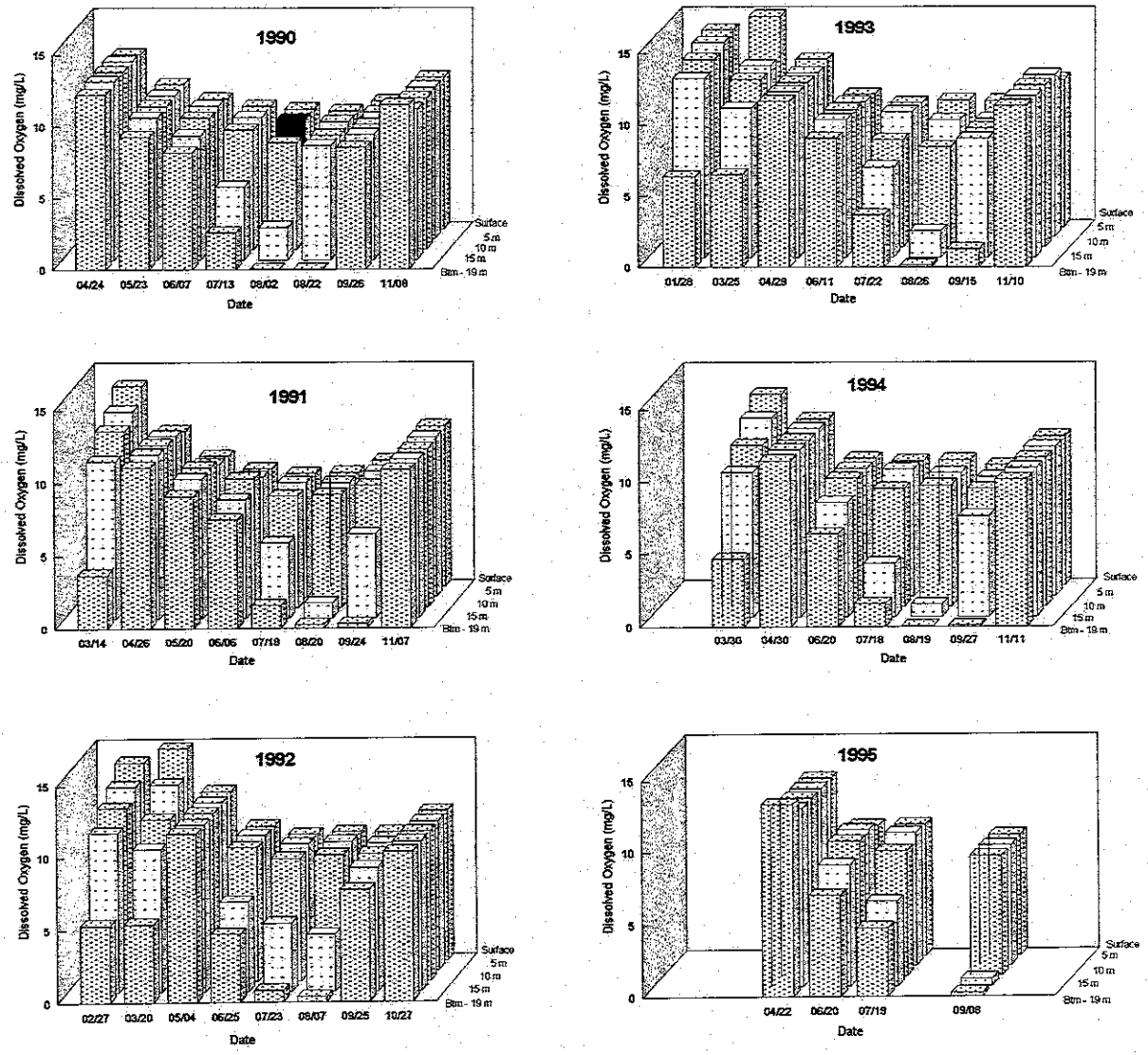


Figure 8. Dissolved oxygen concentrations (mg/L) at depths of the surface, 5m, 10m, 15m, and the bottom, observed in South Lake Leelanau Station 5 throughout each year, 1990 through 1995. Note consistent decrease of oxygen levels at bottom during late summer/early fall.

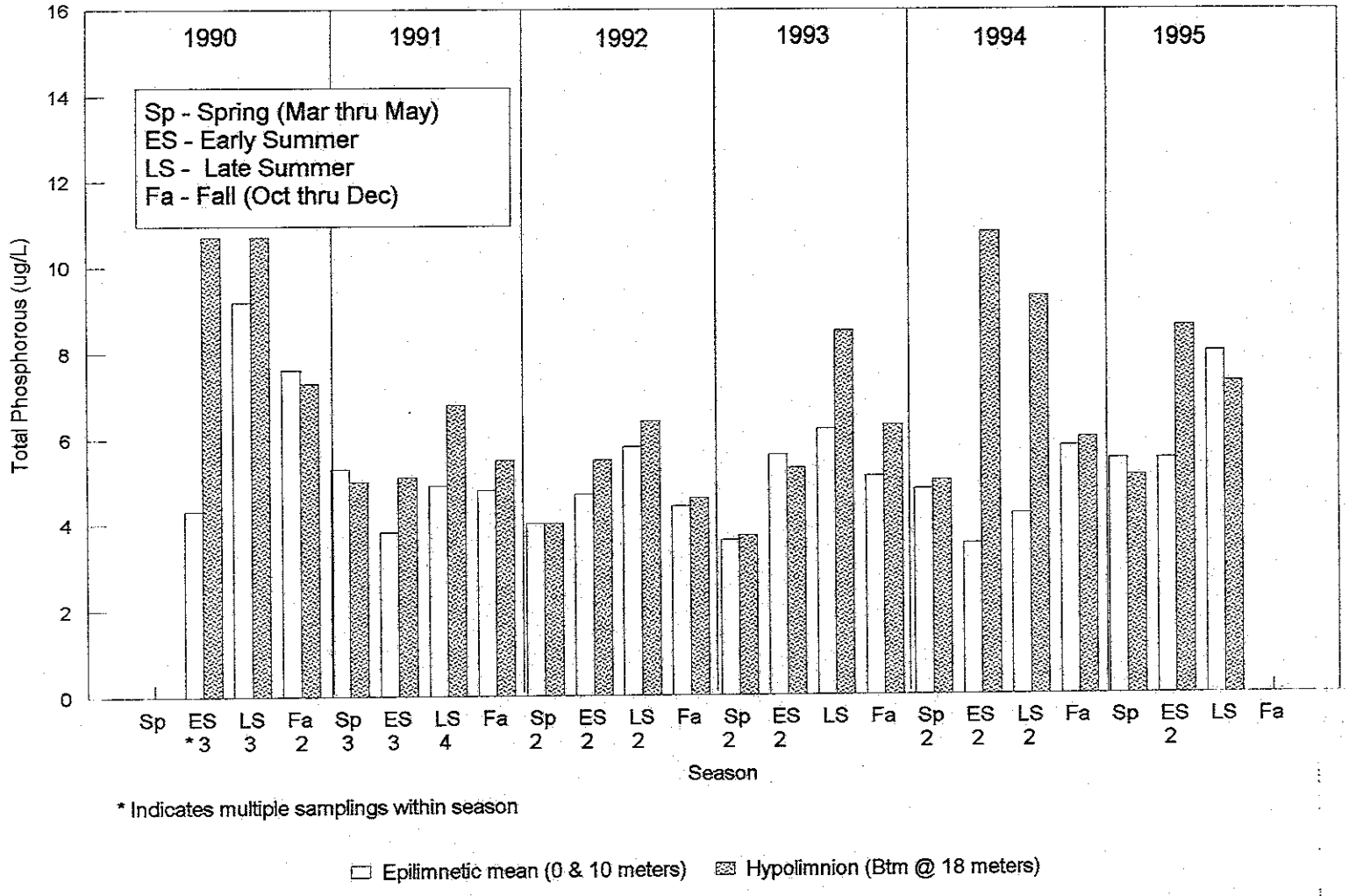


Figure 9. Seasonal (Spring, Early Summer, Late Summer, Fall) epilimnetic and hypolimnetic phosphorous concentrations observed 1990 through 1995 in South Lake Leelanau Sta. 5. Epilimnetic concentration is the mean value of the 0, 10 and 20 m concentrations, while the 18 m value represents the hypolimnion. In cases where multiple samples were collected during a season, values were averaged.

While there may be some internal loading of phosphorus in the southern basin, the entire south lake mean phosphorus concentration from 1990 has still been in or at the oligotrophic range (fig. 4). The relatively high mean value observed during 1990 is due to high deepwater concentrations observed during the summer. Whether that was an unusual summer remains to be seen.

Nitrate levels in the southern basin are somewhat lower than in the northern basin, and late summer epilimnetic concentrations do not decrease (relative to hypolimnetic concentrations) with a great deal of consistency. The lower values are likely due to differences in localized watershed hydrologies, i.e., Houdek creek has a nitrate concentration 3 times that of the Cedar River.

Chlor-a and secchi disc values from the southern basin are very similar to those observed in the northern basin (figures 10 and 11 respectively), with both falling well within the oligotrophic range.

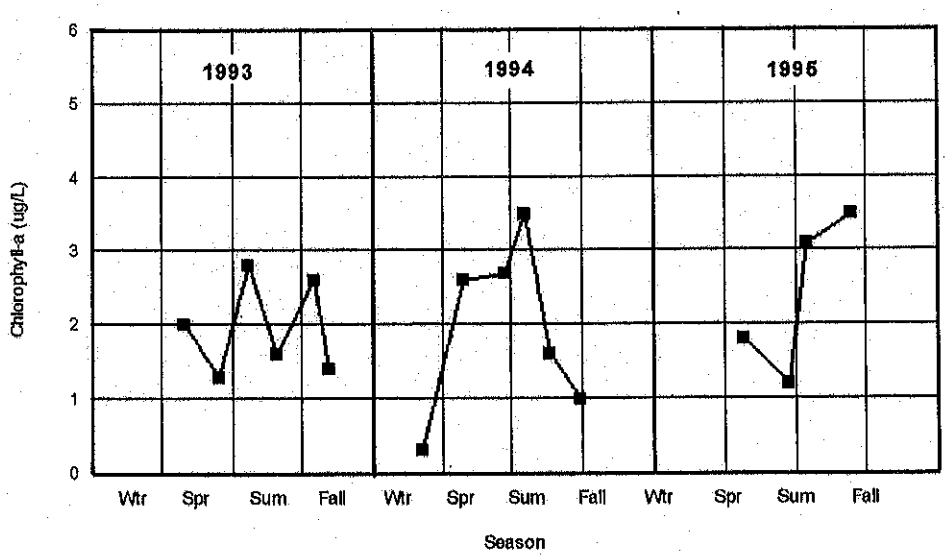


Figure 10. Seasonal chlorophyll-a concentrations (ug/L) observed 1993 through 1995 at South Lake Leelanau Station 5. Each value represents the chlor-a concentration determined from a 50 ml sample composited from the surface, the depth of the secchi observation, and twice the secchi depth.

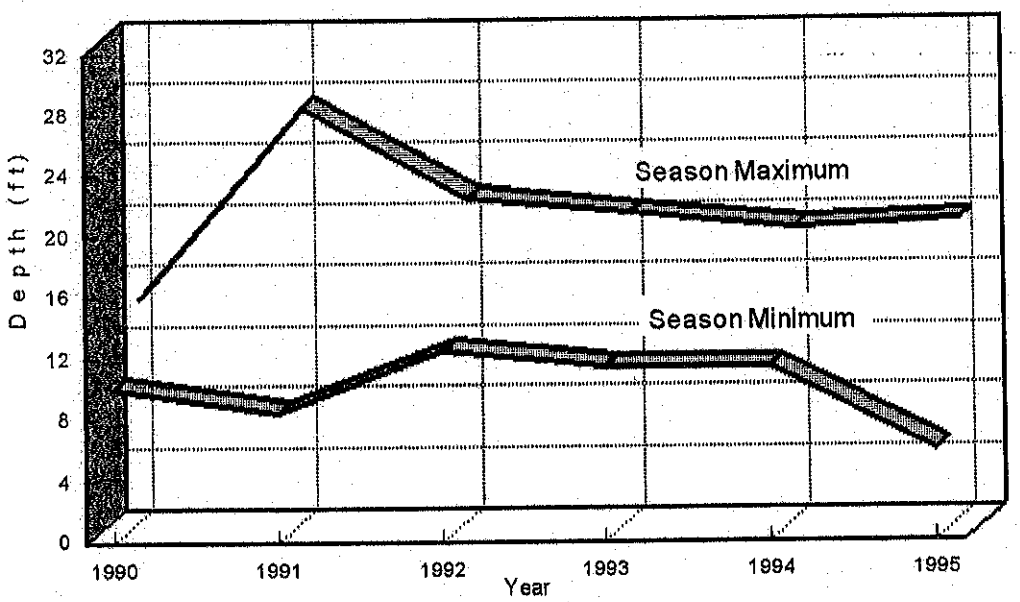


Figure 11. Seasonal maximum and minimum secchi disk observations (depth in feet) from 1990 through 1995 at South Lake Leelanau Station 5.

LIME LAKE

Hydrolab profile data, secchi disk transparency data, and water samples have been collected 6-9 times per year at the single station (fig. 1) on Lime Lake between 1991 to 1995. Water samples were collected at the surface, 10, and 18 meters. 50 ml chlor-a samples have been collected since 1993.

Profile and water chemistry data indicate that the water quality of Lime Lake is also good and stable. Although consistently exhibiting oxygen depletion prior to fall overturn (fig. 12), the internal phosphorus input is probably small. Concentrations in the hypolimnion are elevated relative to the overlying water, particularly in the early and late summer periods (fig. 13). The 1995 data appear the way I would normally expect, while higher concentrations in the early summer are more difficult to interpret. I suspect by combining the data (early summer=June+July), we are slightly inflating the value, for hypolimnetic oxygen depletions consistently develop around mid to late July. Such conditions persist through mid to late September and usually extend from the 14 meter depth to the bottom. From bathymetric charts it is estimated that these conditions would influence about 10 to 15 percent of the lake bottom surface sediments, creating the potential for increased nutrient input in the future.

Presently however, total phosphorus concentrations averaged over depth and time do indicate that Lime Lake is oligotrophic (fig. 12).

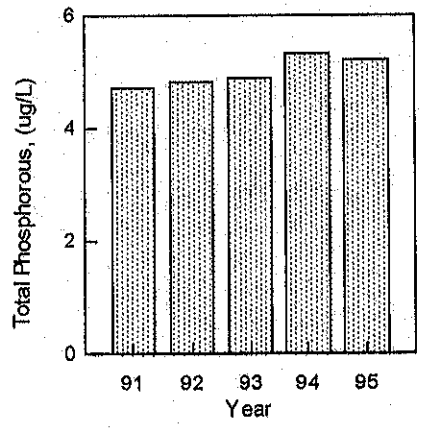


Figure 12. Overall mean phosphorous concentrations (ug/L) observed 1991 through 1995 at Lime Lake.

Nitrate nitrogen concentrations in Lime Lake are similar to other area lakes on an overall average basis. Mid to late summer epilimnetic decreases have not been observed and perhaps this is related to subtle differences in the species composition of the plankton community.

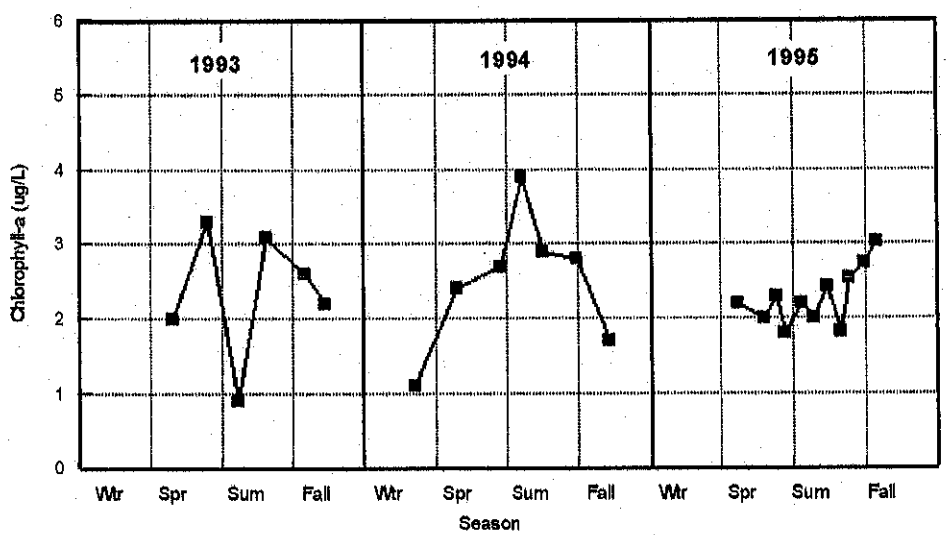


Figure 13. Seasonal chlorophyll-a concentrations (ug/L) observed 1993 through 1995 in Lime Lake. Each value represents the chlor-a concentration determined from a 50 ml sample composited from the surface, the depth of the secchi observation, and twice the secchi depth.

Chlor-a concentrations observed during 1993 to 1995 are all indicative of an oligotrophic system, generally falling between 2 and 3 mg/L, with no prominent and/or recurring peaks (fig. 13). Water clarity decreases in the spring to early summer as evidenced by the secchi data. This is most likely due to a springtime diatom bloom which is characteristic of many lakes. There is no evidence to suggest that it is caused by any large nutrient input, whether internal or external, and it is more likely a particular species or group of species responding to spring water temperatures and other very specific requirements.

Overall secchi data from 1990 to 1995 vary seasonally from minimums of about 5 feet to maximums of about 15 feet (fig. 14). The fact that values are below the oligotrophic standard of 16 feet is likely a function of the carbonate hardwater/photosynthetic whiting than a problem with extensive primary production given the very low total phosphorus and chlor-a concentrations.

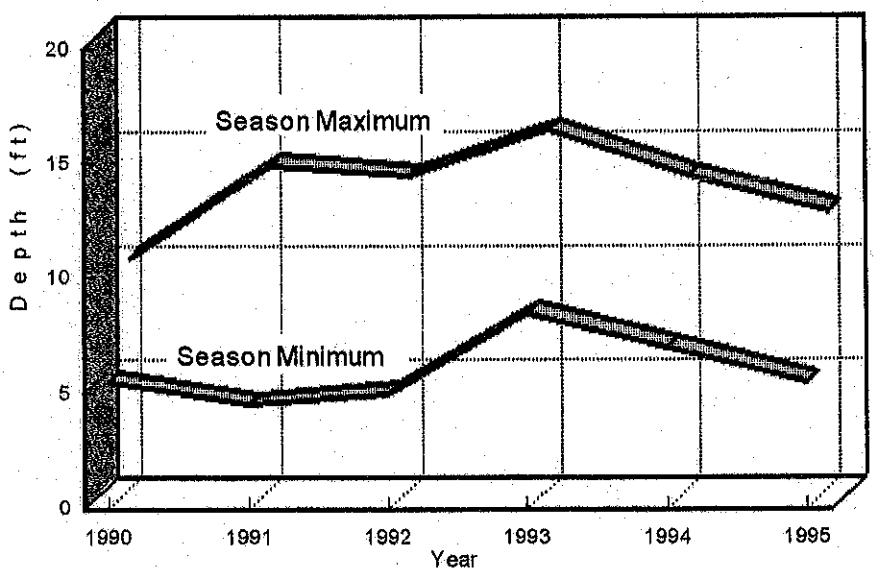


Figure 14. Seasonal maximum and minimum secchi disk observations (depth in feet) from 1990 through 1995 at Lime Lake.

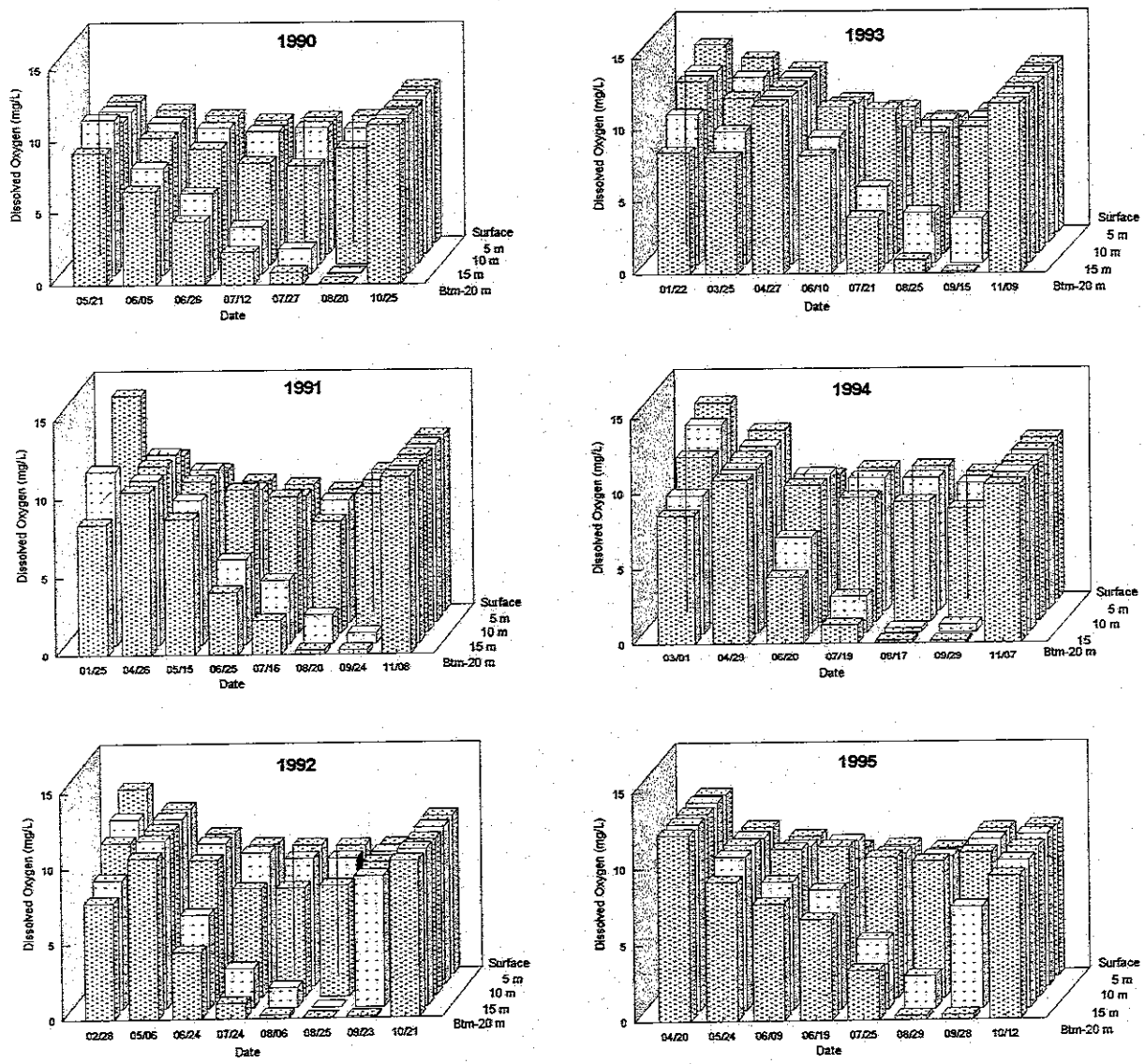


Figure 15. Dissolved oxygen concentrations (mg/L) at depths of- the surface, 5m, 10m, 15m, and the bottom, observed in Lime Lake throughout each year, 1990 through 1995. Note consistent decrease of oxygen levels off bottom during late summer/early fall.

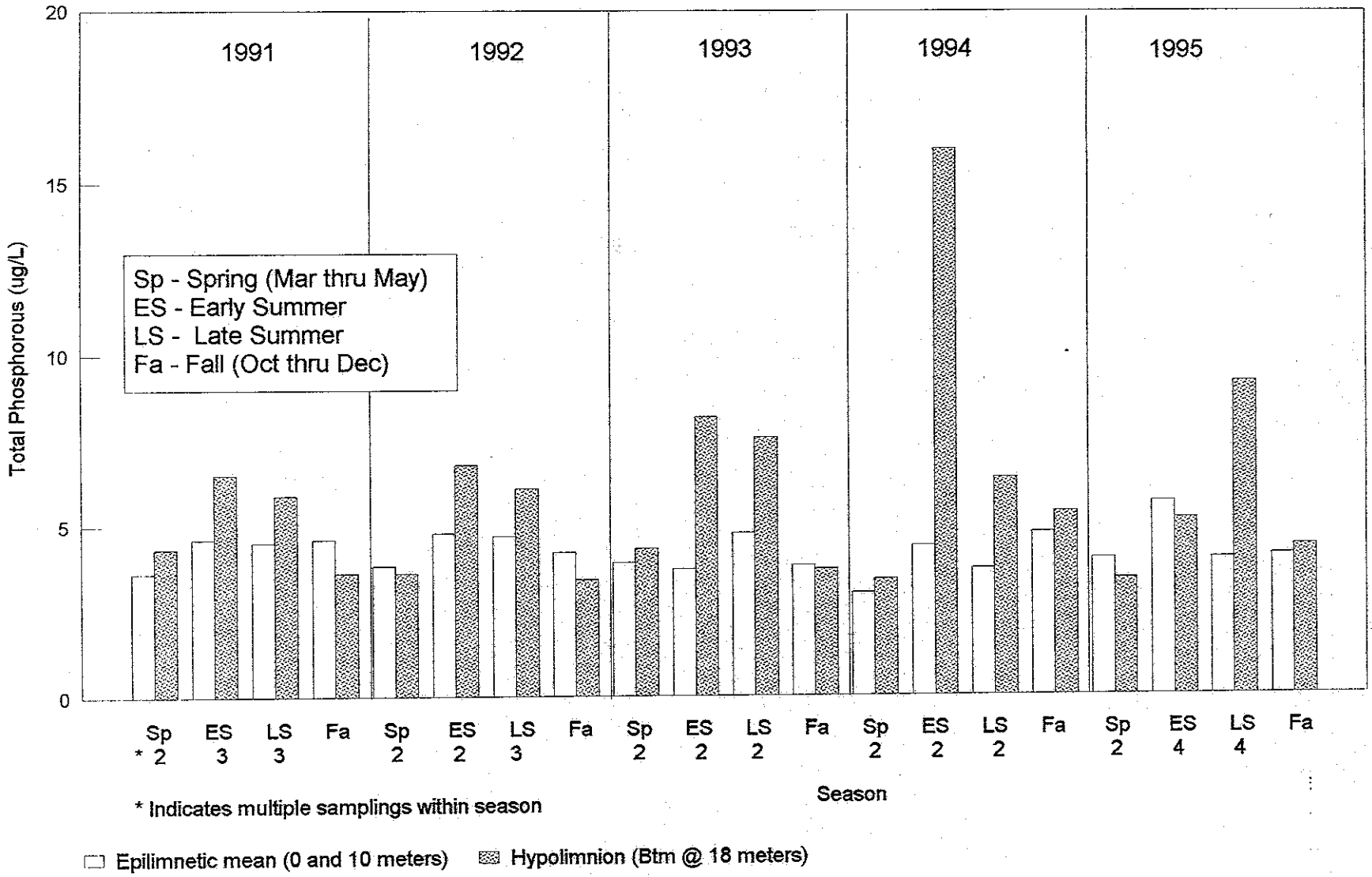


Figure 16. Seasonal (Spring, Early Summer, Late Summer, Fall) epilimnetic and hypolimnetic phosphorous concentrations observed 1991 through 1995 in Lime Lake. Epilimnetic concentration is the mean value of the 0 and 10 meter concentrations, while the 18 meter value represents the hypolimnion. In cases where multiple samples were collected during a season, values were averaged.

LITTLE TRAVERSE LAKE

Hydrolab profile data, secchi disk transparency data, and water samples have been collected 6 to 9 times at the single station (fig. 1) on Little Traverse Lake beginning in 1990. Water samples have been collected at the surface, 7, and 14 meters, and 50 ml composite samples for chlor-a have been collected since 1993.

Profile and water chemistry data indicate that the water quality of Little Traverse Lake continues to be good and not appreciably different from other area lakes. It also consistently exhibits a severe oxygen depletion prior to fall overturn (fig. 20), and the numbers suggest that there is some internal phosphorus input from the oxygen depleted hypolimnion each summer (fig. 21). Higher hypolimnetic concentrations when oxygen is present remains puzzling, but generally, this has been observed in all the program lakes, and is likely inflated a bit more by incorporating July data. One would expect concentrations to be highest during the oxygen depleted times, which in Little Traverse develop in mid to late July and persist until about mid September, below a depth of about 10 meters. This impacts about 20 percent of the bottom sediments and therefore has the potential to be a significant source of phosphorus to the system. Additionally, at times I have noted a distinct hydrogen sulfide smell from deepwater late summer samples and this would suggest that phosphorus released from the sediments would likely be very available when oxygen-fresh water returns. Not measuring hydrogen sulfide or iron however, only makes this anecdotal.

Once again it should be emphasized that the mean total phosphorus concentrations averaged over depth and time from 1990 to 1995 still fall well within the oligotrophic range (fig. 17).

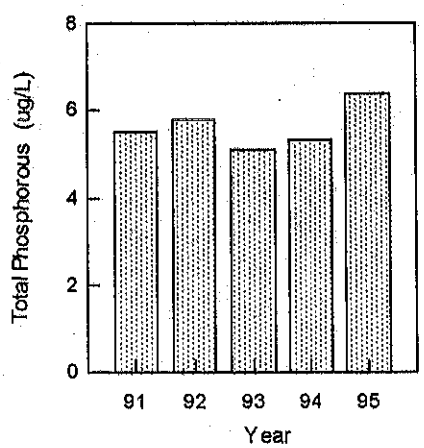


Figure 17. Overall mean phosphorous concentrations (ug/L) observed 1991 through 1995 at Little Traverse Lake.

Although chlor-a values are a bit more variable than other area waters, most values are in the 3 ug/L range. There are some distinct spikes which undoubtedly reflect algal blooms (fig. 18). In late summer to early fall chlor-a jumps to 5 to 7 ug/L. This may be a direct indication of the hypolimnetic phosphorus becoming available to algal populations upon fall mixing, especially in 1993 and 1995.

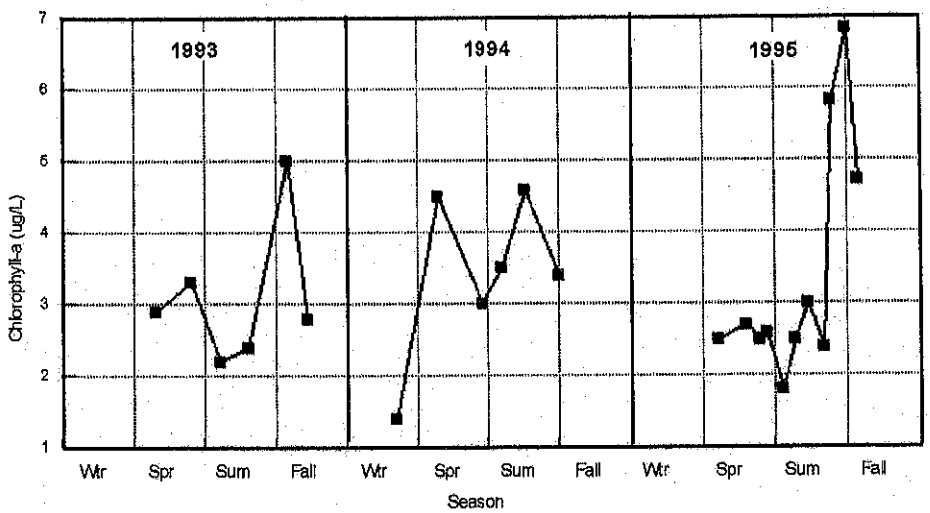


Figure 18. Seasonal chlorophyll-a concentrations (ug/L) observed 1993 thru 1995 in Little Traverse Lake. Each value represents the chlor-a concentration determined from a 50 ml sample composited from the surface, the depth of the secchi observation, and twice the secchi depth.

Nitrate concentrations and secchi data are similar to those of Lime Lake. Observed secchi depth lows from 1990 to 1995 were approximately 6 feet, with concurrent highs in the 10 to 15 foot range (fig. 19).

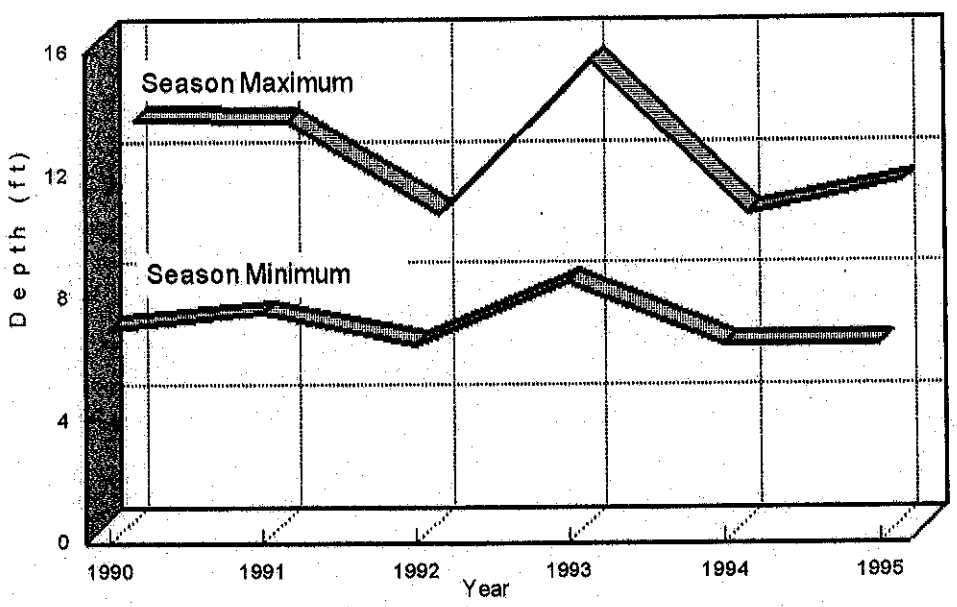


Figure 19 . Seasonal maximum and minimum secchi disk observations (depth in feet) from 1990 through 1995 at Little Traverse Lake.

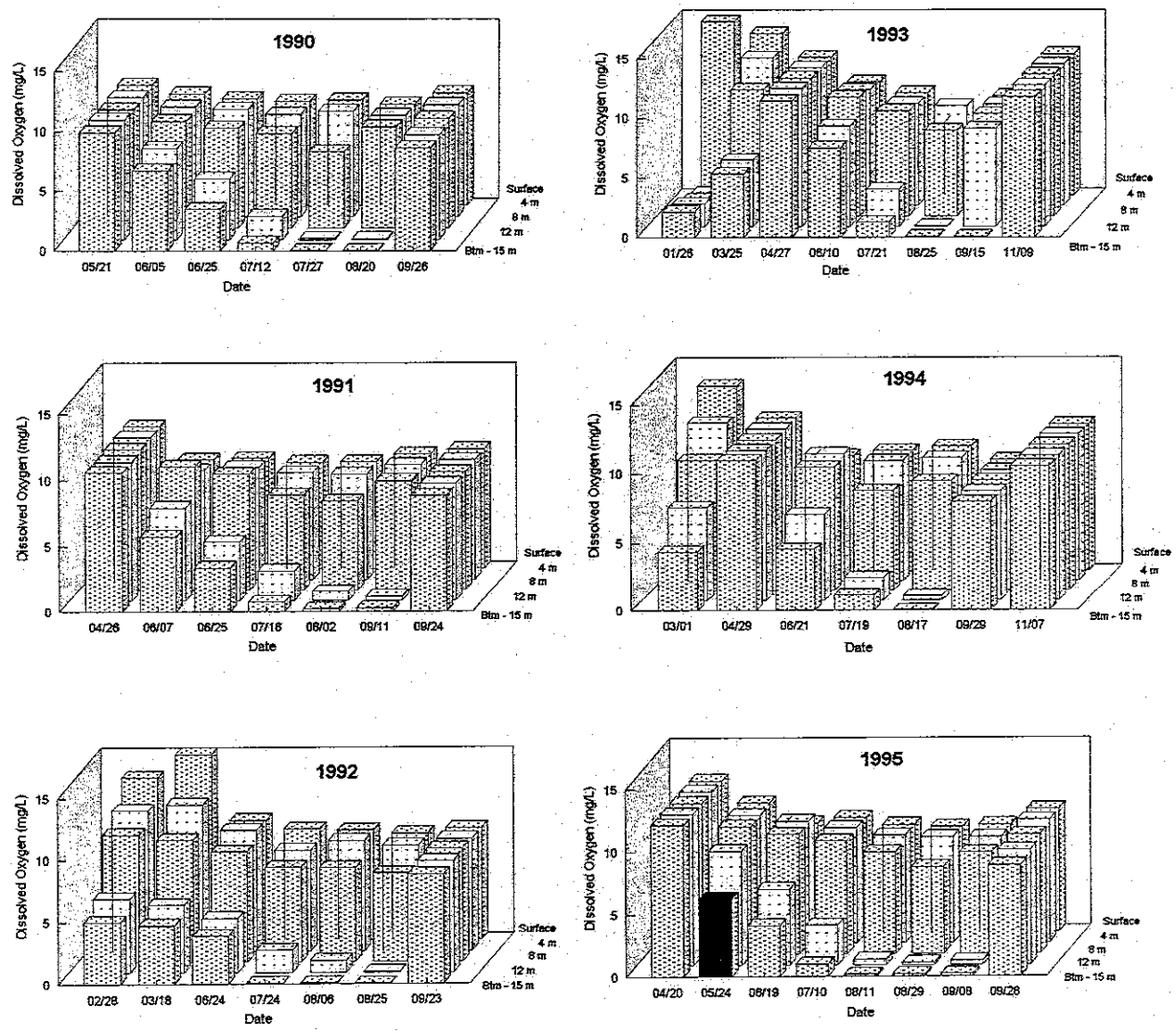


Figure 20. Dissolved oxygen concentrations (mg/L) at depths- the surface, 4m, 8 m, 12m, and the bottom, observed in Little Traverse Lake throughout each year, 1990 through 1995. Note consistent decrease of oxygen levels off bottom during late summer/early fall.

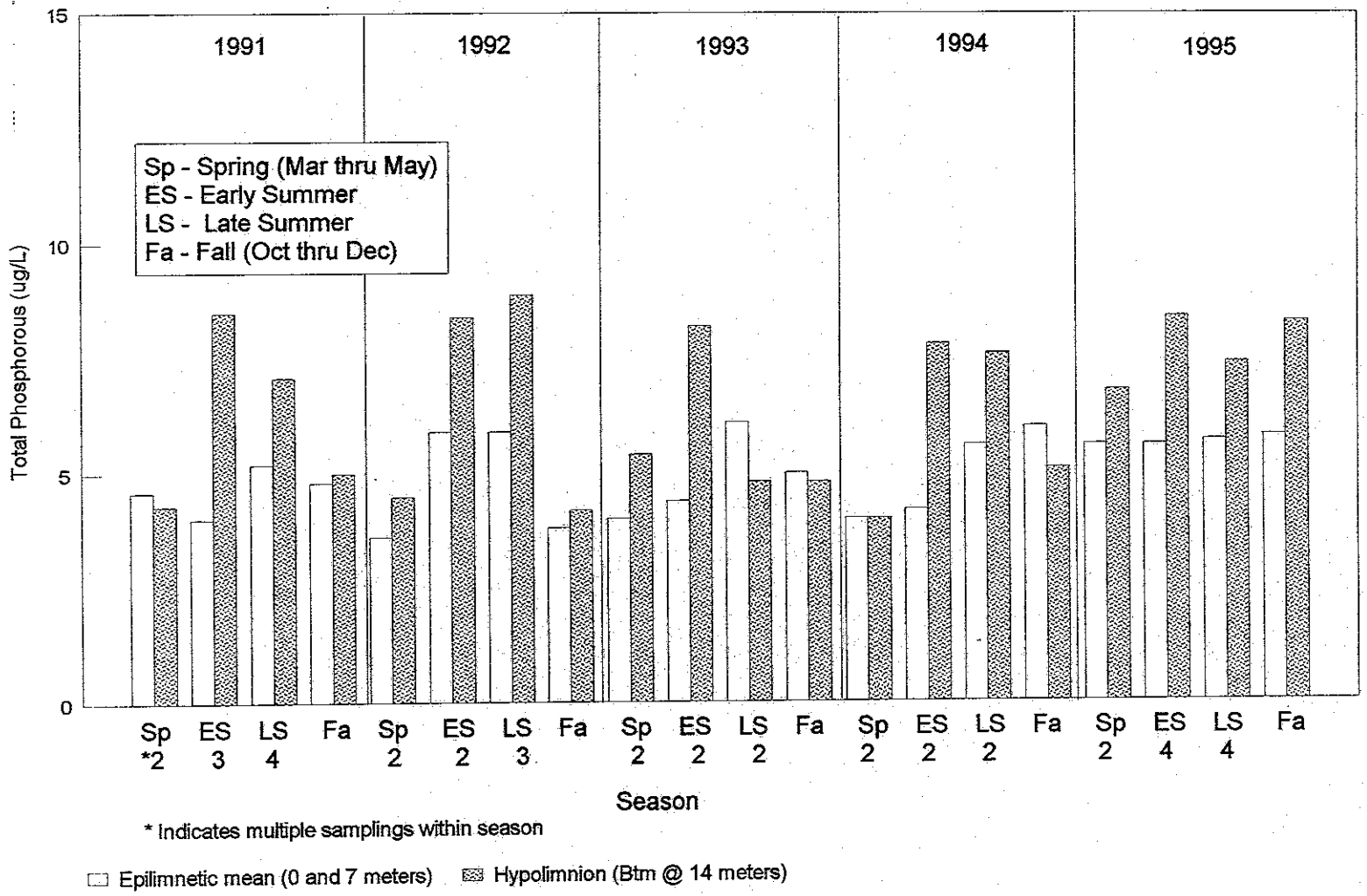


Figure 21. Seasonal (Spring, Early Summer, Late Summer, Fall) epilimnetic and hypolimnetic phosphorous concentrations observed 1991 through 1995 in Little Traverse Lake. Epilimnetic concentration is the mean value of the 0 and 7 meter concentrations, while the 14 meter value represents the hypolimnion. In cases where multiple samples were collected during a season, values were averaged.

GLEN LAKE

Hydrolab profile data, secchi disk transparency data, and water samples have been collected 6-9 times per year at a single station each on Big Glen and Little Glen lakes (fig. 1) beginning in 1990. Water samples were collected at the surface, 10, 20, and at 35 meters on Big Glen and the surface, 1 and 3 meters on Little Glen. 50 ml composite samples for chlor-a have been collected since 1993 from both basins.

Based on all available data, Glen Lake's water quality is excellent and comparable with other area lakes. The hypolimnion in Big Glen does exhibit an oxygen depletion prior to fall turnover, usually developing in mid to late August and persisting until mid to late October (fig. 23). Severely reduced or oxygen depleted water exists below the 34 to 35 meter depth at the peak of stratification. Detectable phosphorus release from the sediments was not observed in 1990 and 1991, however, data suggest that there was some release in the summers of 1992 through 1994 (fig. 24). The 1995 data are inconsistent with the 1990 to 1994 data, with the spring hypolimnetic value likely an anomaly. Due to a lab technician error, the late summer 1995 data were lost.

Based on nutrient budget calculations (as part of the EPA/DNR/Glen Lake Association 1991 study), it was found that phosphorus released from the sediments was likely a minor contribution to the total phosphorus budget. The 1992 through 1994 data imply that this internal source may have been slightly underestimated -- probably not enough to significantly alter the budget, but it would permit a more accurate estimation of the true contribution. For a more detailed discussion of the nutrient budget, refer to the EPA/DNR/GLA report which is now available from the Glen Lake Association.

Total phosphorus values averaged over depth and time (eliminating the anomalous 32.2 ug/L spring 1995 value) in Big Glen are well below the 8.0 ug/L oligotrophic standard (fig. 22), indicative of the excellent water quality exhibited by the lake.

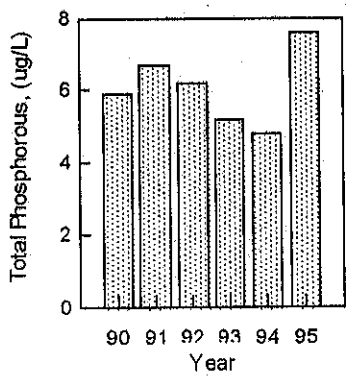


Figure 22. Overall annual mean phosphorous concentrations (ug/L) observed 1990 through 1995 at Big Glen Lake.

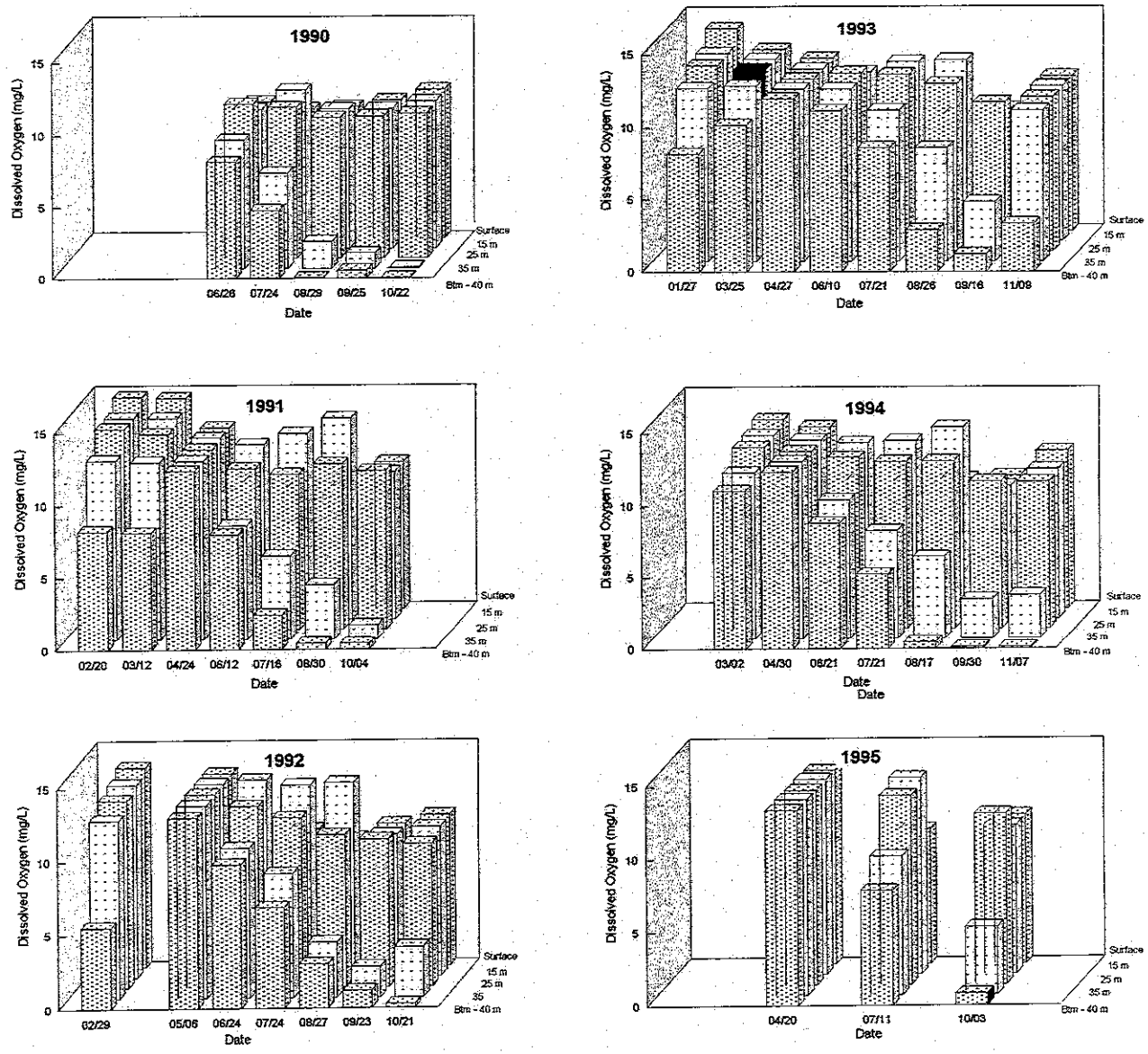
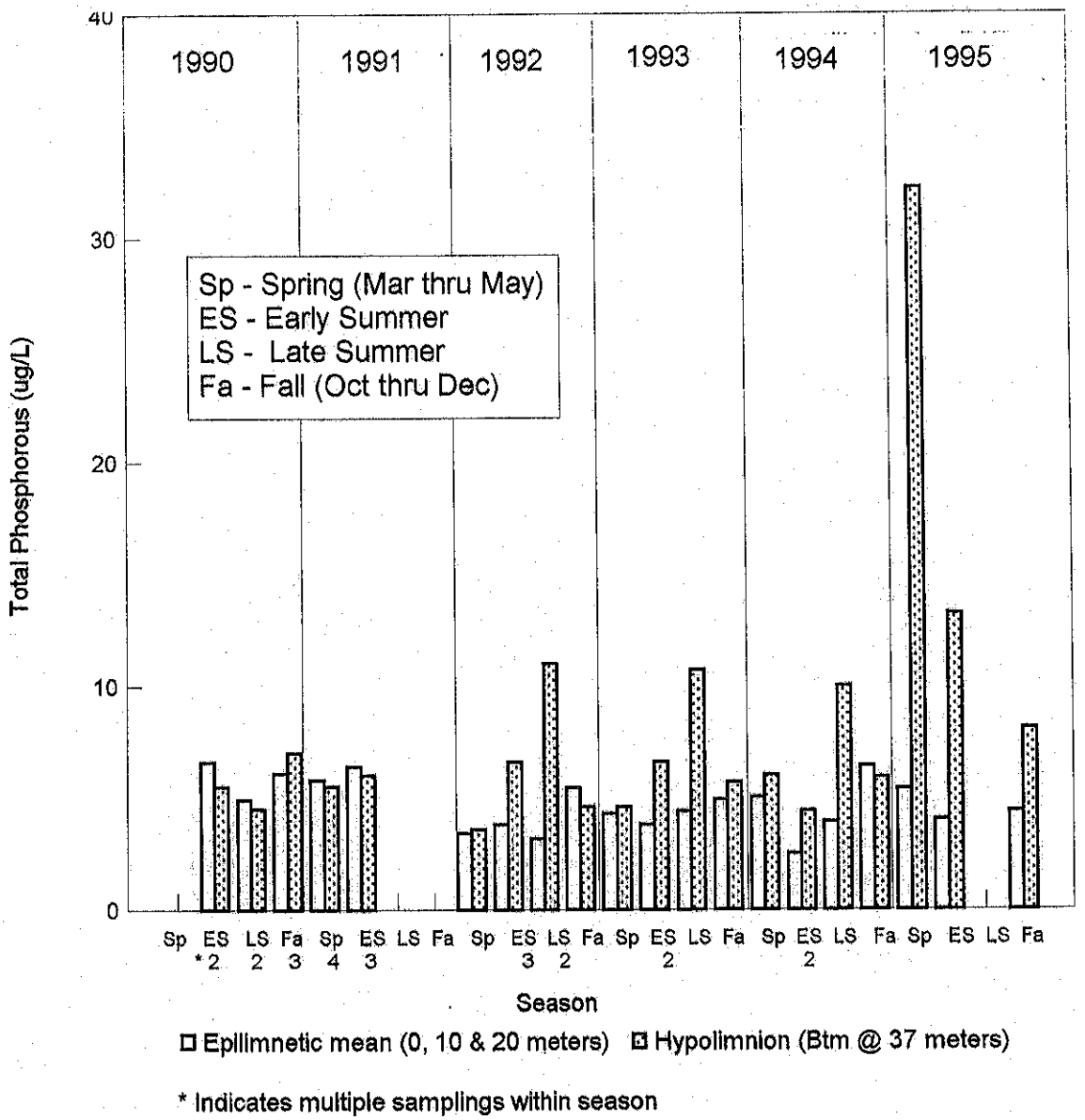


Figure 23. Dissolved oxygen concentrations (mg/L) at depths- The surface, 15 m, 25 m, 35 m, and the bottom, observed in Big Glen Lake throughout each year, 1990 through 1995. Note consistent decrease of oxygen levels off bottom during late summer/early fall.



* Indicates multiple samplings within season

Figure 24. Seasonal (Spring, Early Summer, Late Summer, Fall) epilimnetic and hypolimnetic phosphorous concentrations observed 1990 through 1995 in Big Glen Lake. Epilimnetic concentration is the mean value of the 0, 10, and 20 m concentrations, while the 37 m value represents the hypolimnion. In cases where multiple samples were collected during a season, values were averaged.

Very low or non-existent nitrate nitrogen levels have been observed in epilimnetic Glen Lake samples. These severe late summer decreases are consistent each year (fig. 25), although the magnitude of the in-lake concentrations has varied somewhat. While depressed to some varying degrees in the epilimnia of other county lakes, this phenomenon remains unique to Glen Lake. It is hypothesized that this may relate to the occurance of a particular diatom species (Cyclotella comensis), but at this point, specific nutrient dynamic lab work would be needed to determine this.

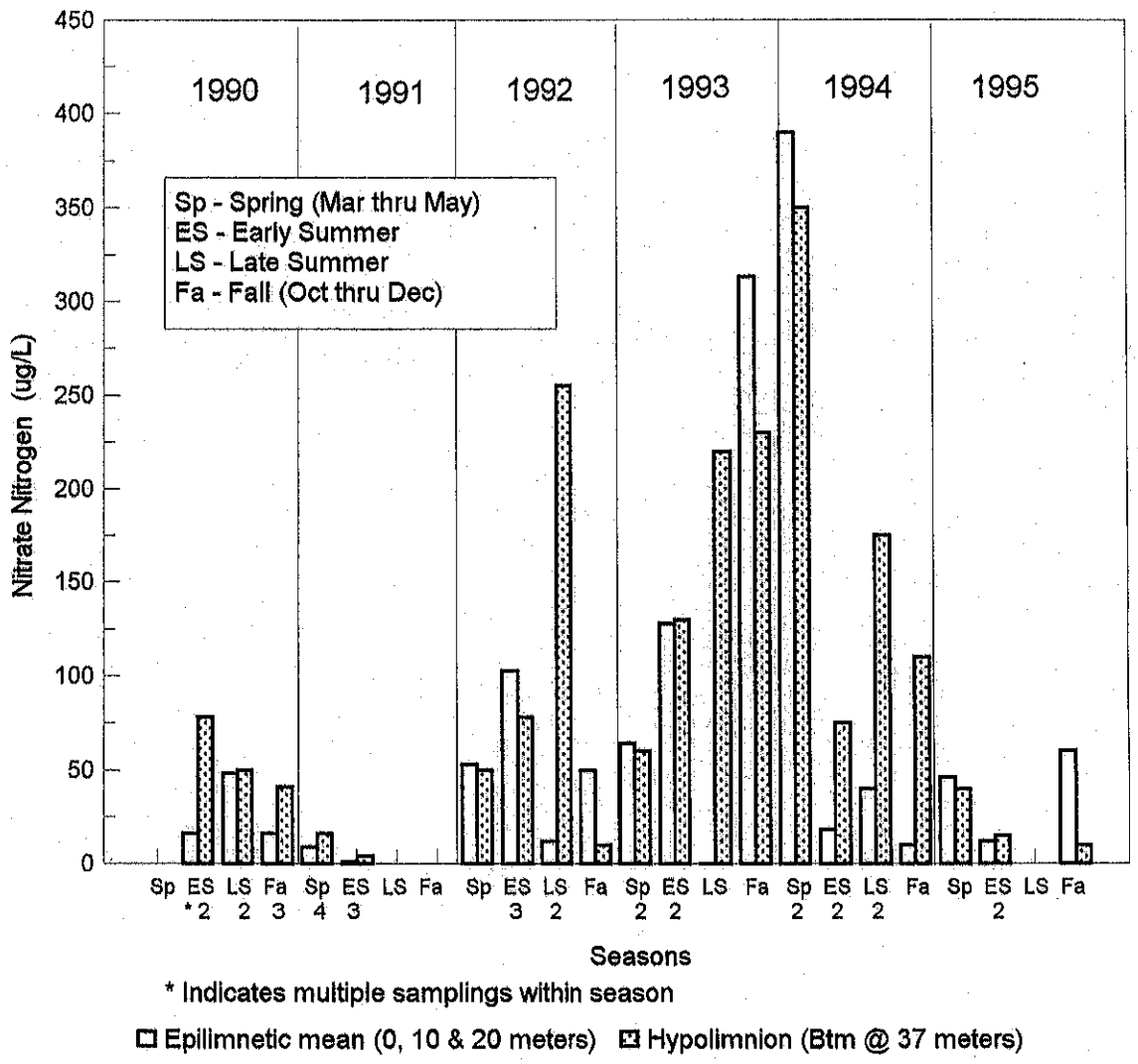


Figure 25 Seasonal (Spring, Early Summer, Late Summer, Fall) epilimnetic and hypoloimnetic nitrate (plus nitrite) concentrations observed 1990 through 1995 in Big Glen Lake. Epilimnetic concentration is the mean of the 0, 10 and 20 m concentrations, while the 37 m value represents the hypolimnion. In cases wher multiple samples were collected during a season, values were

In general, nitrate nitrogen concentrations in all lakes (except Cedar) can be considered in the oligotrophic, tending toward mesotrophic range (ranging on average from 100 - 300 ug/L). In an idealized oligotrophic lake with oxygen saturation top to bottom, nitrate levels should increase slightly in the hypolimnion during stratification. However, when hypolimnetic waters become severely anoxic, nitrate concentrations would be expected to decrease substantially through bacterial denitrification (NO_3 to N_2) and ammonia concentrations would increase. For the most part, we do not observe dramatic relative reductions in late summer hypolimnetic waters.

Chlor-a concentrations have normally fallen within the oligotrophic range (fig. 26), with a distinct bloom evident each spring (spring diatom blooms are common in oligotrophic lakes).

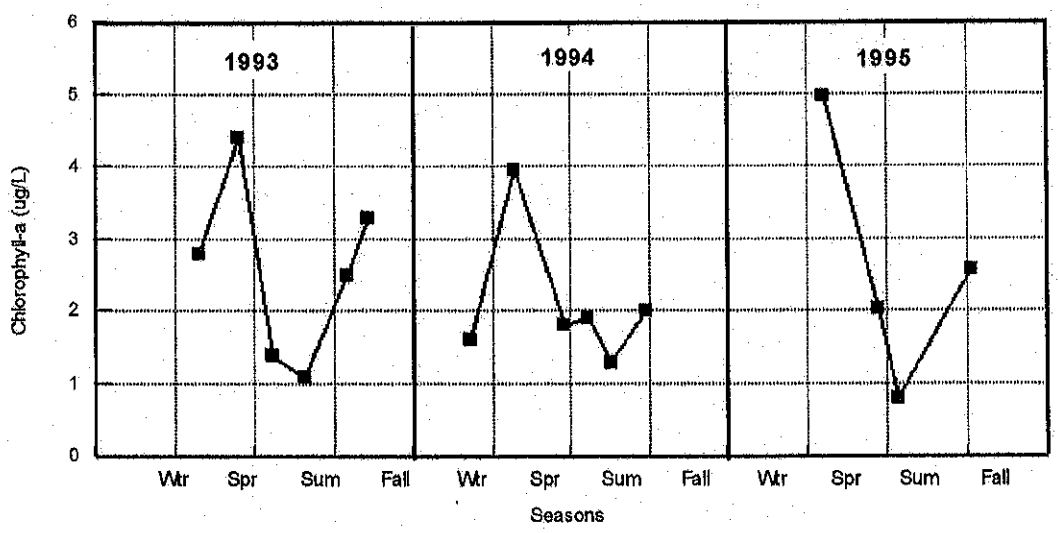


Figure 26. Seasonal chlorophyll-a concentrations (ug/L) observed 1993 through 1995 in Big Glen Lake. Each value represents the mean of a sample composited from the surface, the depth of the secchi observation, and twice the secchi depth.

Secchi visibility is substantial in Big Glen (the deepest of all County lakes), ranging from minimums of 12 to 15 feet, to maximums of 20 to 25 feet from 1990 to 1995 (fig. 27).

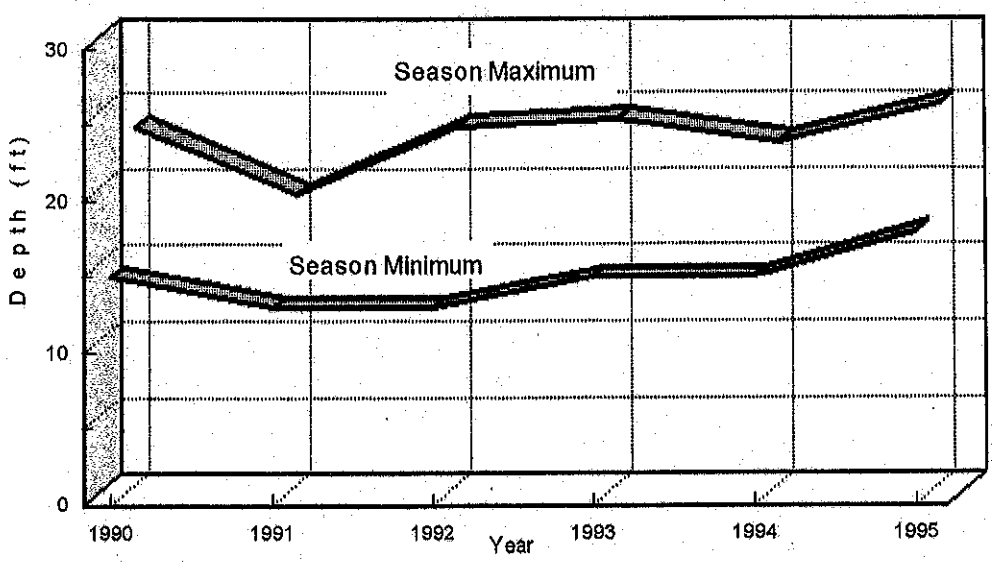


Figure 27. Seasonal maximum and minimum secchi disk observations (depth in feet) from 1990 through 1995 at Big Glen Lake.

Being a shallow basin (maximum depth of about 13 feet), Little Glen does not stratify. It warms rapidly in the spring and is slightly more productive than Big Glen, as evidenced by the higher mean total phosphorus values (fig. 28). Chlor-a levels are similar to Big Glen, with a substantial amount of the production tied up in the extensive submerged plant mat carpeting much of the bottom.

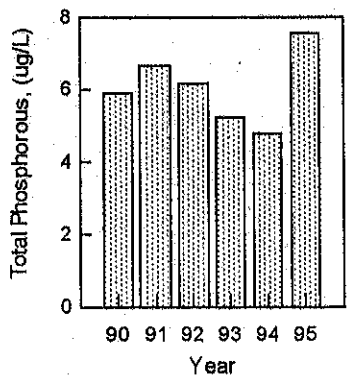


Figure 28. Overall annual mean phosphorous concentrations (ug/L) observed 1990 through 1995 at Little Glen Lake.

CEDAR LAKE

Cedar Lake was incorporated into the program as of June of 1992. Hydrolab profile data, secchi disk transparency, and water samples have been collected 5 to 9 times per year at the single station (fig. 1) thereafter. Water samples were collected at the surface, 7, and at 13 meters, as well as 50 ml composite chlor-a samples.

Cedar Lake has stratified early and sharply with respect to dissolved oxygen (fig. 29) providing the right conditions for the release of phosphorus from the deep-water sediments as well. Stratification develops in mid-July and lasts through mid-September. Through July, the layer of oxygen reduced water tends to be below the 13 meter level which influences a very small bottom area. However, this encroaches up to the 11 meter mark by mid-September. Because there is a relatively large basin area below the 11 meter contour (approximately 30 percent), the sediment surface area affected by these conditions is quite large.

Data indicate that there may be a substantial release of phosphorus from the sediments during this period (fig. 30). Early summer (including the July samples) and late summer hypolimnetic phosphorus concentrations are much higher than overlying waters. Using some simple calculations, one can determine that the mean above-hypolimnetic phosphorus concentration during the June through September time periods for 1992 to 1995 was 4.8 ug/L for 24 observations, while the mean hypolimnetic concentration during the same time frame was 12.0 ug/L for 14 observations. If we assume an increase of 7 ug/L in the hypolimnion and use the bathymetric chart to calculate the hypolimnetic volume below 11 meters, we arrive at an annual internal input of approximately 70 pounds of phosphorus. As a check of this, one can utilize a model which predicts the input from the sediment concentration of total phosphorus, which for Cedar Lake was determined at the deepwater station to be 396 mg/kg. Using this, one obtains a release rate of 2.77 mg per square meter per day, which computes to about 2 pounds per day. Assuming a period of reduced oxygen of about 40 to 45 days (as it develops gradually), one obtains an input of about 80 to 90 pounds. Because this model was developed on much more eutrophic lakes (averaging 10 to 1000ug/L total phosphorus), I did not attempt to apply it to the other lakes because they have not exhibited these higher concentrations in their respective hypolimnia relative to overlying waters.

To put this crudely, estimated internal input into perspective (relative contribution), we need to know the total annual load of phosphorus. Without a few other bits of data, this cannot be estimated very accurately at this time, however, I suspect that this input is about 10 percent. We will refine this, and hopefully adopt the use of these models to all the lakes in the near future.

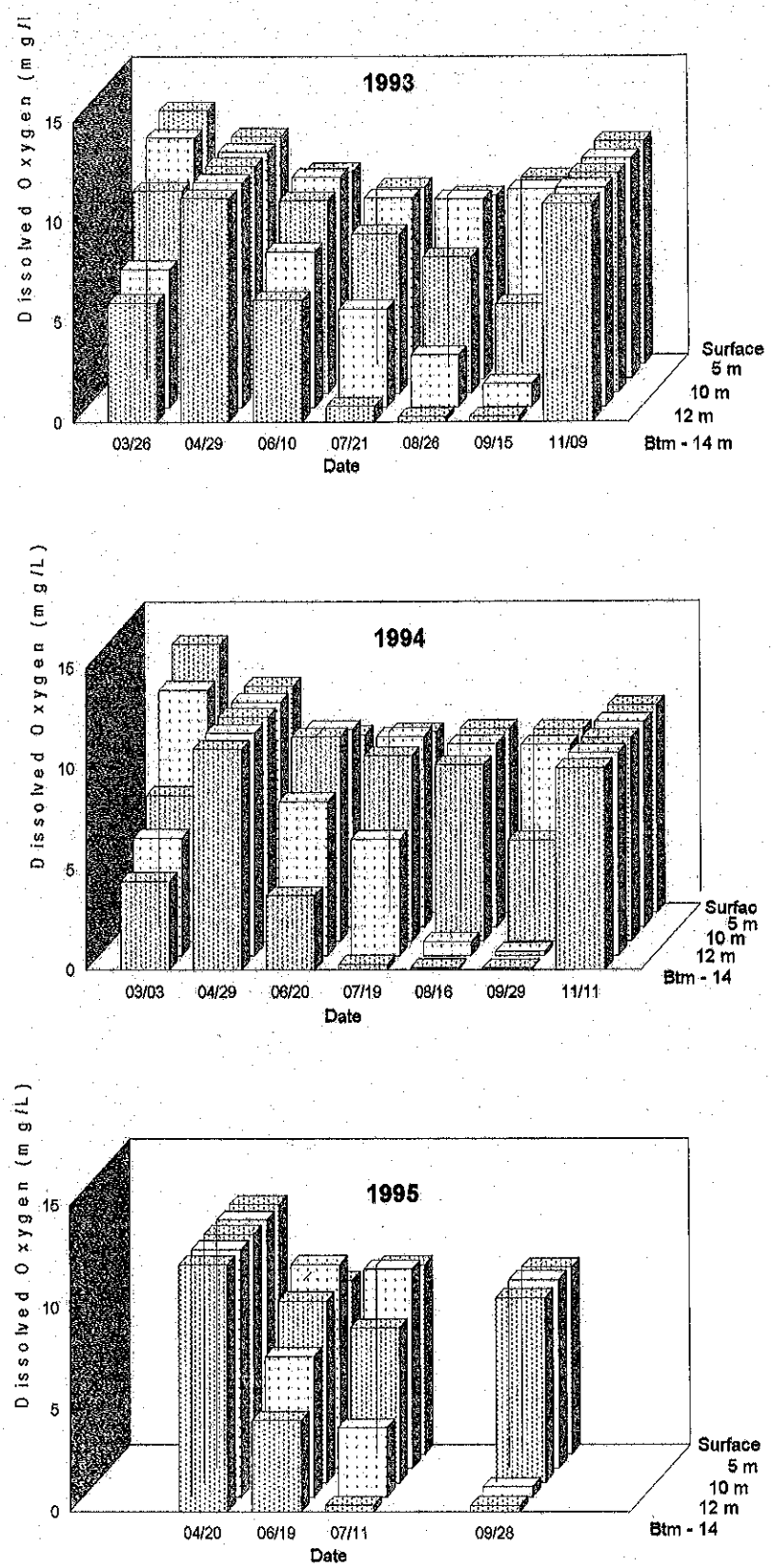


Figure 29. Dissolved oxygen concentrations (mg/L) at depths of- the surface, 5 m, 10 m, 12 m, and the bottom, observed in Cedar Lake throughout each year, 1993 through 1995. Note consistent decrease of oxygen levels off bottom during late summer/early fall.

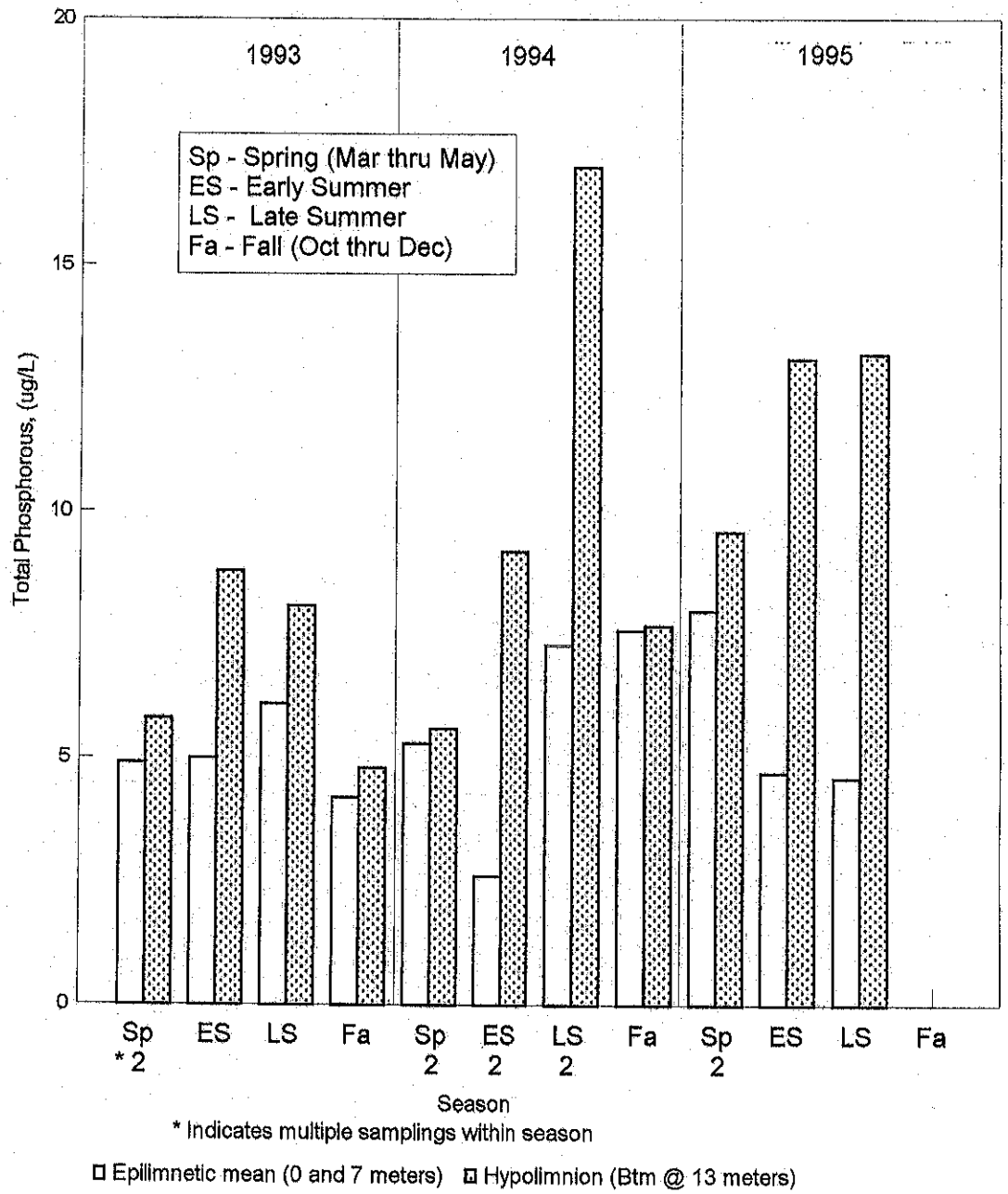


Figure 30. Seasonal (Spring, Early Summer, Late Summer, Fall) epilimnetic and hypolimnetic phosphorous concentrations observed 1993 through 1995 in Cedar Lake. Epilimnetic concentration is the mean value of the 0 and 7 meter concentrations, while the 13 meter value represents the hypolimnion. In cases where multiple samples were collected, values were averaged.

Total phosphorus concentrations averaged over depth and time are slightly higher than the other lakes due to the higher hypolimnetic values. However, they still place the lake close to the oligotrophic standard of 8.0 ug/L (fig. 31).

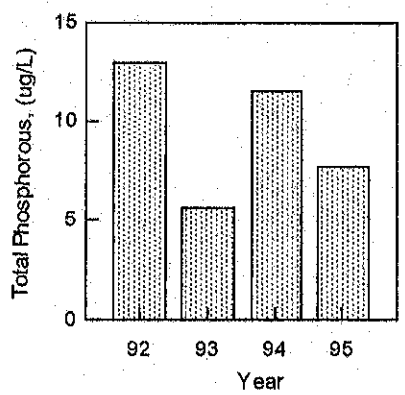


Figure 31. Overall anual mean phosphorous concentrations (ug/L)observed 1992 through 1995 at Cedar Lake.

Cedar lake also exhibits the highest levels of nitrate nitrogen (fig. 32) when compared to the other lakes. It is some 200 ug/L more than other lakes and in and of itself would tend to put the lake in the mesotrophic range. A summer time epilimnetic depression does not occur, and possible sources of nitrate in the watershed are being identified.

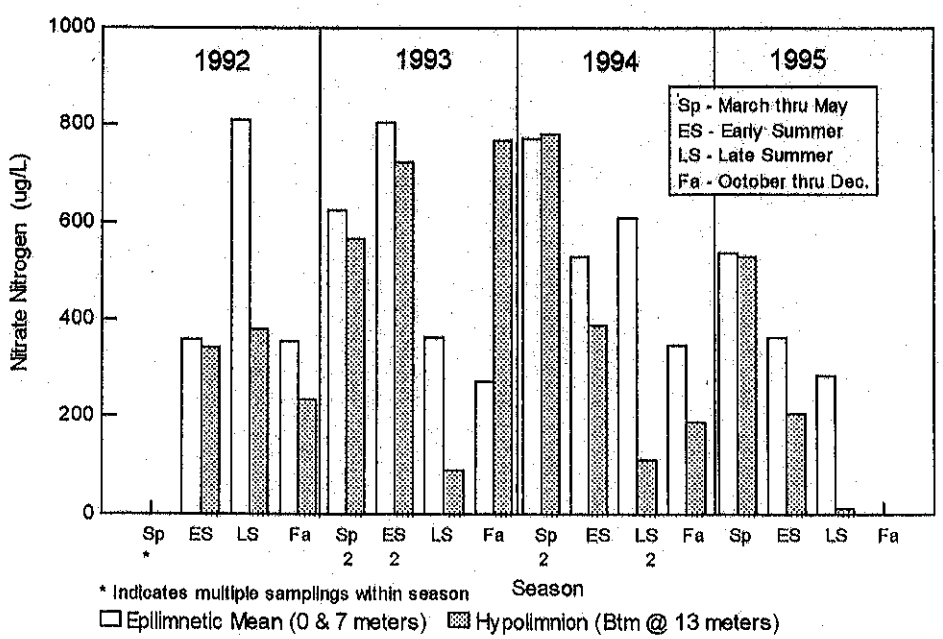


Figure 32. Seasonal (Spring, Early Summer, Late Summer, Fall) epilimnetic and hypolimnetic nitrate (plus nitrite) concentrations observed 1992 thru 1995 in Cedar Lake. Epilimnetic concentration is the mean of the 0 and 7 m concentrations, while the 13 m value represents the hypolimnion. In cases where multiple samples were collected, values were averaged.

Surprisingly, chlor-a values are quite low (fig. 33), well within the oligotrophic range. A spring peak of 4.2 ug/L was observed in 1994, but otherwise all concentrations are below 3.0 ug/L. Production may be limited by the low phosphorus levels in the epilimnion during stratification.

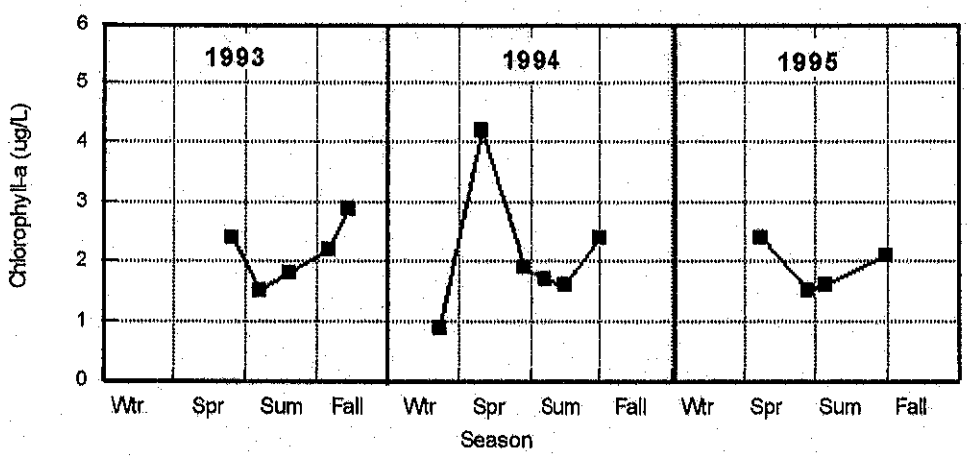


Figure 33. Seasonal chlorophyll-a concentrations (ug/L) observed 1993 through 1995 at Cedar Lake. Each value represents the chlor-a concentration determined from a 50 ml sample composited from the surface, the depth of the secchi observation, and twice the secchi depth.

Secchi data (fig. 34) in Cedar Lake are also the lowest in the program, however, as alluded to earlier, this may not be a direct indication of production in our lakes.

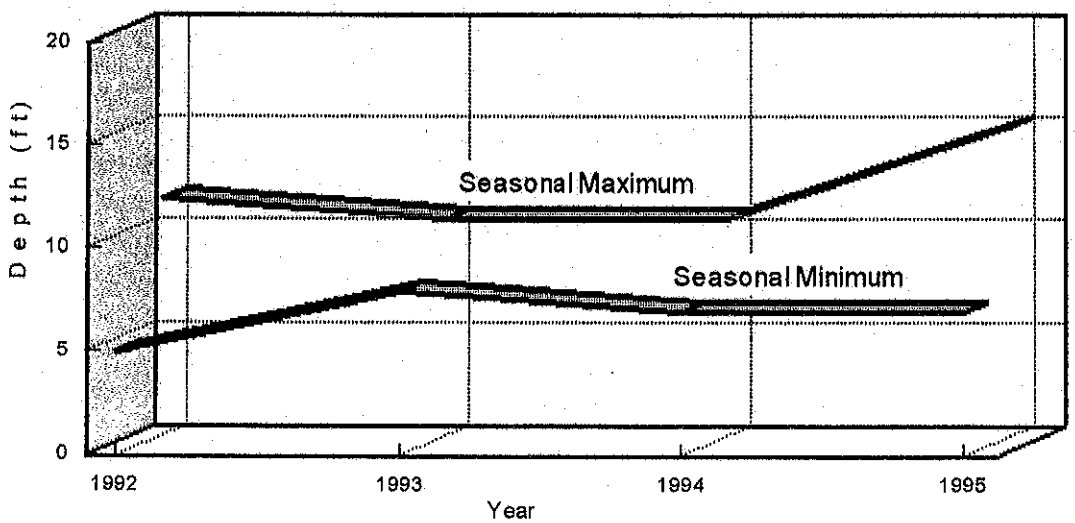


Figure 34. Seasonal maximum and minimum secchi disk observations (depth in feet) from 1992 through 1995 at Cedar Lake.

TROPHIC STATUS COMPARISONS

Based on available current data, program lakes can be classified as oligotrophic to mesotrophic. By most standards, all lakes lean toward the oligotrophic end of the continuum (see tables 2a and 2b). Although data are limited for Cedar Lake, it is clear that it is closer to the mesotrophic status than any of the other basins.

There are many indices available which rely on various component measurements (bottom organisms, plankton assemblages, etc.) to classify a system. Trophic state indexes (TSI) developed by Carlson are probably the most widely used (including use by the Michigan Department of Natural Resources) and are based on total phosphorus concentrations, secchi disk visibility depth data, and chlorophyll-a concentrations. They achieve greatest accuracy and consistency when numerous measurements in all three categories are obtained over a period of time.

Using our program data, TSI values based on total phosphorus concentrations place all lakes well within the oligotrophic range. TSI values for secchi disk data tend to place lakes in or toward the mesotrophic range (mesotrophic for Lime, Little Traverse, and Cedar), however, this may be misleading due to calcium carbonate clouding. Chlorophyll-a data places Lime and Little Traverse lakes as mesotrophic and the others as oligotrophic. It is important to realize that each measure is simply another tool with which to assess, and ultimately manage our resources. And the more tools we have at our disposal, the better the job we will do.

STREAM DATA

With the financial (and philosophical of course as well) support of Mike Stifler (MDEQ district surface water quality division head) in 1990 we were able to begin looking at nutrient concentrations in North Lake Leelanau tributary streams. This activity continued through 1991 and the program then expanded to include a total of 25 locations across the County, sampled six times during the course of the year for both nutrient chemistry and discharge. The discharge measurement is an estimation of the volume of water moving through the streambed (cross-sectional area x mean flow measurements). Sampling times reflect baseline periods throughout the year (as opposed to storm event sampling) and these activities continue today thanks to a small group of very dedicated volunteers.

While it is difficult to state what the extent of each stream's impact on lake water quality is without knowing its percent contribution to the total nutrient input, these data will provide an extremely important component to future nutrient budget calculations, as well as identify any potential nutrient pollution "hotspots" in the interim.

Stream data to date are being summarized in a separate document and should be available shortly after this report.

Table 2a. Summary of suggested values of selected parameters used to define the trophic status of lakes. References are cited only to indicate there is latitude in assigning trophic status to the lake.

	Oligotrophic	Mesotrophic	Eutrophic	Reference
Secchi Disk (meters)	>5 >6 9.9 (13)	5 - 3 6 - 3 4.2 (20)	<3 <3 2.5 (70)	(1) (2) (3)*
Total P (ug/L)	< 10 < 15 8.0 (21)	10 - 20 15 - 25 26.7 (19)	> 20 > 25 84.4 (71)	(4) (5) (3)*
Total N (ug/L)	< 300 < 400 661 (11)	300 - 650 400 - 600 753 (8)	> 650 > 600 1875 (37)	(6) (5) (3)*
Chlorophyll-a (ug/L)	< 3.0 < 4.3 1.7 (22) 4.2 (16)	3.0 - 7.0 4.3 - 8.8 4.7 (16) 16.1 (12)	> 7.0 > 8.8 14.3 (70) 42.6 (46)	(5) (7) (3)* (3)*
Organic Matter in Sediments (% dry weight)	< 17	17 - 30	> 30	(8)
Trophic Status Index based on: Secchi Chlor-a Total P	 < 38 < 38 < 38	 39 - 50 39 - 50 39 - 50	 50 - 100 50 - 100 50 - 100	 (9)

(1) Chapra and Dobson, 1991
(2) Vallentyne et al, 1969
(3) Wetzel, 1983
(4) Chapra and Robertson, 1977
(5) Forsberg and Ryding, 1980
(6) Vollenweider, 1968
(7) Dobsen et al, 1974
(8) Edwards and Ryder, 1990
(9) Carlson, 1977

* Data from Wetzel (1983) are mean values from a survey of over 200 water bodies. Parenthetical values are the number of observations upon which the mean is based.

Table 2b. Observed data values used to assign trophic status to program lakes. Mean values used in calculations incorporate all available data. Nitrate (+ nitrite) nitrogen values are used as a starting point for total N (organic and ammonia values are unknown and not included).

	North Lake Leelanau	**South Lake Leelanau**	**Little Traverse Lake**	**Lime Lake**	**Glen Lake**	**Cedar Lake**
Total P (ug/L)	5.6 (5)*	5.5 (5)	5.6 (5)	4.9 (5)	5.4 (5)	6.8 (4)
Total N (ug/L)	292 (5)	223 (5)	176 (5)	236 (5)	77 (5)	438 (4)
TSI**						
Secchi	**39*** **	38	**45**	**44**	35	**46**
Total P	29	29	29	27	28	32
Chlor-a	36	38	**42**	**40**	31	38
Chlor-a (ug/L)	1.8 (3)	2.1 (3)	3.3 (3)	2.5 (3)	2.4 (3)	2.1 (3)
Organic matter in Sediments (% dry wt.)					5-8	

* Numbers within parentheses in table are the number of years over which data used was collected.

** TSI = Carlson's Trophic State Index as calculated using secchi, total P and chlorophyll-a data.

*** Bold face values in the TSI section are values in the mesotrophic range. All others are in the oligotrophic range

APPENDIX

All data collected during the work reported herein is on computer file at the Leelanau Conservancy. These data include:

Hydrolab (water column) profiles
- temperature
- dissolved oxygen
- pH
- conductivity
- oxidation-reduction potential

Secchi disk observations

Chemical analyses
- total phosphorous
- nitrate nitrogen (+ nitrite)
- chlorophyll-a
- phosphorous in bottom sediment

All files are available on disk upon request.

A limited number of paper print-outs of these data are available as well, but due to the large volume (77 pages), they will not be included in all copies of this report.