Lake management
committee

HISTORICAL ANALYSIS OF THE CULTURAL EUTROPHICATION OF LAKE MAXINKUCKEE, INDIANA

by

THOMAS L. CRISMAN

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Submitted to the Lake Maxinkuckee Association

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Department of Environmental Engineering Sciences
University of Florida
Gainesville, FL 32611

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INTRODUCTION

During recent years, there has been growing concern among shoreline residents of Lake Maxinkuckee that the lake is experiencing progressive cultural eutrophication. Eutrophication is an enhancement of the growth of either algae or aquatic macrophytes (weeds) when supplied with some limiting nutrient, normally phosphorus or nitrogen. While excessive plant growth in itself can cause problems, the secondary effects of eutrophication are often of equal concern. Foremost among these are health problems caused by bacteria and algal toxins, and alterations in the fish community whereby rough fish, such as gizzard shad and carp, replace game fish as dominants. Although many lakes are naturally eutrophic, it is rapid man-induced cultural eutrophication that is of prime concern in most lake management studies.

The present study was initiated to: 1) delineate the trophic history of Lake Maxinkuckee for the past 100 years, 2) determine the factors that may be contributing to the cultural eutrophication of the basin, 3) predict future changes in the water quality of the lake, and 4) provide management alternatives to prevent further deterioration of water quality from current levels.

During the spring and early summer of 1984, data from all previous limnological investigations of Lake Maxinkuckee were compiled as well as initial information regarding historical changes in land use in the lake's watershed. A citizen's water quality monitoring program was initiated in June, whereby lake resident volunteers were asked to measure water clarity throughout the summer at twenty stations in the lake. Each volunteer was provided with a <u>secchi disc</u>, a metal disc 20 cm in diameter painted with alternating triangles of black and white radiating from the disc center. The depth in the water column at which the Secchi disc is no longer visible roughly approximates the depth limit to which photosynthesis extends, and as such is a useful indicator of water quality. In lakes such as Lake Maxinkuckee that lack appreciable inorganic turbidity, the deeper the Secchi depth, the fewer the algae and by extension, the better the water quality. Maintenance of a Secchi disc program every year will be extremely useful in determining if water quality is further degraded in the future.

In August 1984, sediment cores were collected from three deep water sites of Lake Maxinkuckee as part of a paleolimnological reconstruction of water quality in the lake for the past 100 years. Selected levels in the cores were dated with 210-Pb analysis so that the year of deposition of any level in the core could be approximated. Dating of the cores was completed after one year to permit time for ingrowth of the 208-Pu isotope. Past water quality was reconstructed from sediment chemistry and animal microfossils for selected core levels. When combined with 210-Pb age determinations, one can tell not only how much water quality has degraded, but also when major events in this process occurred. Finally, data derived from sediment cores were related to known historical events including land clearance, population growth, dredging, etc. to estimate the importance of individual events on lake water quality.

The Secchi disc monitoring program was continued in 1985, but instead of relying on lake resident volunteers, Chester Gut, a local high school student, was hired to monitor Secchi disc transparency at 26 lake stations. Mr. Gut collected data at all 26 stations on 29 dates between 7 June and 27 August 1985.

At the initiation of Mr. David Gaskell, inlet streams to Lake Maxinkuckee were sampled at 12 stations for fecal coliform bacteria contamination on 19 August 1985. Bacterial analyses on these samples were provided by the Indiana State Board of Health in Indianapolis.

The present report is a synthesis of data from previous investigations as well as the monitoring and paleolimnological analyses described above that were conducted during 1984 and 1985. A series of recommendations pertinent to the future management of Lake Maxinkuckee to reduce cultural eutrophication are provided.

HISTORICAL DATABASE FOR LAKE MAXINKUCKEE

A total of seventeen investigations were conducted on Lake

Maxinkuckee between 1899 and 1985 (Table 1). The most extensive survey of the lake was that of the United States Bureau of Fisheries, which maintained a field station on the lake between 1899 and 1914. The results of this work have been published in two volumes authored by Evermann and Clark (1920). With the exception of a 1921 sampling by the Indiana State Board of Health; no other data on the lake were found before 1965 when the Indiana DNR conducted the first extensive fish survey of the lake. This was followed in 1970 by sampling for coliform bacteria by the Indiana State Board of Health.

Starting in 1971 with a survey by J. Hamelink, the emphasis of investigations at Lake Maxinkuckee shifted from biological parameters to determining water quality (trophic state) based on concentrations of nutrients (phosphorus and nitrogen) critical to algal and aquatic weed growth. While Hamelink tried to roughly estimate the sources of the phosphorus getting into the lake, it was not until 1973 that the first detailed phosphorus budget for the lake was formulated by the United States Environmental Protection Agency. The EPA study was especially important in that it provided estimates of the percentage of the water concentration of phosphorus in the lake which was contributed annually by inflowing streams and septic tanks. All future estimates of nutrient loading to the lake were based on the EPA model.

TABLE 1. Chronology of investigations at Lake Maxinkuckee

1899-1914	United States Bureau of Fisheries. Detailed survey of physical, chemical and biological parameters of the lake. Data are summarized in Evermann and Clark (1920).
1921	Indiana State Board of Health. Sanitary survey of northern end of lake by J.G. Diggs.
1965	Indiana Department of Natural Resources. Survey of fish community with some field data on physical/chemical parameters.
1970	Indiana State Board of Health. Bacteriological survey for coliforms.
1971	J. Hamelink. Chemical survey of lake with some biological data.
1973	United States Environmental Protection Agency. Collection of water chemistry and plankton, and calculation of nutrient budget for the lake.
1974	Indiana State Board of Health. Bacteriological survey for coliforms.
1975	Indiana Department of Natural Resources. Survey of fish community with some field and laboratory data on physical/chemical parameters.
1975	Indiana State Board of Health. Survey of physical and chemical parameters and algal composition and abundance for use in BonHomme eutrophication index.
1977-1978	J.M. Bell and A. Spacie. Collection of physical and chemical parameters and phytoplankton for use in evaluating trophic status.
1982	Howard Consultants, Inc. Revision of phosphorus model for the lake. Prediction of potential effects of further development.
1982	ESEI. Prediction of potential effects from proposed development of Cove West condominiums.

1982	*Clyde E. Williams and Associates, Inc.* Survey of chemical and microbiological parameters and calculations of nutrient loading model.
1983-1984	*Indiana Department of Natural Resources.* Survey of fish community with some field and laboratory on physical/chemical parameters.
1984	*Lake Maxinkuckee Association.* Initiation of a citizens Secchi disc monitoring program and a paleolimnological investigation of cultural eutrophication.
1984	*J.M. Bell and A. Spacie.* Collection of physical and chemical parameters and phytoplankton for use in evaluating trophic status.
1985	*Lake Maxinkuckee Association.* Secchi disc monitoring program and initial survey of coliform bacteria in inlet streams.

Three biological investigations were conducted in 1974 and 1975. The Indiana State Board of Health surveyed the lake for coliform bacteria in 1974 and returned in 1975 to collect physical, chemical and biological data on the lake as part of a statewide lake survey. These data formed the basis for construction of the BonHomme eutrophication index, which is a way to quantify the water quality of Indiana Lakes. The Indiana DNR conducted the second detailed analysis of the fish community of the lake in 1975 and included some physical and chemical data.

J. Bell and A. Spacie from Purdue University collected physical, chemical and biological data during 1977 and 1978 as part of a fifteen lake study to evaluate whether the phosphorus detergent ban initiated in 1973 was having any effect on lake water quality. This was followed by three investigations by consulting firms in 1982 and 1983 that evaluated whether projected development in the lake's watershed would increase phosphorus loading to the lake and thus accelerate cultural eutrophication of the system.

The Indiana DNR performed detailed analyses of the fish community in 1983 and 1984 in order to assess the impact of stocking walleye fry into the lake in 1980 (5.6 million), 1982 (5.6 million), and 1983 (5 million). In addition to fish data, a limited database on select physical and chemical parameters was also provided. J. Bell and A. Spacie again sampled the lake in 1984 for the same physical, chemical and biological parameters examined during their 1977 and 1978 surveys. The final assessment of the water quality of Lake Maxinkuckee have been the 1984 and 1985 Secchi disc programs, the paleolimnological core investigations, and the 1985 survey of coliform bacteria levels in inlet streams organized as part of the current research effort.

A complete citation for each of the past investigations is provided in the reference section of this report, and xerox copies of data are available from T. Crisman upon request. Throughout the remainder of this report, the source of individual data points included in tables and figures has not been specifically identified. Rather, reference to the chronological listing of past investigations given in Table 1 should clarify the source of data for individual years.

HISTORICAL TRENDS IN PHYSICAL AND CHEMICAL PARAMETERS

The following section summarizes historical changes in the major physical and chemical parameters used to assess water quality. Results of the 1984 and 1985 Secchi disc program and the 1985 stream sampling are also incorporated.

Phosphorus. The United States EPA (1976), through the use of bioassays, determined that Lake Maxinkuckee was phosphorus limited in 1973. More recent studies at the lake have not challenged this finding. To say that a lake is phosphorus limited means that the photosynthesis of algae and aquatic weeds is limited by the availability of phosphorus. Thus, the more phosphorus that is added to a lake, the greater the growth and abundance of algae or weeds. Enhanced plant growth is normally interpreted as eutrophication and is assumed to be a reduction in water quality.

Total phosphorus concentrations for Lake Maxinkuckee are available for eight years between 1957 and 1983 (Figure 1). Error bars are provided for four of the eight years during which multiple samplings of the lake occurred. From a baseline value of .08 - .014 mg/L in 1957-1970, total phosphorus levels increased 64% to .023 mg/L in 1973. The .025 mg/L recorded for both 1977 and 1983 represents an 8% increase over 1973 values and a 78% increase over total phosphorus concentrations in 1965-1970. Although Bell and Spacie were unable to release the results of their 1984 monitoring at Lake Maxinkuckee because the data have not been reviewed yet by the Monsanto corporation which funded their research, they did say (Bell letter dated 27 February 1985) that their 1984 values were "about the same" as what they recorded during their 1978 sampling of the lake.

While it is undoubtedly true that phosphorus has increased in the lake since 1965-1970 and may have stabilized at about .025 mg/L, strict reliance on the percentage increase data should be tempered somewhat by realizing that: 1) several years were represented by only one sampling date, 2) for two of the years with multiple samplings, a great deal of variation exists between phosphorus values for individual dates, and 3) different analytical

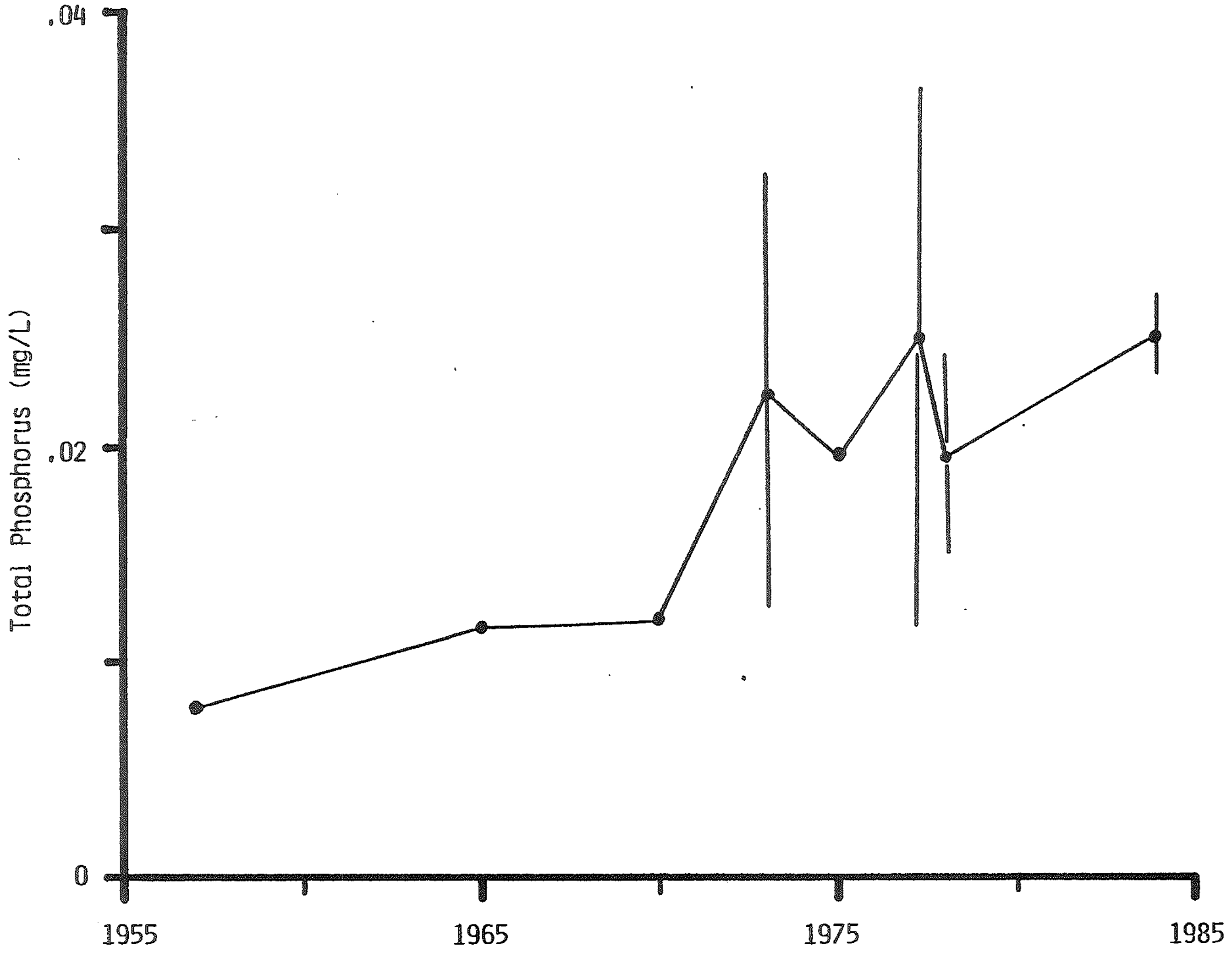


Figure 1. Total phosphorus values (mg/L) for Lake Maxinkuckee from 1957 through 1984. Standard error bars are provided for years with multiple samplings.

methods were likely used by the various investigators. Phosphorus annual accumulation rates in the sediment calculated as part of the ongoing paleolimnological project will act as a check on trends established from historical phosphorus data.

In lake management studies it is convenient to assign lakes to broad categories based on their water quality (trophic state). Clear water unproductive lakes that support little algae and aquatic weeds and have reduced fish abundance are termed oligotrophic. Lakes of moderate algal/weed production and water clarity with well developed gamefish populations are termed mesotrophic. On the opposite end of the classification scale from oligotrohpic systems are lakes that are extremely productive and experience either major weed management problems in shallow areas or prolonged periods during summer and fall when "scums" or blooms of blue-green algae cover the surface of the water and often form windrows of decaying organic matter along the shore. These lakes are termed eutrophic. The prime example of a eutrophic lake is Lost Lake, Indiana.

As a means of predicting the trophic state of a lake, scientists commonly look at the relationship between the loading rate of phosphorus to the lake from the watershed and the retention of that phosphorus within the lake for algal utilization. The most common quantification of this relationship is a Vollenweider loading model. Retention is a function of lake residence time, the amount of time it takes for the entire volume of the lake to be flushed out and replaced naturally. In effect, the term is a water budget for the lake that looks at the relationship between the amount of water entering the lake (precipitation, streams, groundwater), the volume of the lake, and the amount of water leaving the lake (outlet streams).

The EPA (1976) calculated the residence time of Lake Maxinkuckee to be 6.7 years. Thus, only 15% of the lake's volume is replace every year. Using EPA phosphorus loading data and estimated lake residence time, Howard Consultants, Inc. (1982) constructed a Vollenweider phosphorus model for Lake Maxinkuckee (Figure 2). Their results suggested that while the trophic state of Lake Maxinkuckee at the turn of the century was at the boundary between oligotrophic and mesotrophic conditions, by the mid-1970's the lake was at the upper end of the mesotrophic range and dangerously close to becoming eutrophic. They suggested that a 5% increase in phosphorus loading to the lake would lead to eutrophic conditions, but that even a 100% increase in the number of septic tanks would be insufficient to cause the shift from mesotrophic to eutrophic.

Clyde Williams and Associates, Inc. (1983) measured water concentrations of total phosphorus for three dates during 1983 and constructed a new Vollenweider phosphorus model for Lake Maxinkuckee (Figure 3). Their model placed the trophic state of the lake at the mesotrophic-eutrophic boundary, but they definitely felt that the lake had become highly eutrophic by 1983.

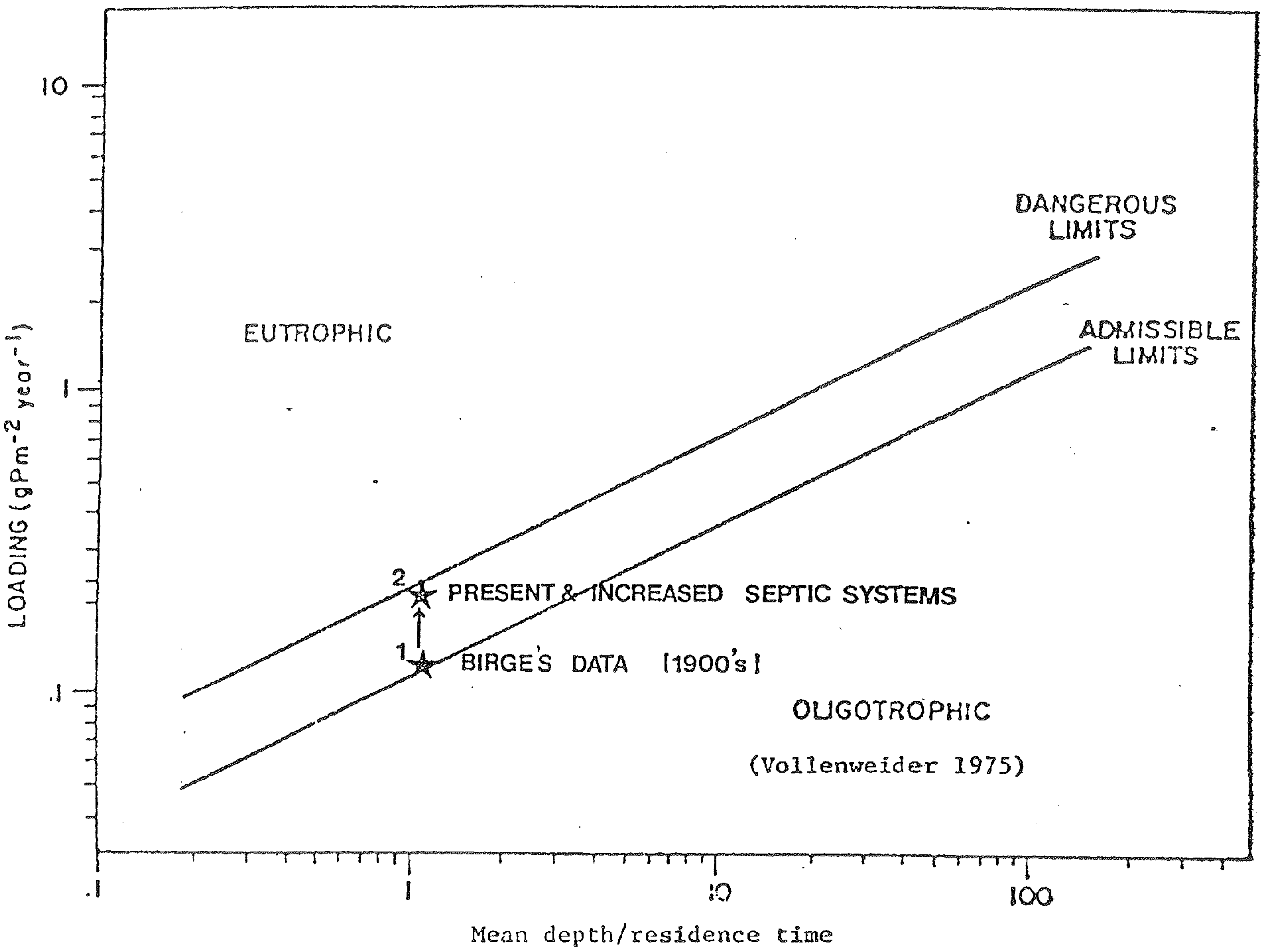


FIGURE 2. Vollenweider phosphorus loading diagram for Lake Maxinkuckee. Figure from Howard Consultants, Inc. (1982). Area below "admissible limits" represents oligotrophic conditions, and that area above "dangerous limits" represents eutrophic conditions. The area between the two lines represents mesotrophic conditions.

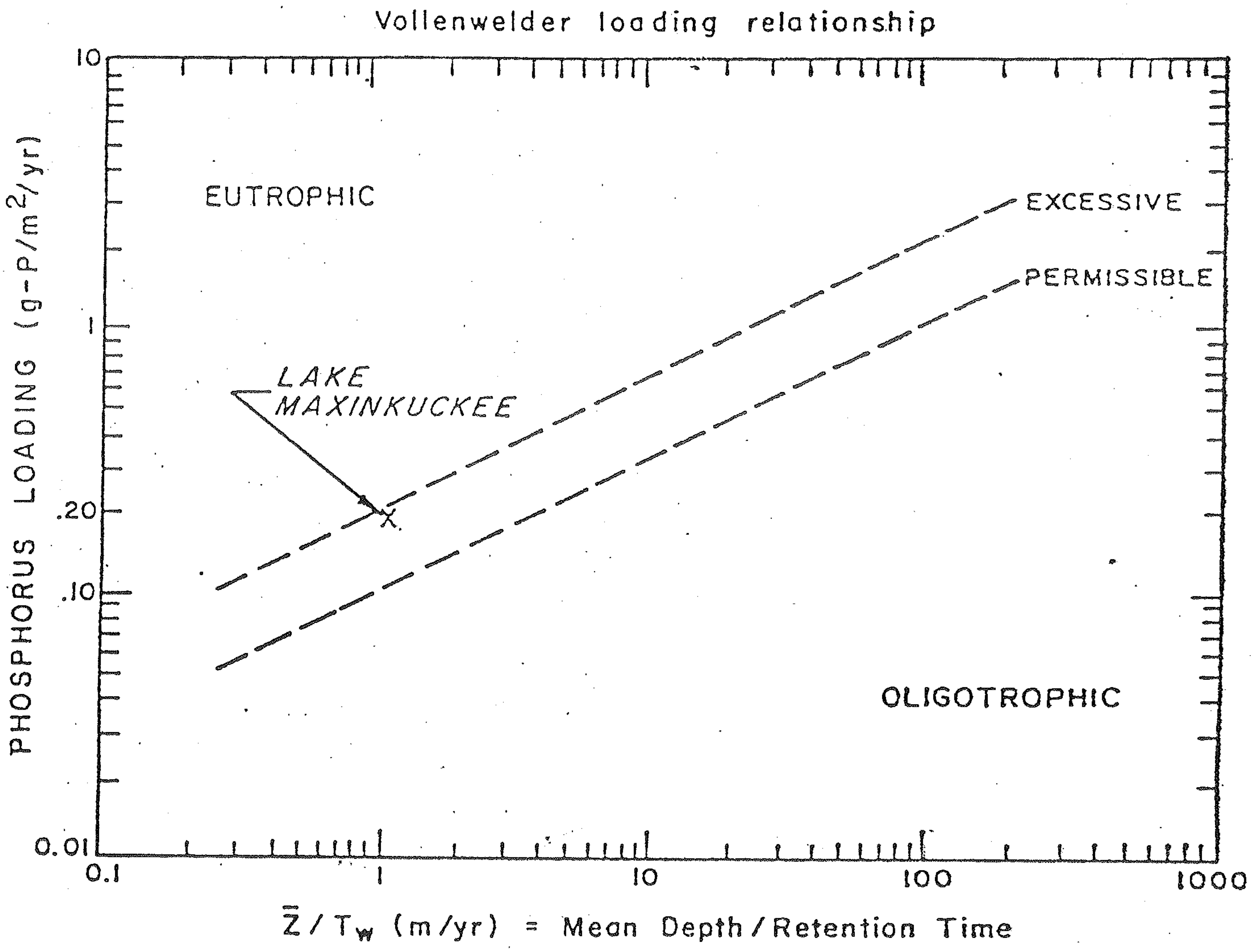
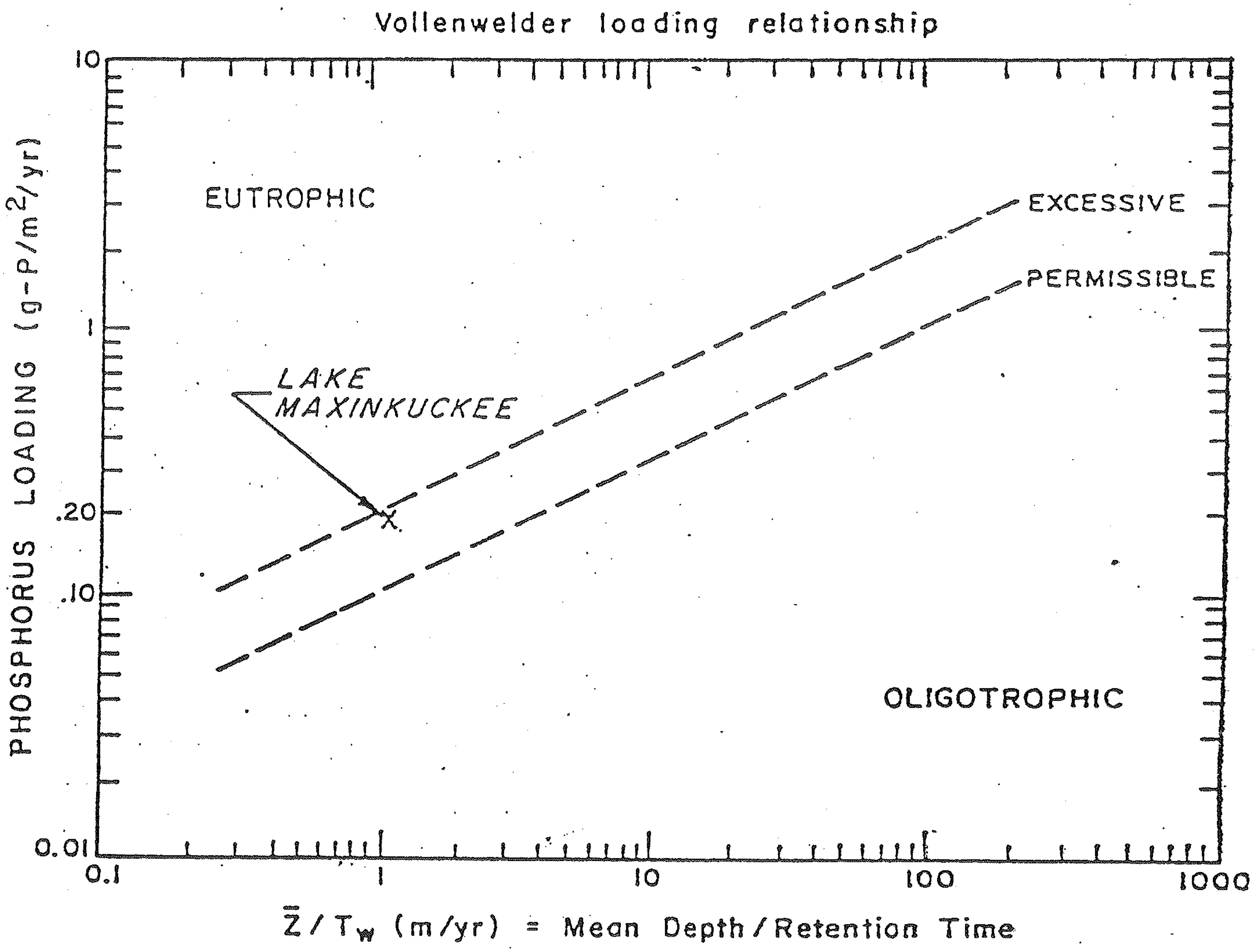


FIGURE 3. Vollenweider phosphorus loading diagram for Lake Maxinkuckee. Figure from Clyde E. Williams and Associates, Inc. (1983).

Other Water Chemistry. In addition to an increase in total phosphorus concentrations, the limited data available suggest a 150% increase in soluble phosphorus (.0056 ± .004 to .014 ± .01 mg/L) and a 14% increase in total nitrogen (.775 ± .24 to .887 ± .21 mg/L) water concentrations between 1973 and 1977. Also, total alkalinity, a measure of the carbonate content of water, increased by 14% between 1965 and 1975 and 35% between 1907 and 1975 (Figure 4). Alkalinity normally increases with eutrophication and is influenced by lake pH and delivery of carbonate-rich erosional material from the watershed.

Water Clarity. In natural lakes like Lake Maxinkuckee that appear to have little suspended inorganic turbidity, water clarity is influenced principally by the density of algal cells suspended in the water column. In a recent study of several Indiana lakes, the Indiana Stream Pollution Control Board found a significant statistical relationship between water clarity measured by a Secchi disc and the concentration of algae in the water estimated from chlorophyll *a* levels. Thus, in a lake like Maxinkuckee, the shallower the depth in the water column that a Secchi disc disappears from view, the more algae there are suspended in the water and thus the more eutrophic the lake is.

Secchi disc transparency in Lake Maxinkuckee in 1971 approximated that of 1907 (Figure 5). Between 1971 and 1977, water clarity progressively declined, displaying a 25% reduction for the six year period. The results of the 1984 and 1985 Secchi



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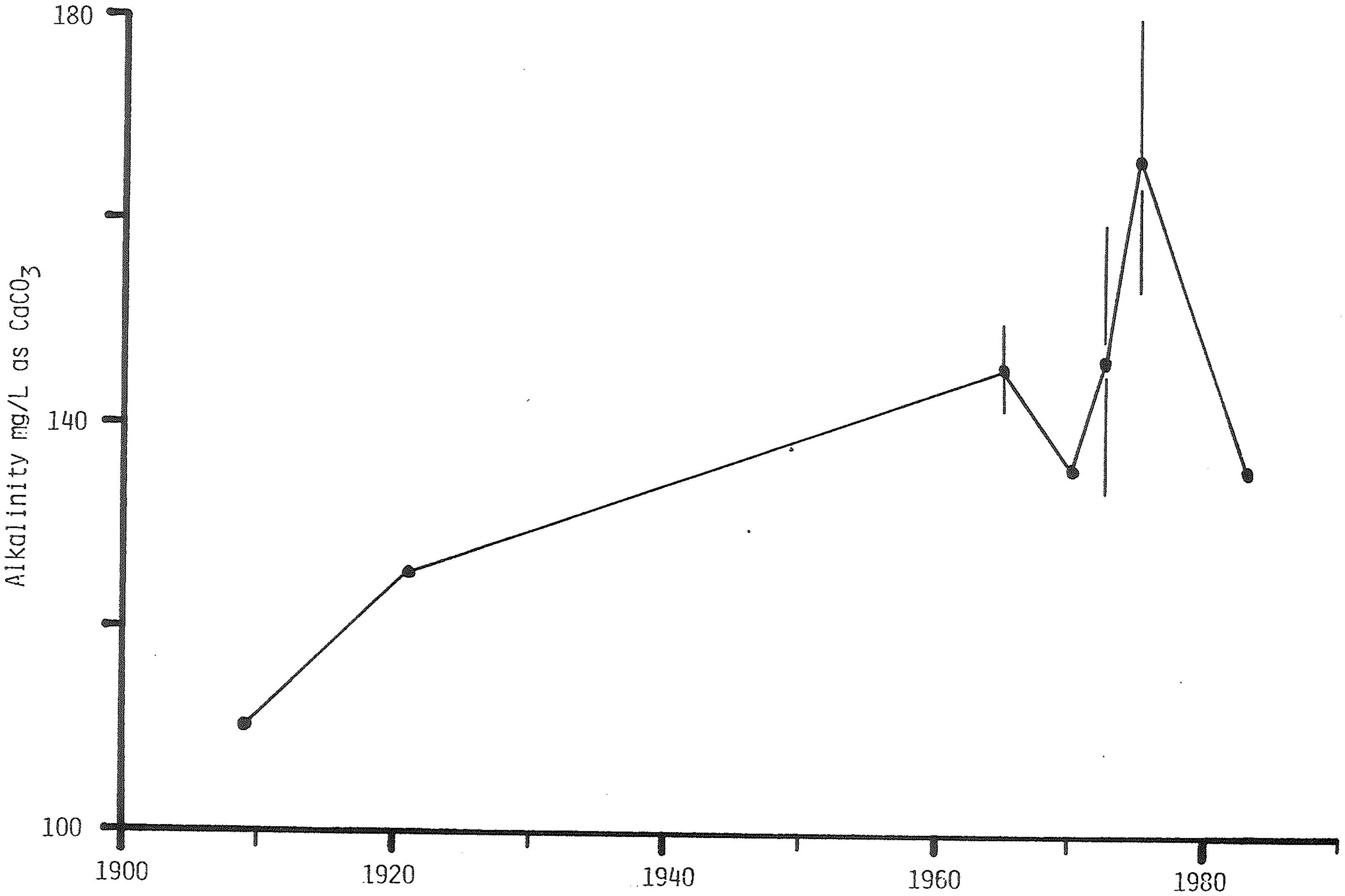


Figure 4. Total alkalinity (mg/L as $CaCO_3$) of Lake Maxinkuckee for the period 1907-1983. Standard error bars are provided for years with multiple samplings.

disc monitoring programs suggest that water clarity has not changed appreciably since 1977. Although the mean for 1985 was lower than that of 1984 (5.81 ± .99 feet versus 7.24 ± 1.32 feet, respectively) there was no statistical difference between the means. Thus, Secchi disc trends agree with those of phosphorus that Lake Maxinkuckee has become progressively more eutrophic in the last fifteen years.

The 1984 Secchi disc monitoring program was initiated with twenty monitoring stations scattered throughout Lake Maxinkuckee (Figure 6). Citizen volunteers were asked to measure Secchi disc transparency at their assigned stations at weekly or shorter intervals. Data from only six stations are missing from the database. The earliest record of water clarity was for 2 June 1984 and the last was for 10 October 1984.

Mean lake water clarity during 1984 was lowest during June after which it increased rapidly during July and remained relatively stable until the end of monitoring in October (Figure 7). The low water clarity during June is likely associated with an expansion in algal density during this period. Both the timing and duration of such long-term periods of reduced water clarity must be watched closely in the future as they may signal potential algal management problems. As June is normally the wettest summer month the reduced clarity could also reflect enhanced stream input of phosphorus for algal growth and/or silt eroded from upland farms during periods of increased rainfall.

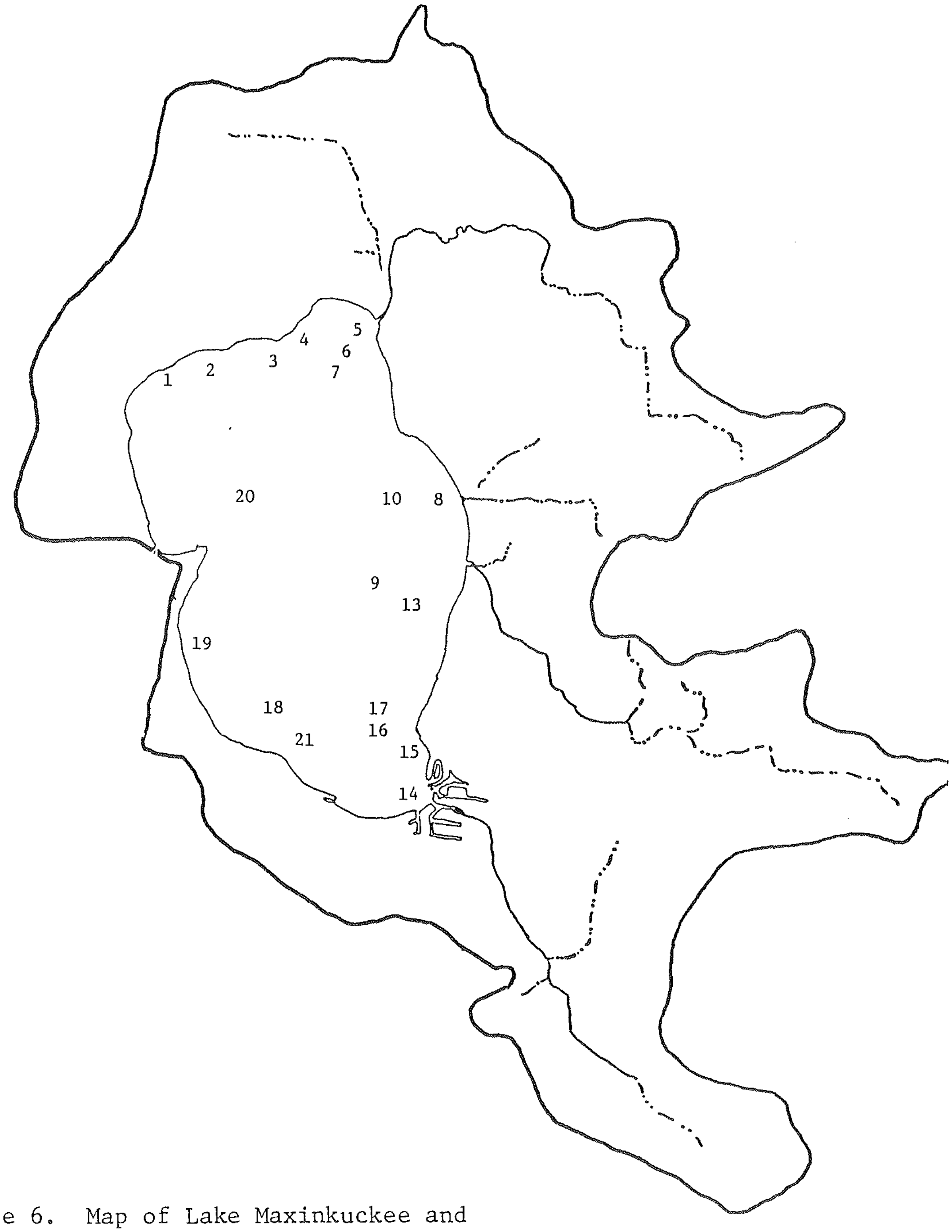


Figure 6. Map of Lake Maxinkuckee and surrounding watershed showing monitoring sites for the 1984 Secchi disc program.

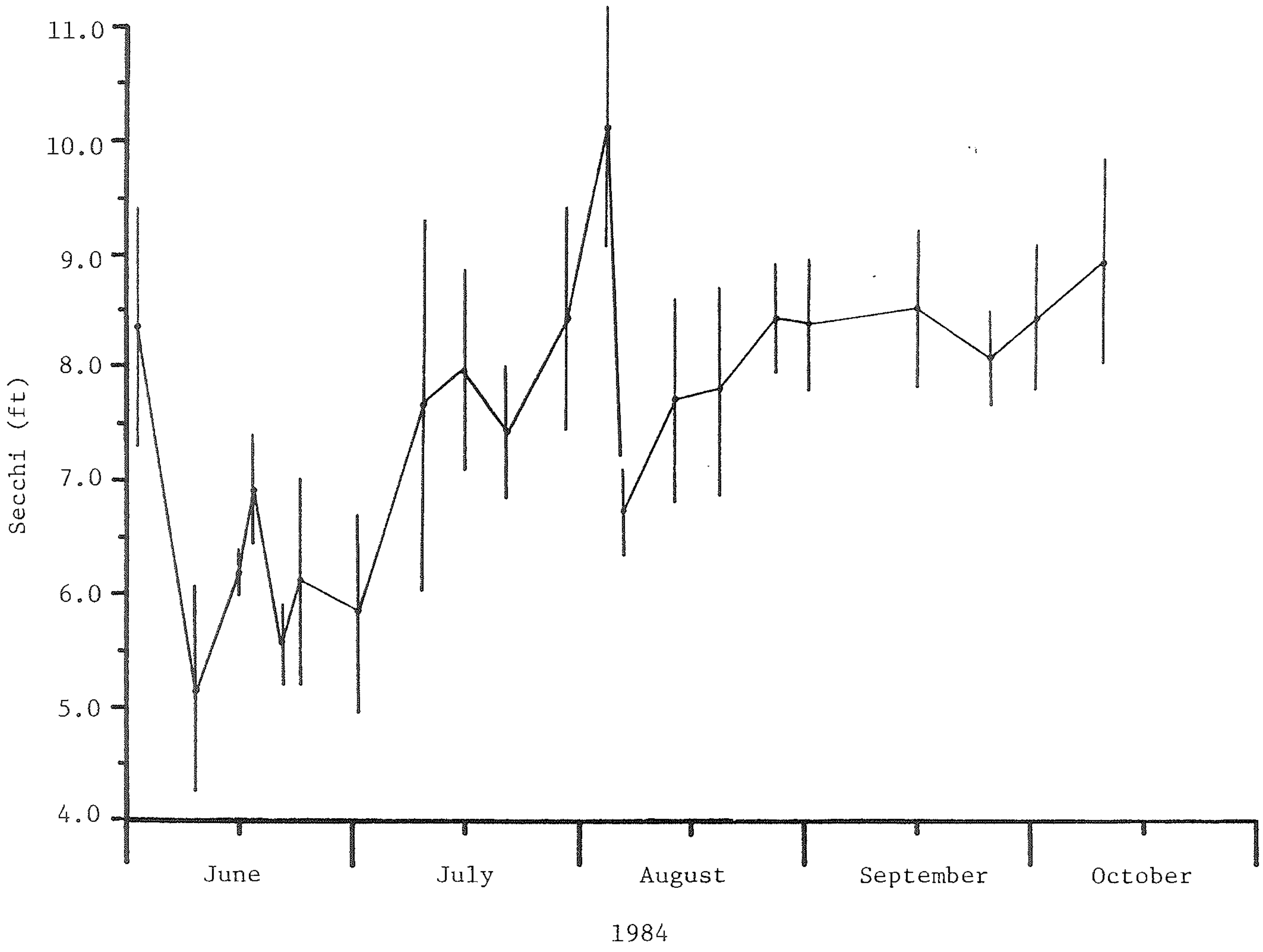


FIGURE 7. Mean Secchi disc transparency in Lake Maxinkuckee for the period June to October 1984. Each data point represents the mean of all monitoring stations reporting for that date.

When averaged for the entire monitoring period of 1984, Secchi disc transparency displayed pronounced differences between lake stations (Figure 8). The greatest variation in Secchi transparency for the year was displayed by the seven stations (1-7) in the northern portion of the lake, and the least variation in clarity was shown by the three stations (15-17) closest to Venetian Village on the southeast shore. The lowest mean clarity was seen at the four stations at the southeast corner of the lake, and the clearest water was recorded along the eastern shore (Figure 9). For the Venetian Village area, water clarity generally improved at increasing distance from the shore, and a similar trend was observed in the area of the Culver Military Academy dock area at the entrance of Wilson Ditch into Aubeenaubee Bay. Water clarity was also somewhat reduced in the northwest corner of the lake offshore from the old Farm Bureau site with clarity progressively improving at nearshore stations running east along the north shore.

The Secchi disc program was continued in 1985, but rather than rely on lake resident volunteers, a local high school student, Mr. Chester Gut, was hired to perform all monitoring. A number of problems arose during the 1984 monitoring effort including: six stations of the sampling network were never monitored by the volunteer(s) assigned them, most volunteers were able to collect data only on weekends and some volunteers sampled irratically throughout the summer. By hiring someone to

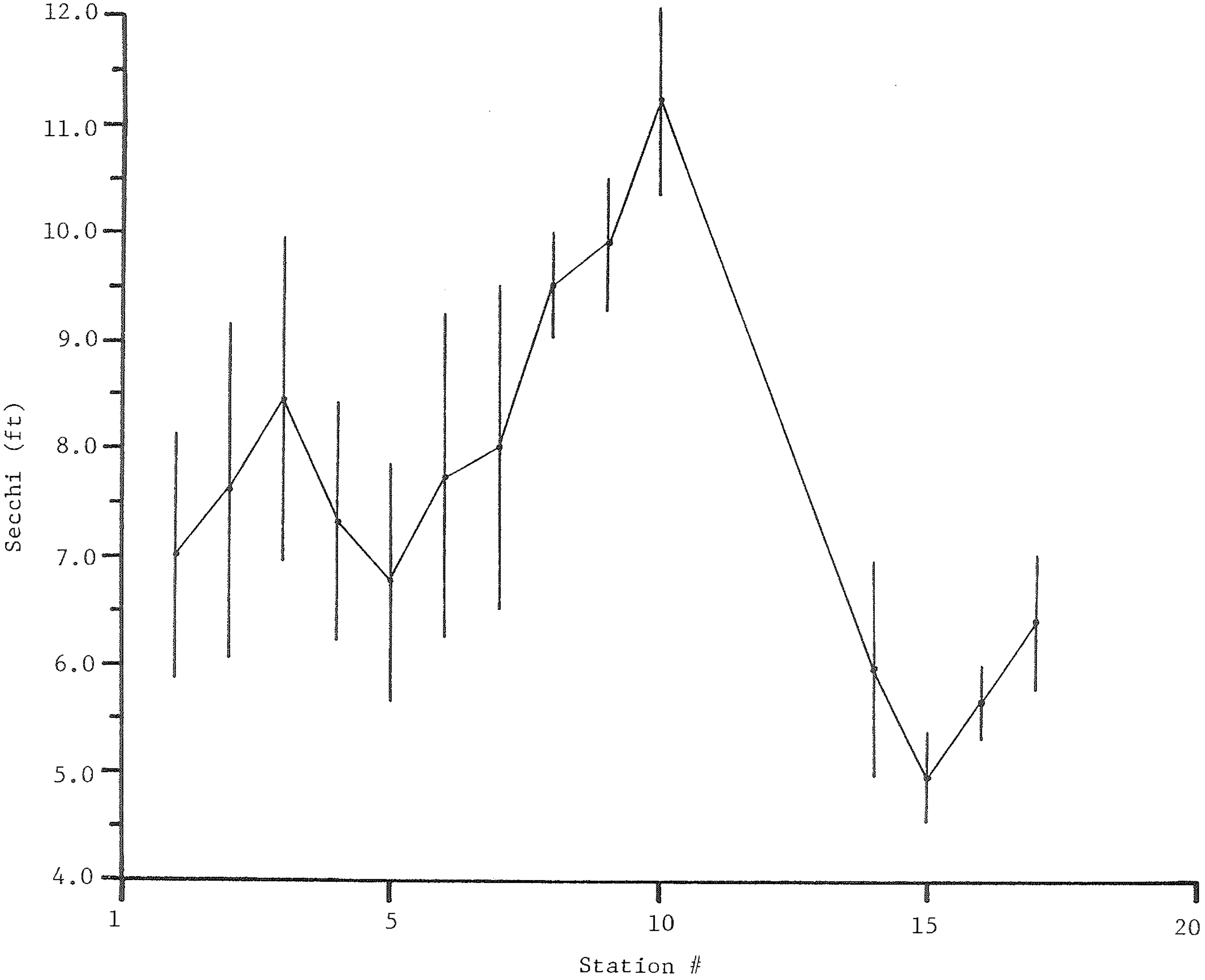


FIGURE 8. Mean Secchi disc transparency for individual monitoring stations of Lake Maxinkuckee for the period June to October 1984. Location of station numbers are given on Figure 6.

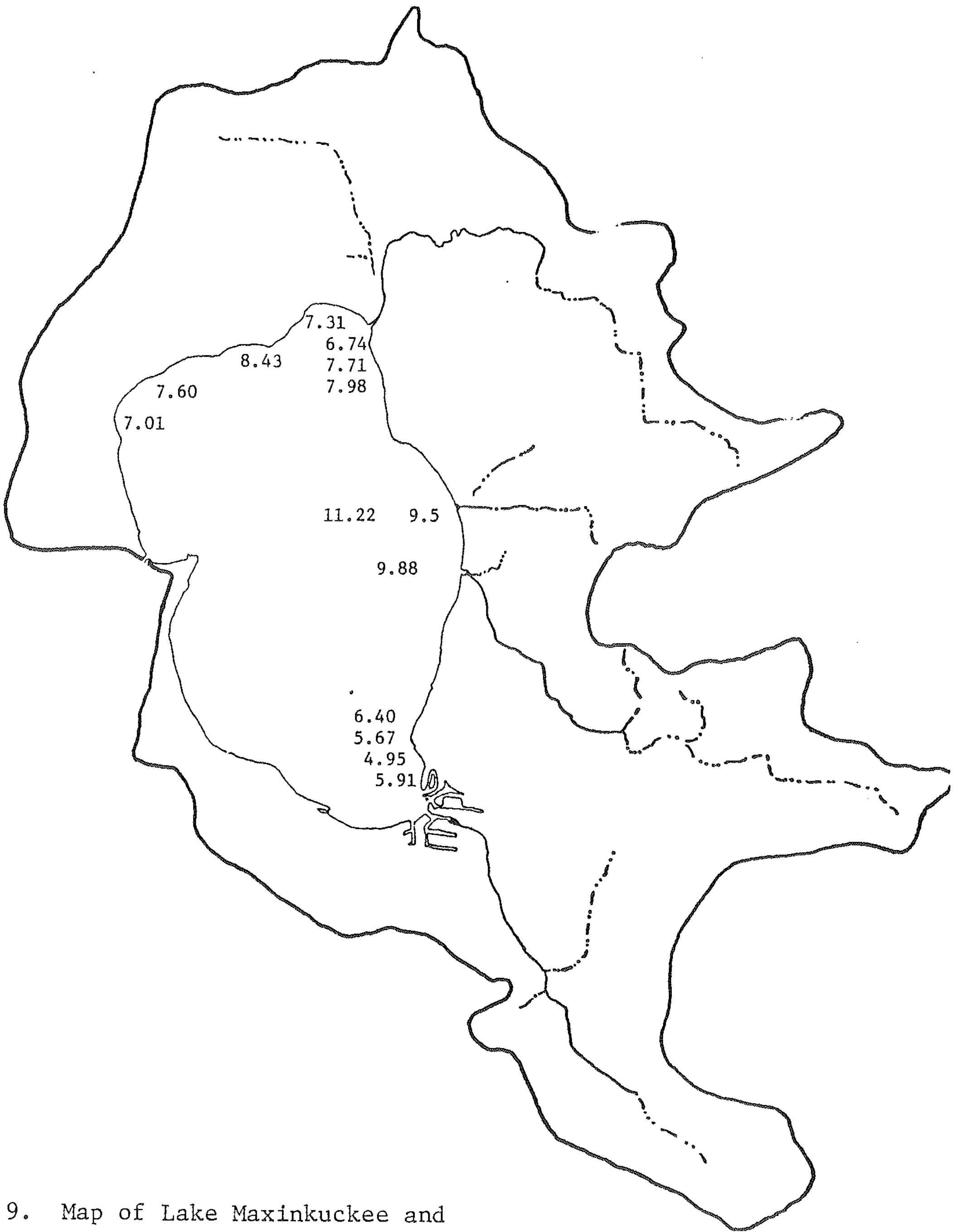


Figure 9. Map of Lake Maxinkuckee and surrounding watershed showing mean Secchi disc transparency (feet) for individual stations of the 1984 monitoring program.

do the monitoring, we could be assured that all stations were monitored at set intervals and at the same time of the day, sampling could be done during the week as well as on the weekend, and all data would be standardized to a single pair of human eyes.

The 1985 Secchi program was designed to address specifically: 1) whether, as originally suggested by Hamelink (1971), power boats significantly alter water clarity in the lake, 2) the impact of inflowing streams on water clarity, and 3) if trends delineated from the 1984 database were repeatable in 1985. A total of 26 Secchi stations were selected to address these three points (Figure 10). Every station was monitored on a given sampling day, and all Secchi disc readings were taken at the same time of day (mid day) throughout the study.

Each station was monitored 25 times from 7 June until 27 August. In addition to a routine weekly monitoring schedule, Secchi readings were taken everyday for three one-week periods during the summer in order to assess the impact of weekend power boating on lake clarity. The first one-week sampling (3 July - 9 July) spanned the 4 July holiday, presumed to be the period of most intense recreational activity at Lake Maxinkuckee. An additional two weeks of daily Secchi monitoring were conducted during August (14 August - 27 August) thus spanning two weekends assumed to represent "typical" weekend recreational activity.

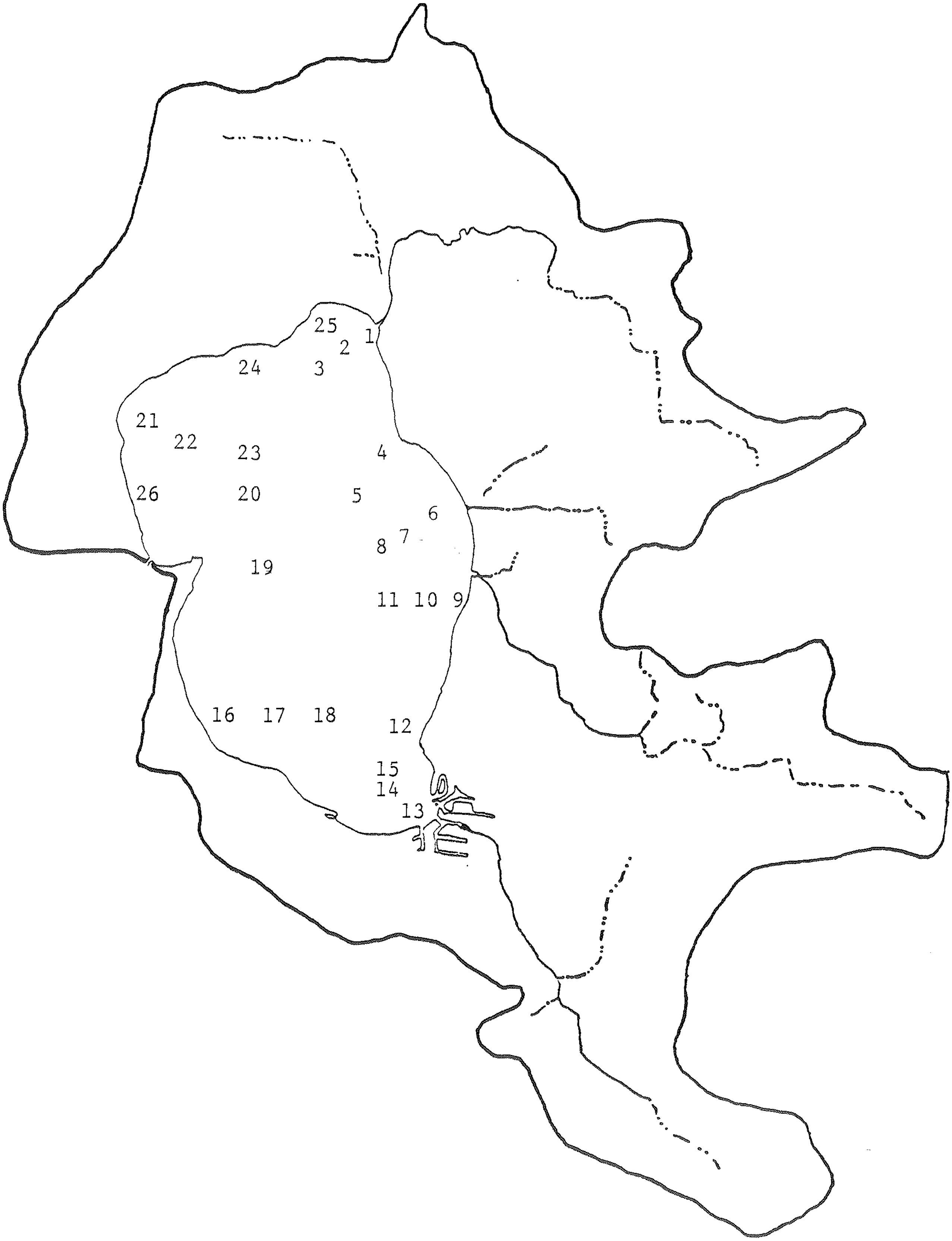


Figure 10. Map of Lake Maxinkuckee and its watershed showing monitoring sites for the 1985 Secchi disc program.

Mean Secchi disc transparency in Lake Maxinkuckee for the 25 monitoring dates between 7 June and 27 August 1985 are presented in Figure 11. Water clarity displayed a similar trend in 1985 as established for 1984, namely a decline during June to minimum annual clarity values by the end of June and the first week of July after which clarity increased gradually throughout the remainder of the summer. Unlike 1984 lake-wide means did not vary significantly throughout the summer monitoring period of 1985. This likely reflects the greater number and diversity of stations in 1985.

The lowest Secchi disc values of 1985 were recorded during the 4 July weekend. Water clarity declined by approximately 17% during this period of intense recreational use of the lake, but the depression of clarity was short-lived. July fourth was on Thursday, thus peak holiday lake usage lasted through Sunday 7 July. By Tuesday 9 July Secchi disc transparency had returned to levels considered normal for July.

The effect of recreational activities on water clarity was also monitored for the weekends of August 17-18 and 24-25 as part of a two week (14 - 27 August) daily monitoring of Secchi transparency at all 26 monitoring stations. The data collected for these two weekends are considered representative of "typical" recreational weekend usage for the summer. Mean water clarity in the lake was reduced by 2% during the first weekend and by

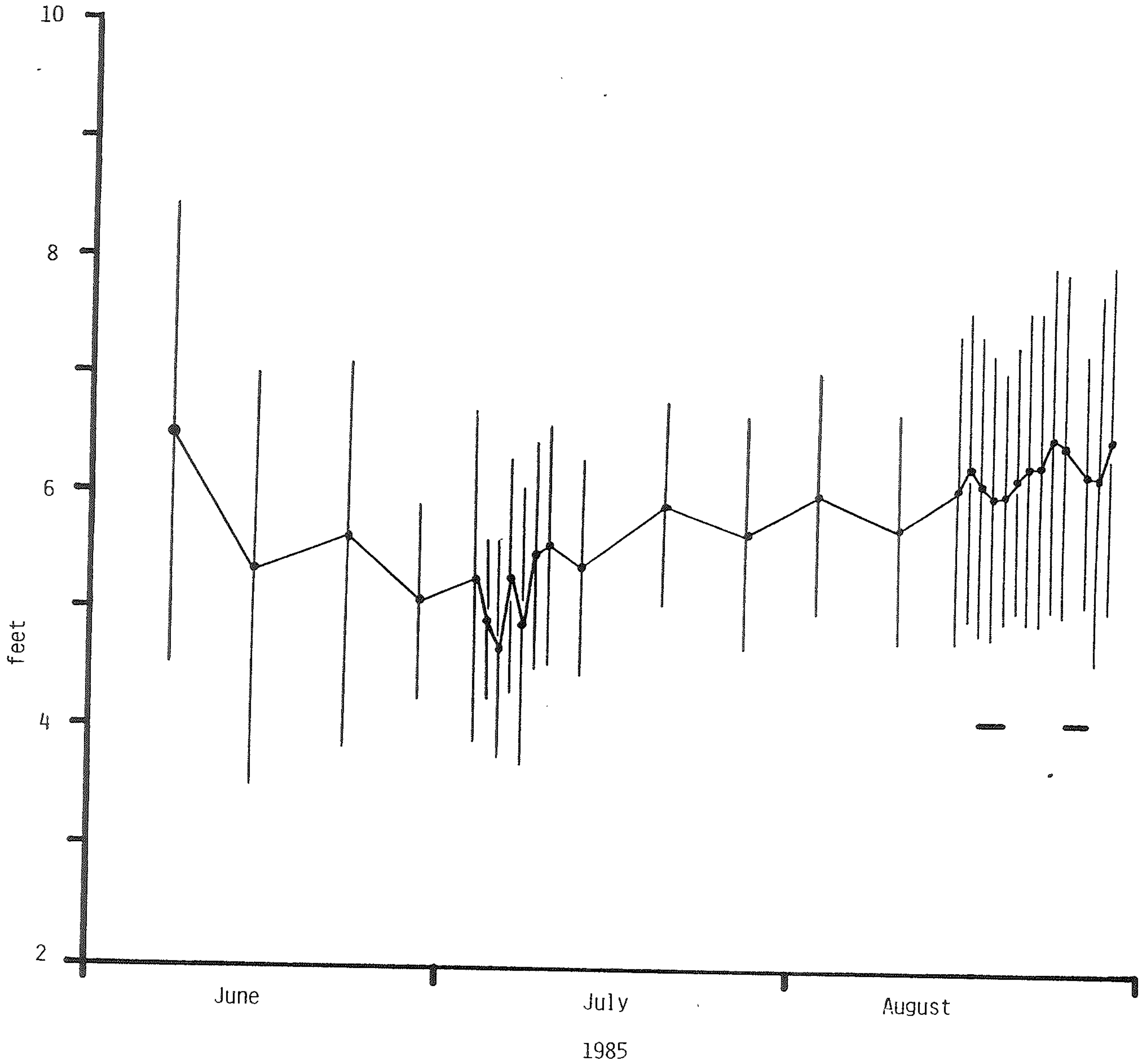


Figure 11. Mean Secchi disc transparency in Lake Maxinkuckee for the period June to August 1985. Each data point represents the mean of all 26 stations. Weekends (Friday-Sunday) during the intensive monitoring periods of August are underlined.

5% during the second. In both cases clarity returned to pre-weekend levels by the following Tuesday. At no time during either the 4 July holiday or the two weekends in August was mean water clarity in Lake Maxinkuckee altered significantly.

The 1985 Secchi data have been plotted for each of the 26 lake stations separately (Figures 12-37). While the general data trends were similar between stations, it is apparent that weekend recreational usage affects regions of the lake differentially. The 4 July holiday is assumed to be representative of periods of peak recreational activity and will be used to illustrate a few points. The lowest Secchi values for this holiday weekend were recorded at station 9 at the mouth of Curtiss Ditch and at stations 13 and 14 at the southeast corner of the lake. In general, the weekend reduction in water clarity was very pronounced for all stations in the eastern half of the lake, while the stations of the western half of the lake (#16-24) were much less affected. The reduction in clarity was not limited to shallow stations but extended throughout the lake basin. As was mentioned previously, even after a peak use period such as the 4 July weekend, clarity was restored throughout the lake to levels considered normal background by the following Tuesday.

Annual mean Secchi values for 1985 for each monitoring station are presented graphically in Figure 38 and according to station location in Lake Maxinkuckee in Figure 39. The lowest mean water

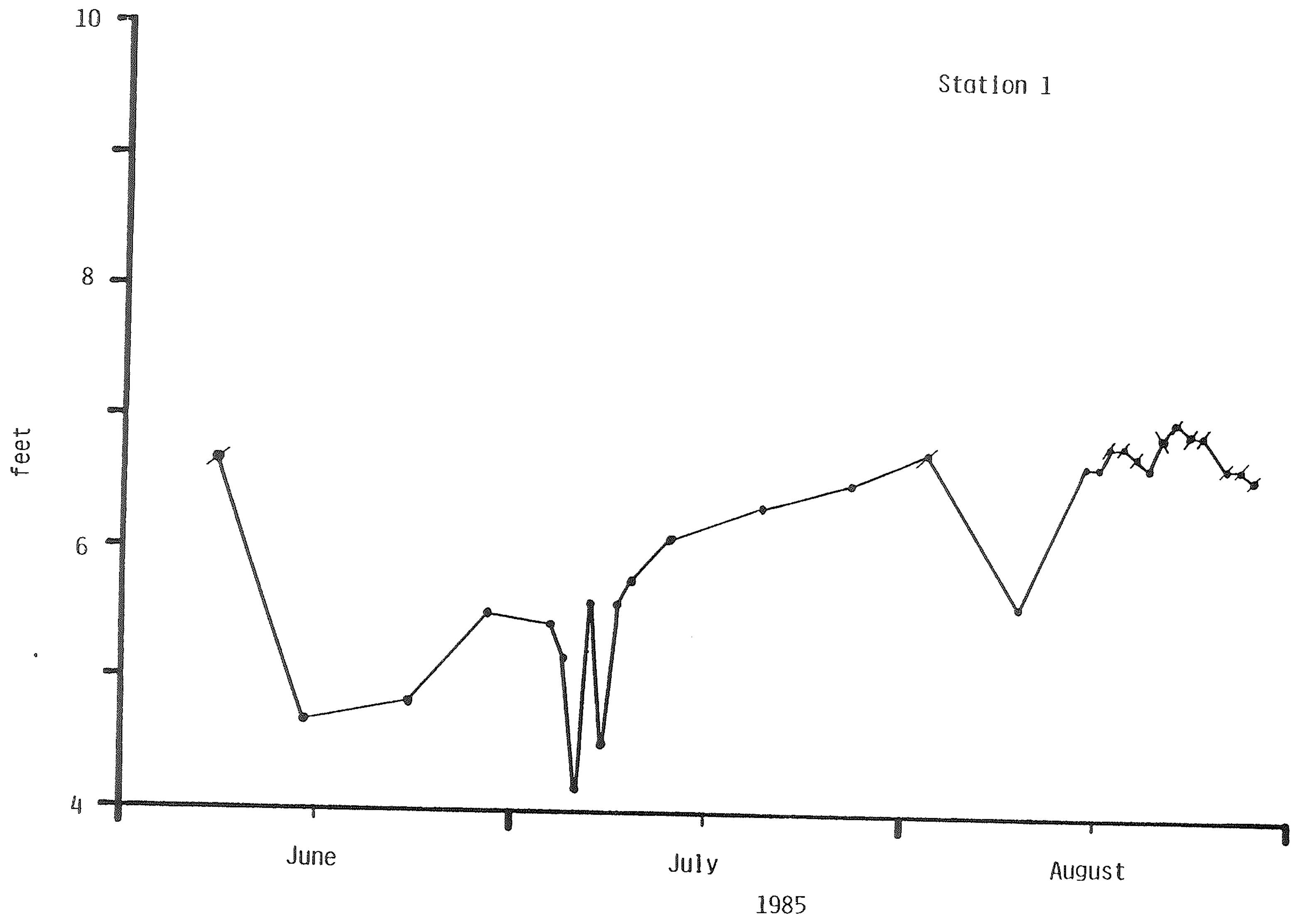


Figure 12. Secchi disc readings for individual monitoring dates of the 1985 survey at station 1 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

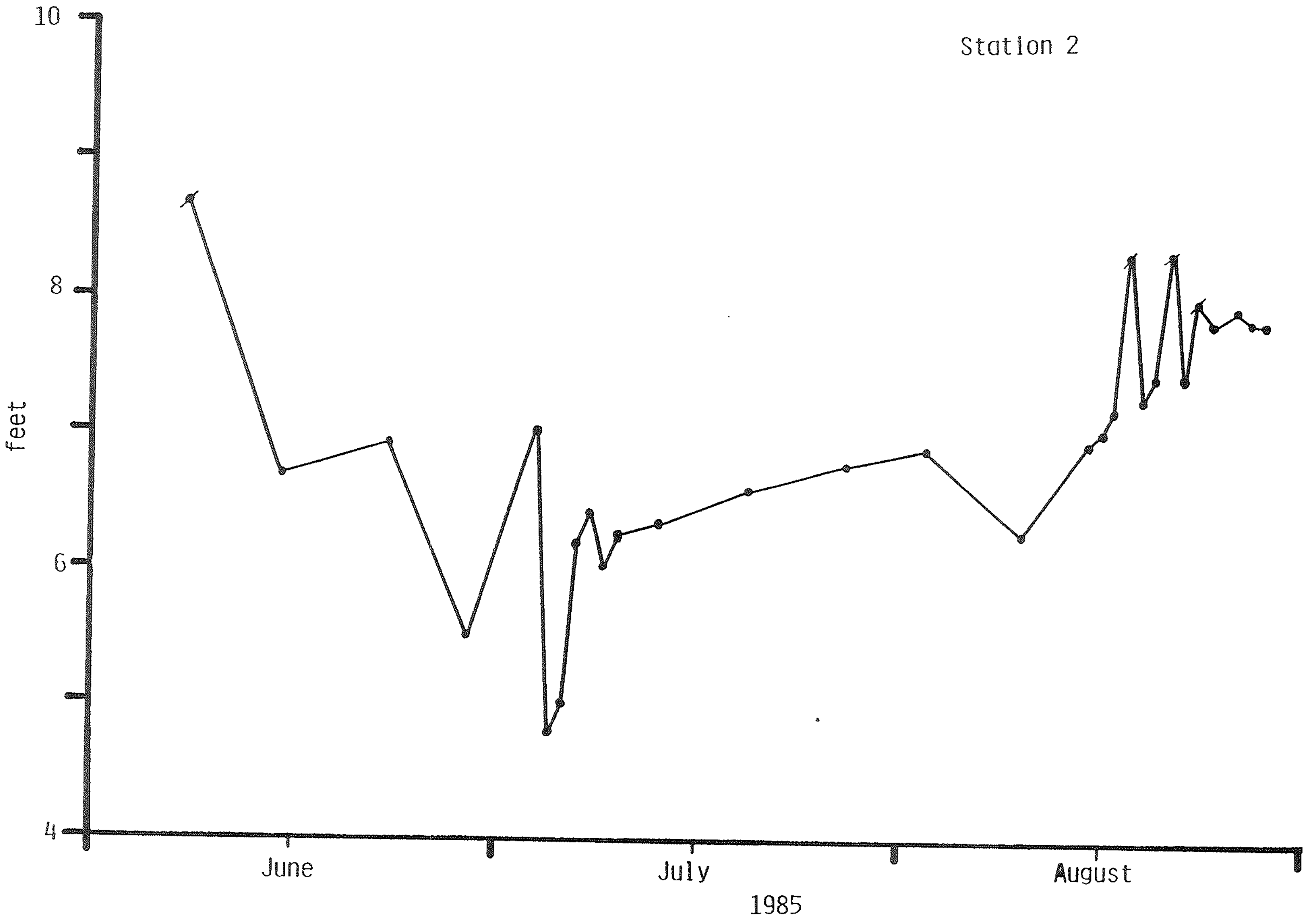


Figure 13. Secchi disc readings for individual monitoring dates of the 1985 survey at station 2 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

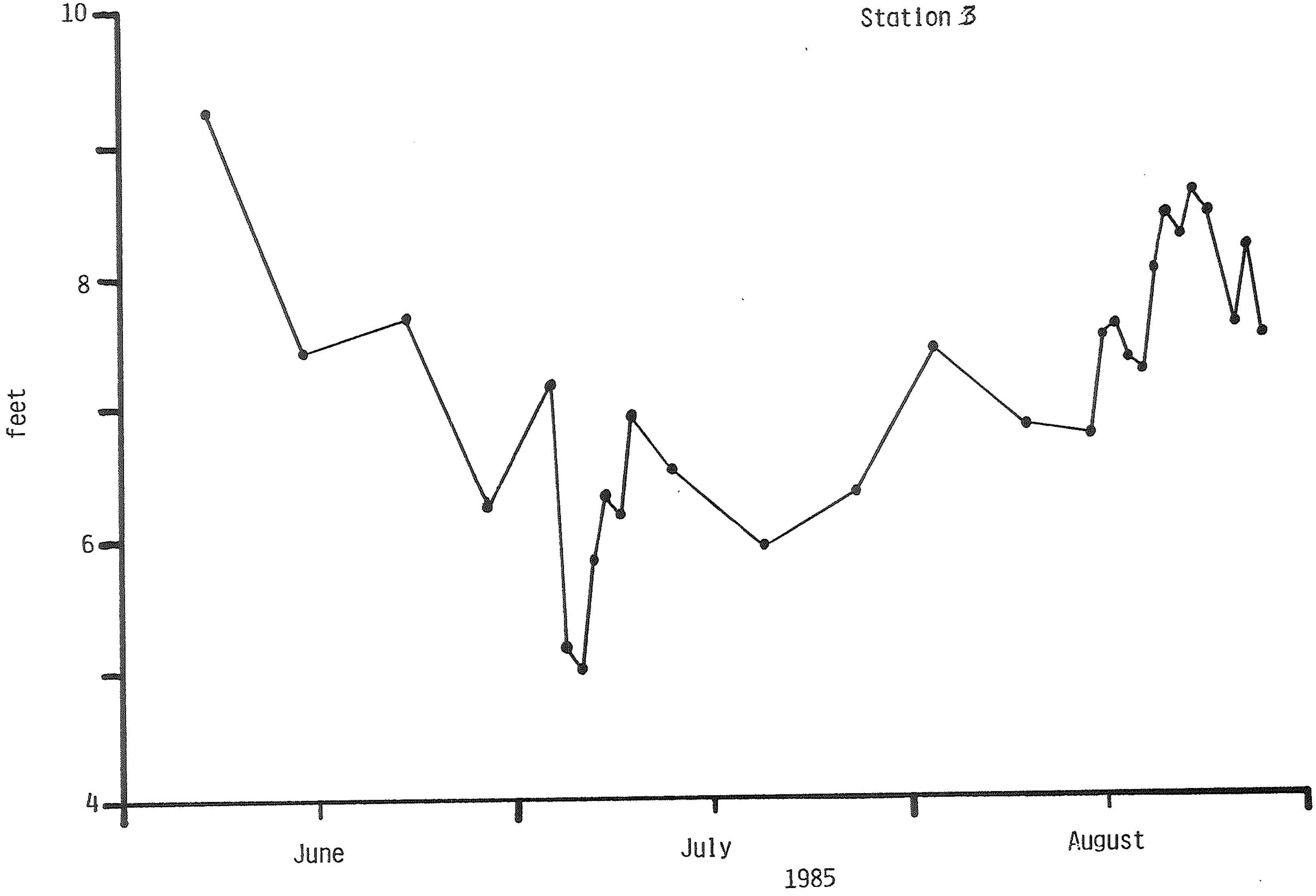


Figure 14. Secchi disc readings for individual monitoring dates of the 1985 survey at station 3 of Lake Maxinkuckee.

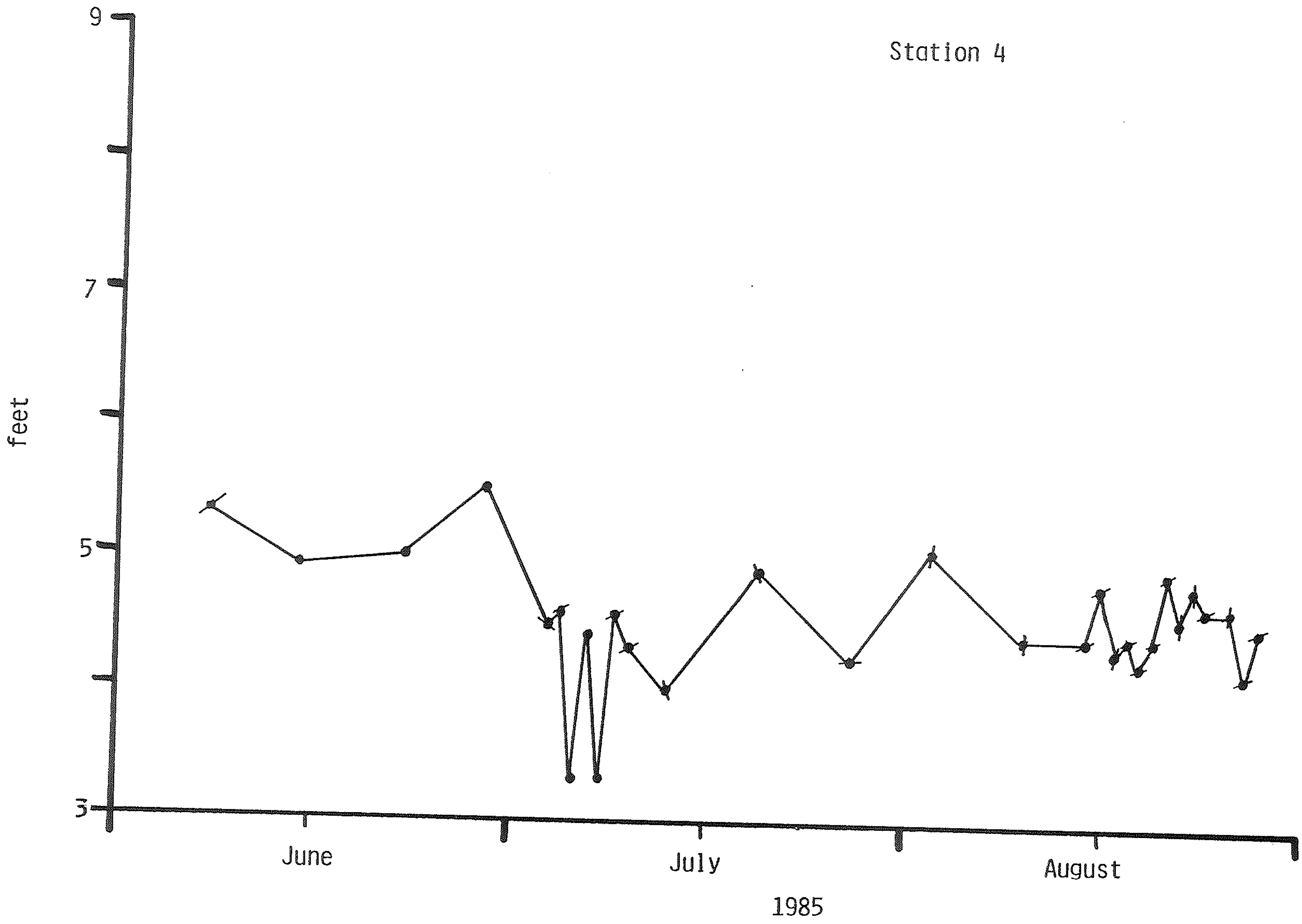


Figure 15. Secchi disc readings for individual monitoring dates of the 1985 survey at station 4 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

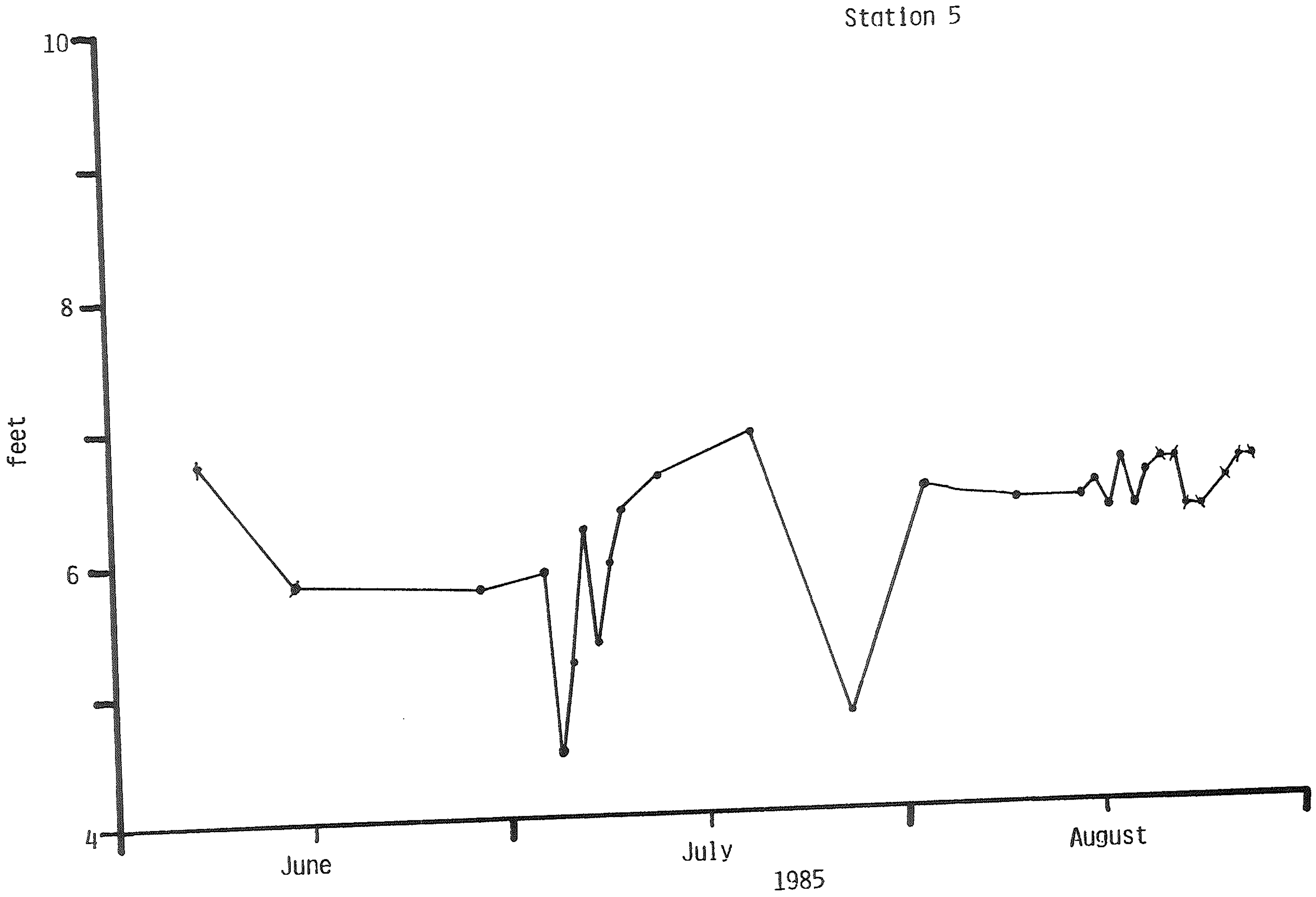


Figure 16. Secchi disc readings for individual monitoring dates of the 1985 survey at station 5 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

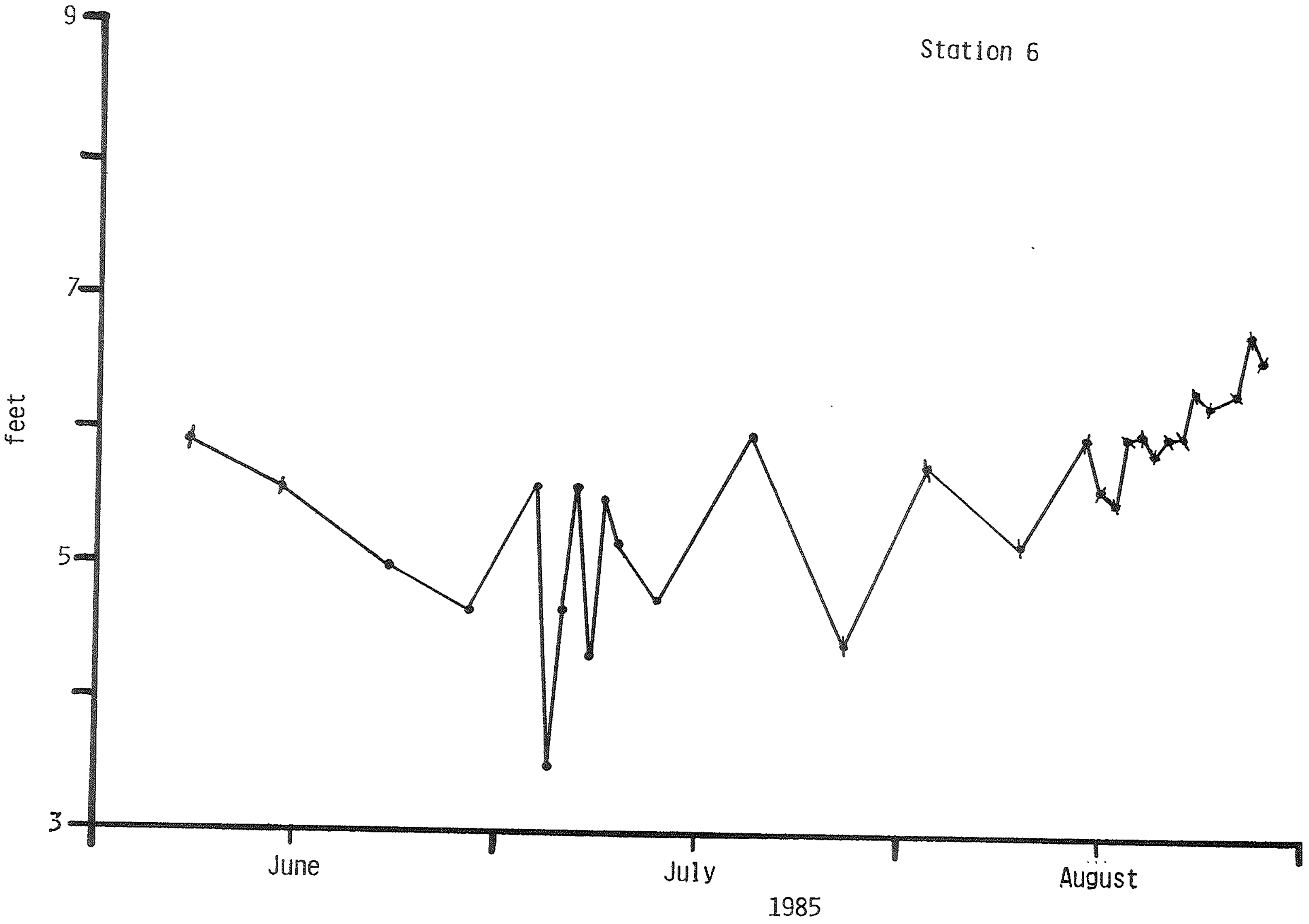


Figure 17. Secchi disc readings for individual monitoring dates of the 1985 survey at station 6 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

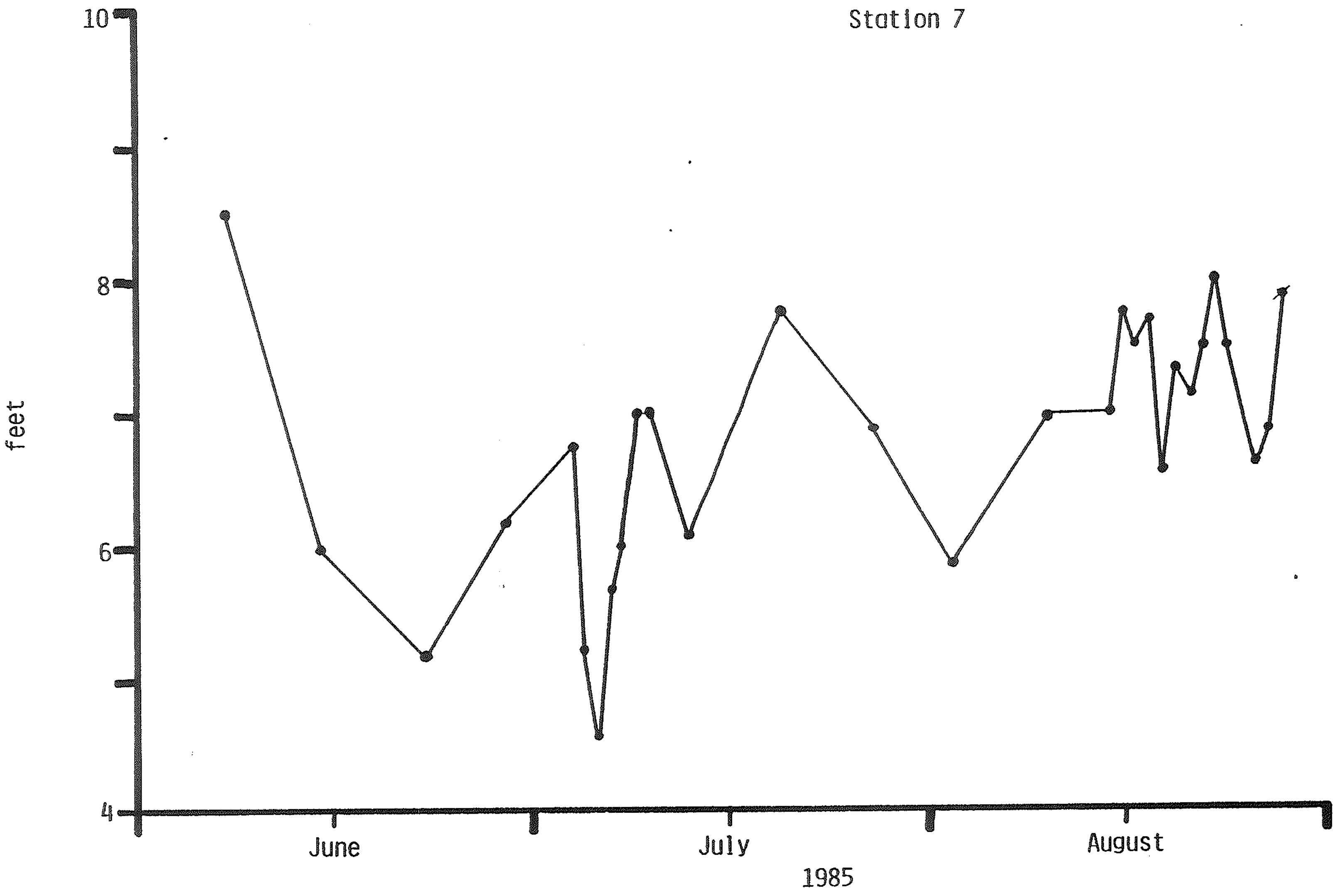


Figure 18. Secchi disc readings for individual monitoring dates of the 1985 survey at station 7 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

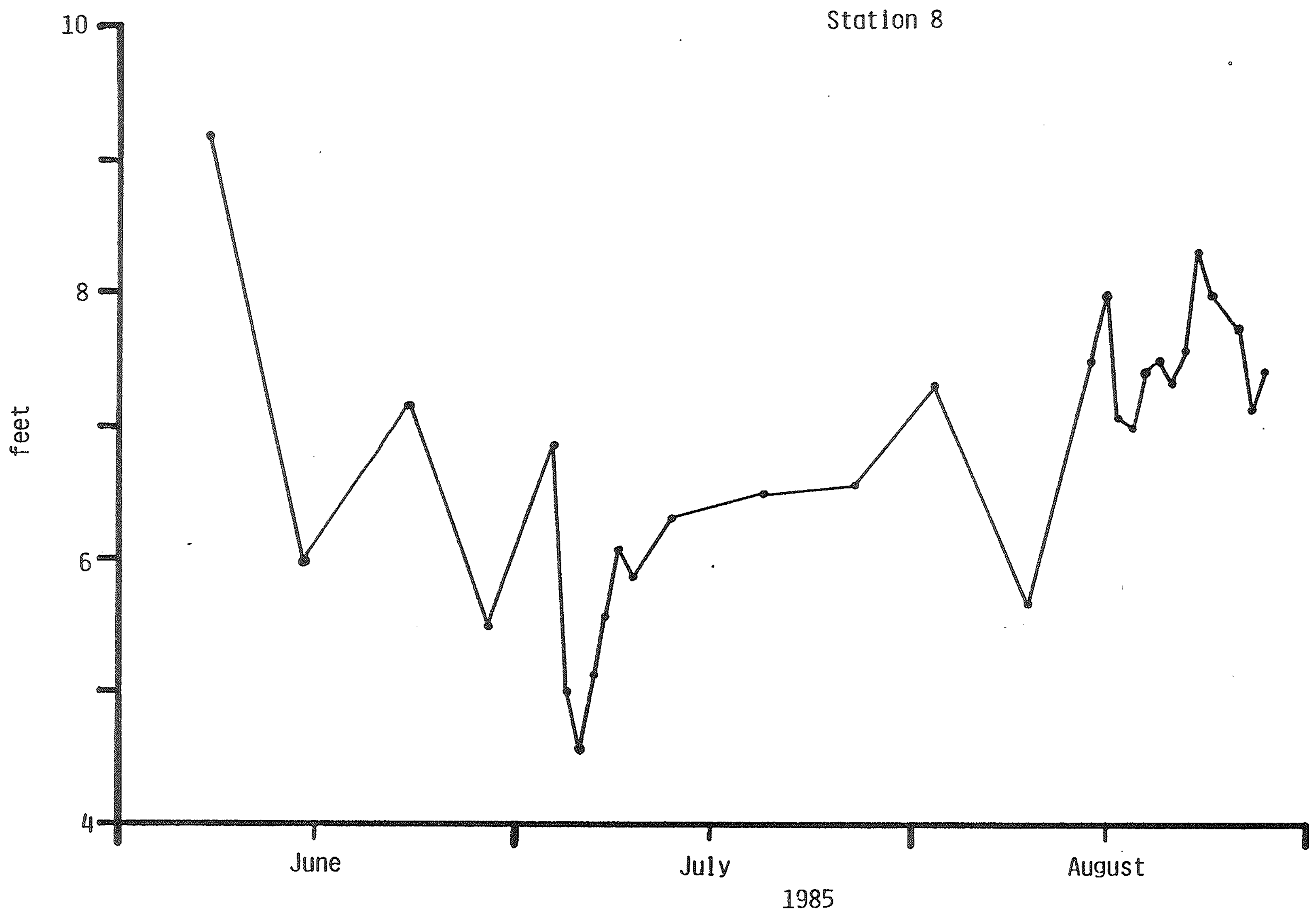


Figure 19. Secchi disc readings for individual monitoring dates of the 1985 survey at station 8 of Lake Maxinkuckee.

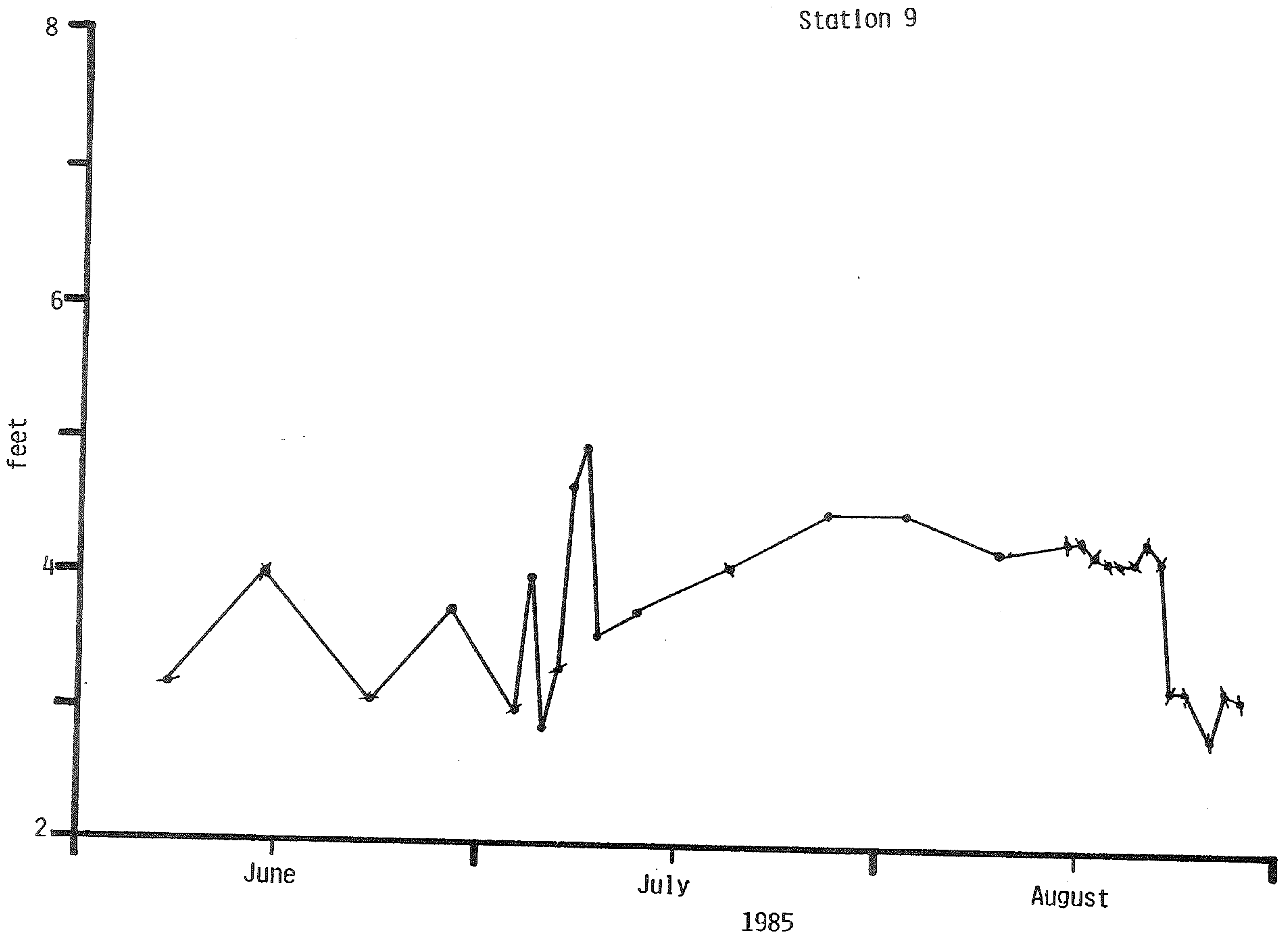


Figure 20. Secchi disc readings for individual monitoring dates of the 1985 survey at station 9 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

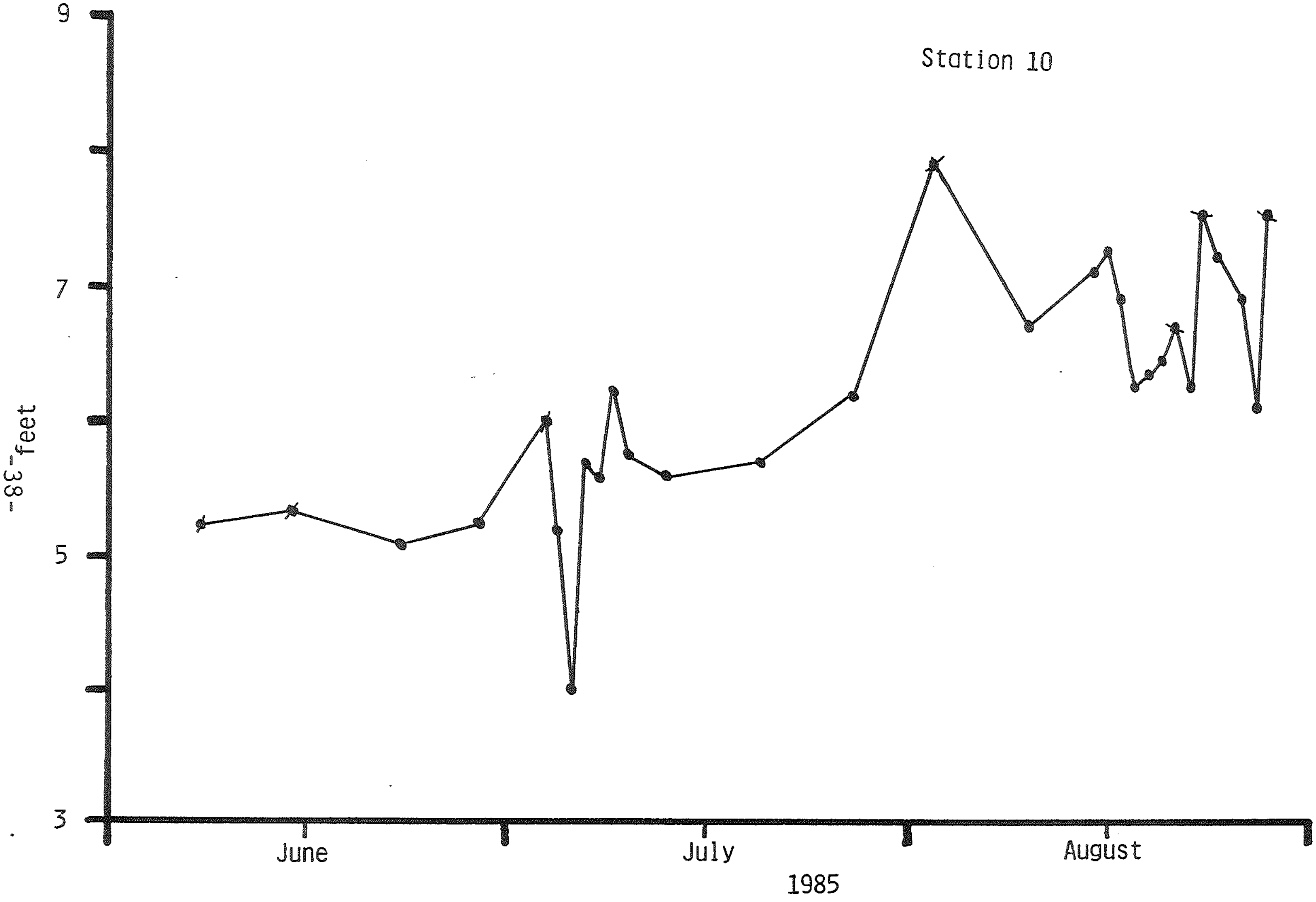


Figure 21. Secchi disc readings for individual monitoring dates of the 1985 survey at station 10 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

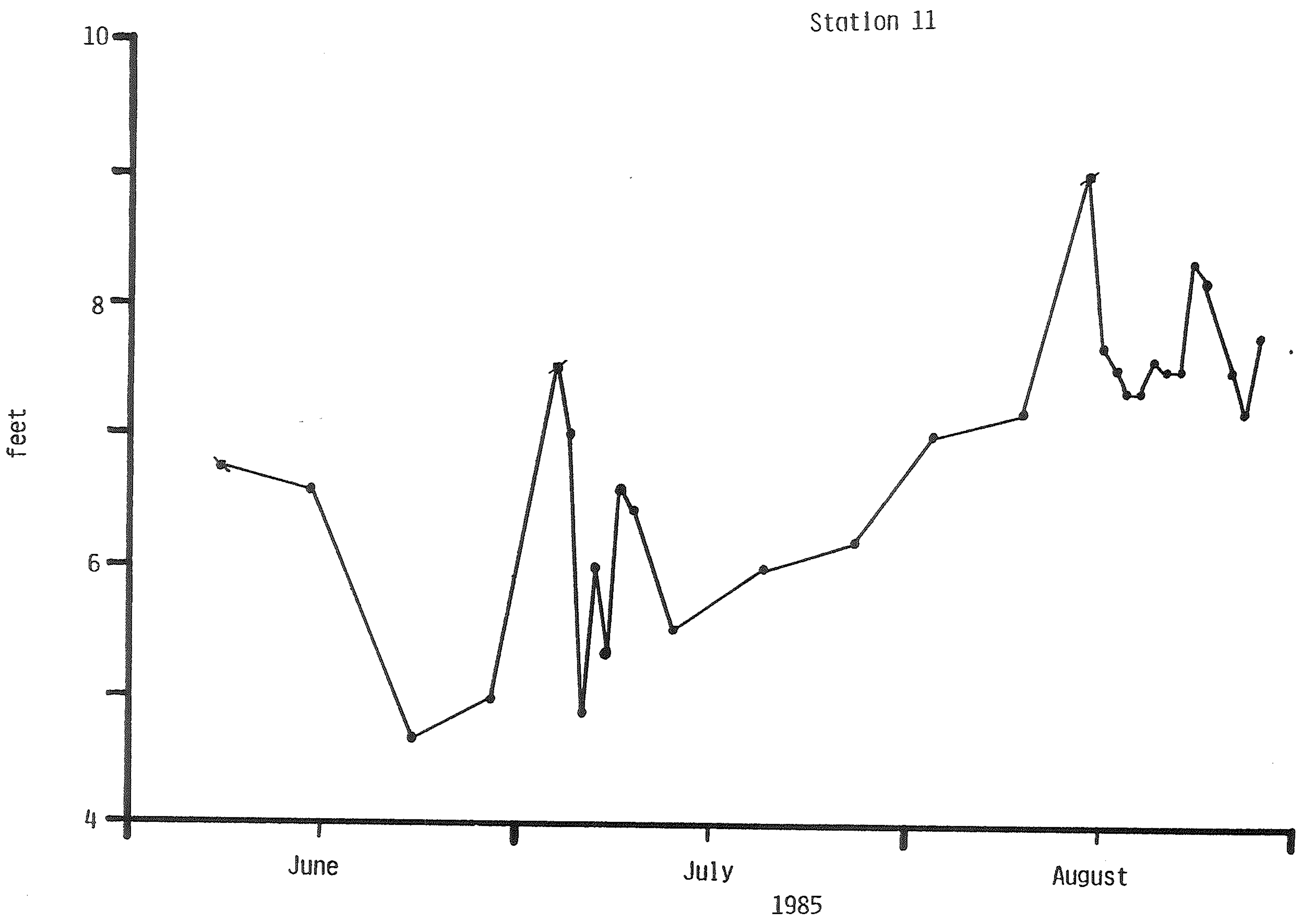


Figure 22. Secchi disc readings for individual monitoring dates of the 1985 survey at station 11 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

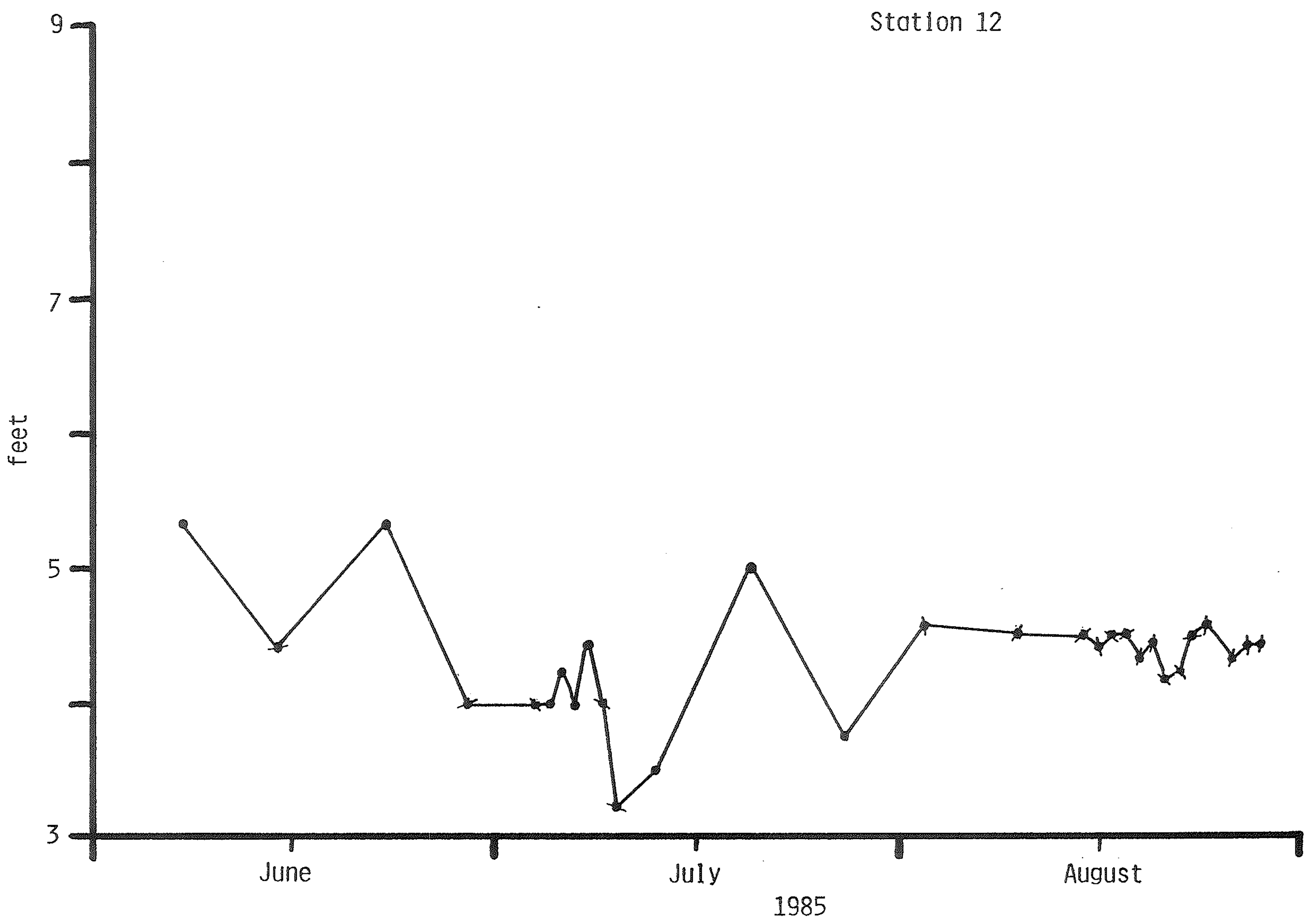


Figure 23. Secchi disc readings for individual monitoring dates of the 1985 survey at station 12 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

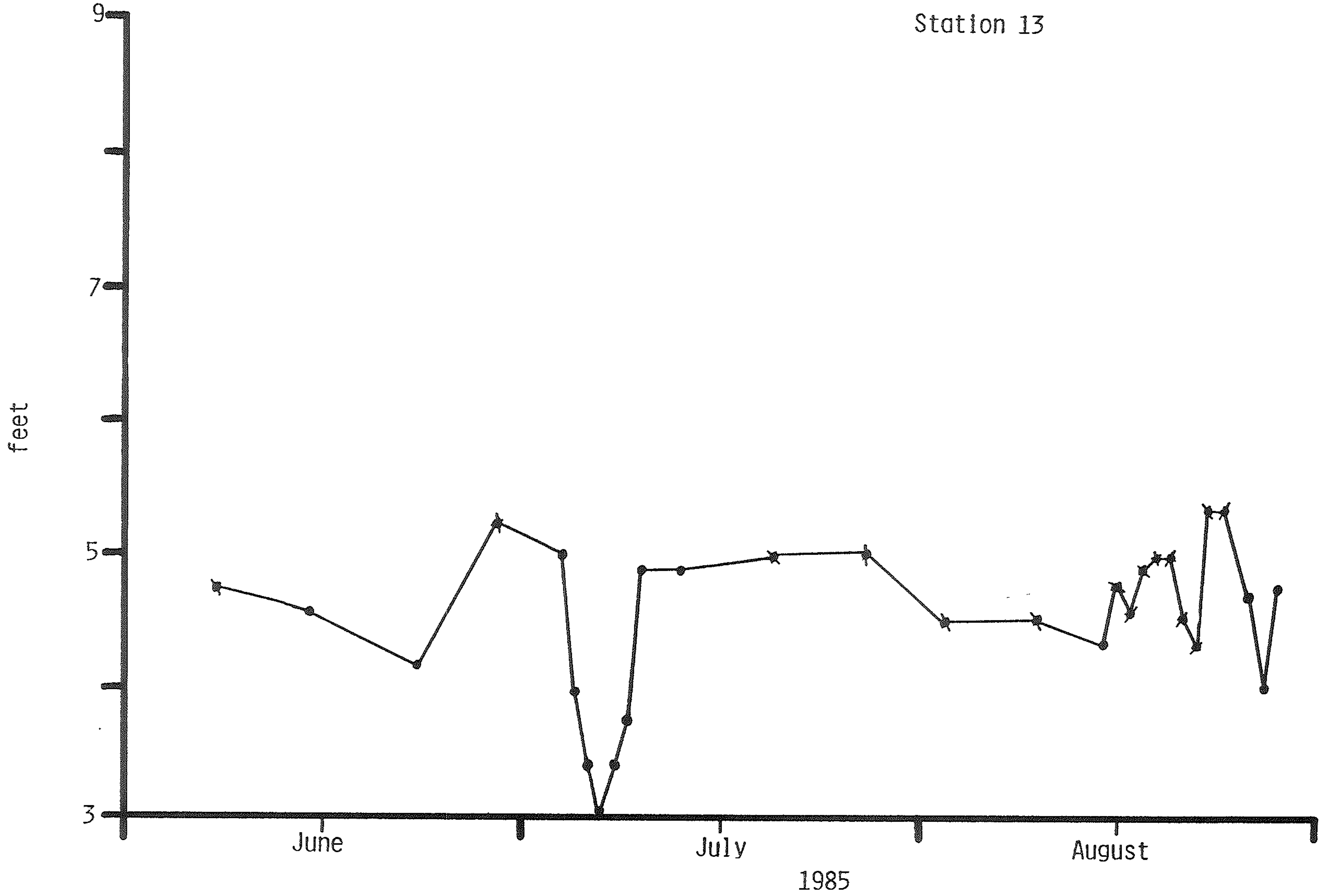


Figure 24. Secchi disc readings for individual monitoring dates of the 1985 survey at station 13 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

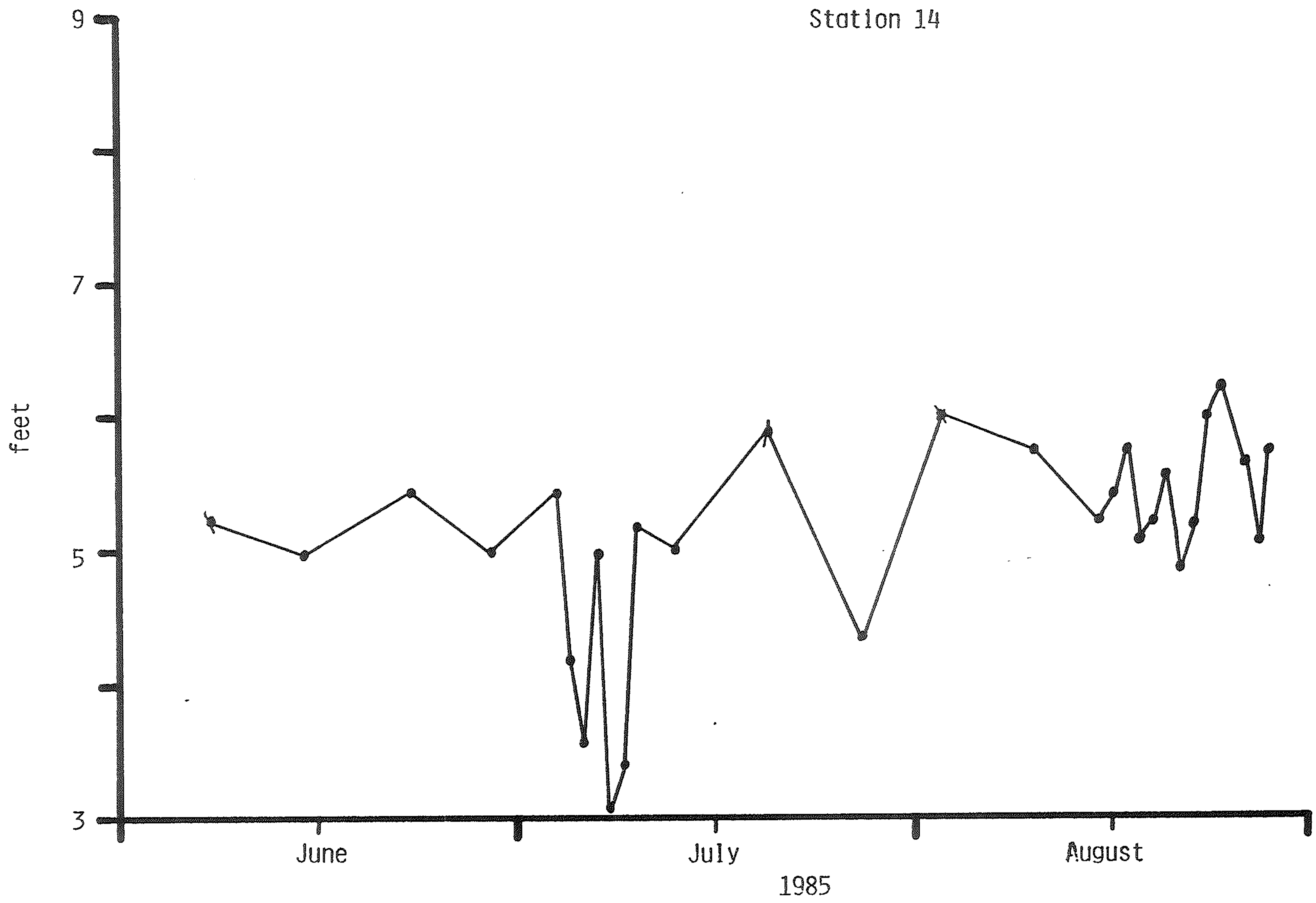


Figure 25. Secchi disc readings for individual monitoring dates of the 1985 survey at station 14 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

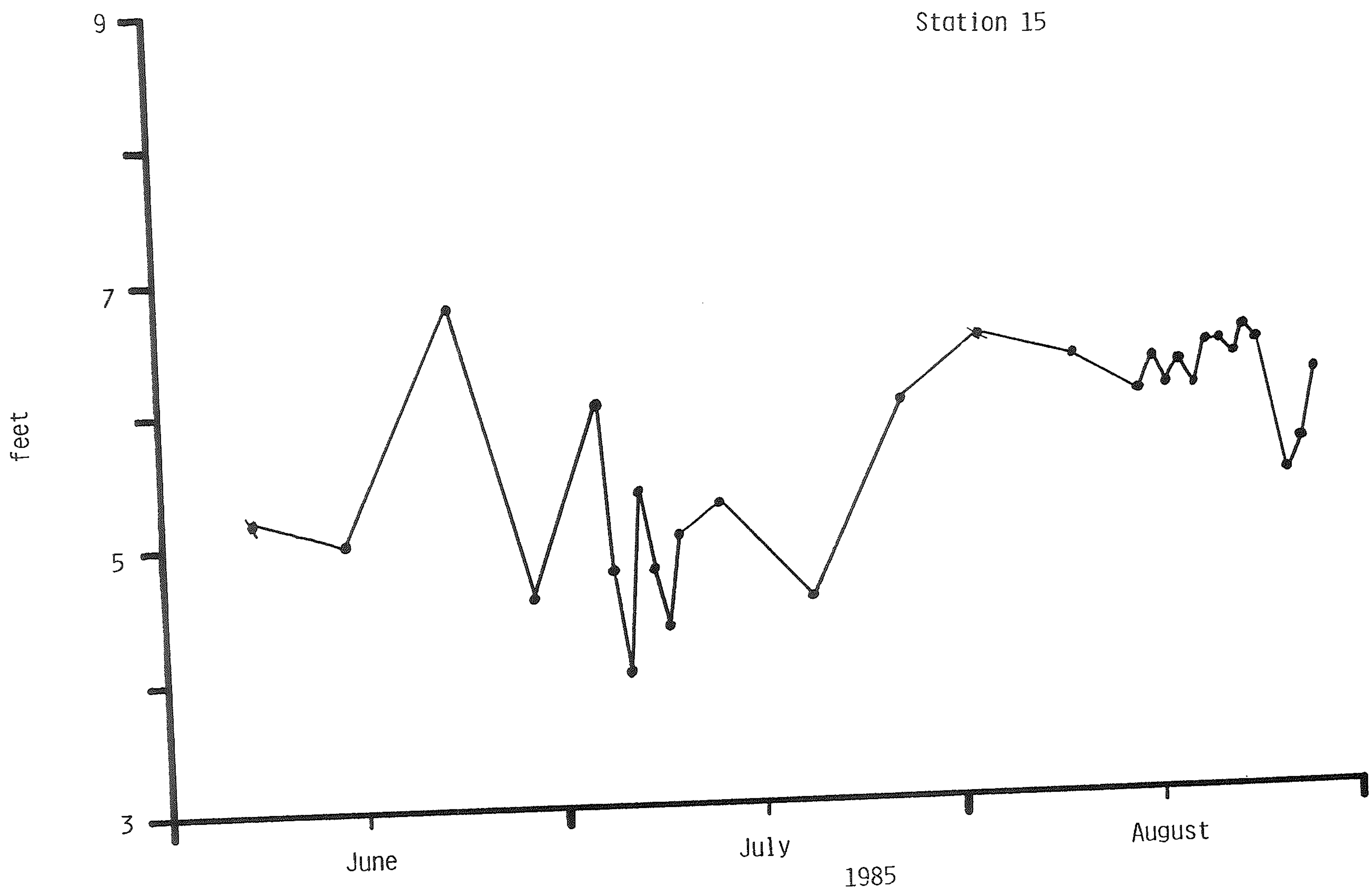


Figure 26. Secchi disc readings for individual monitoring dates of the 1985 survey at station 15 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

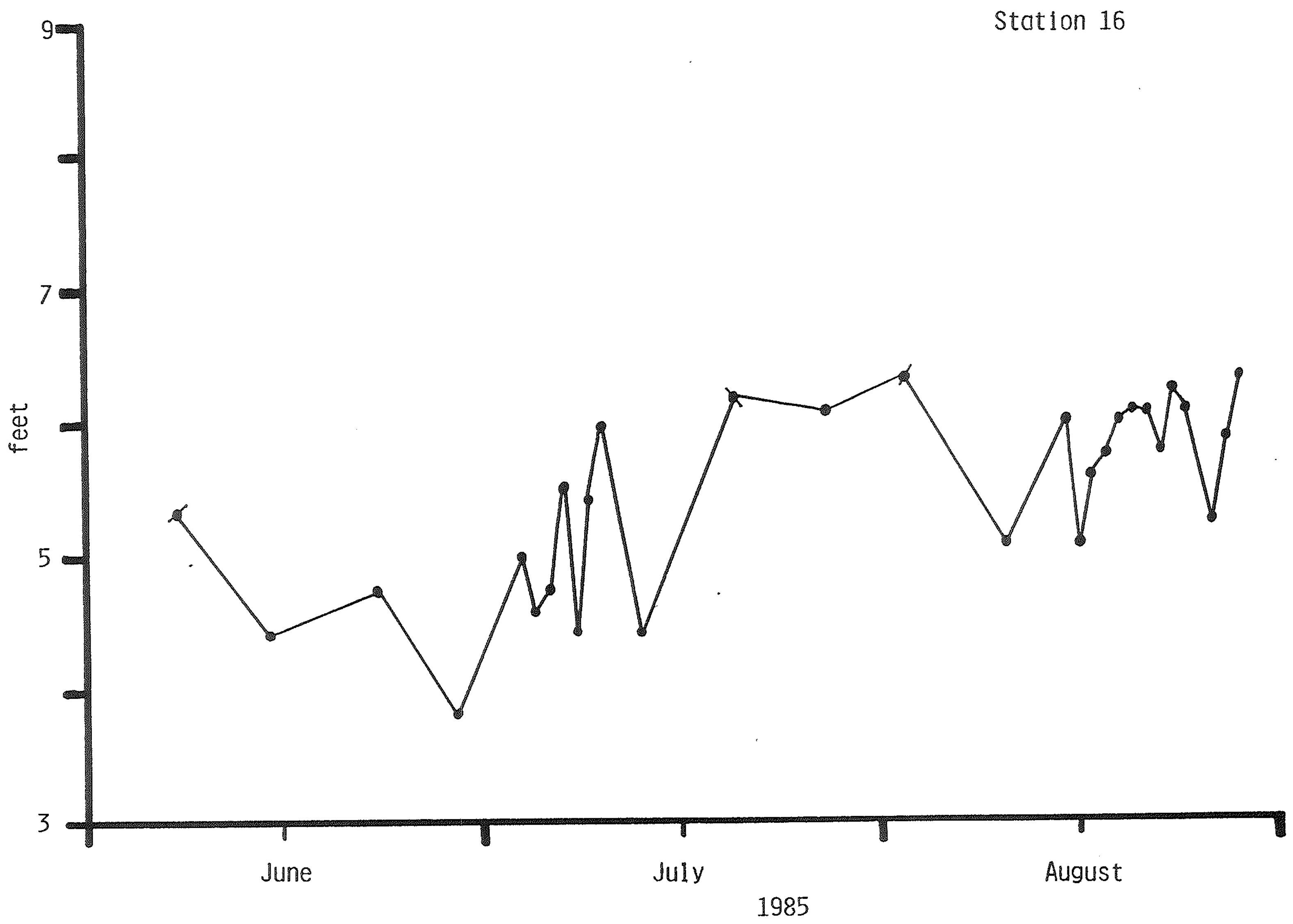


Figure 27. Secchi disc readings for individual monitoring dates of the 1985 survey at station 16 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

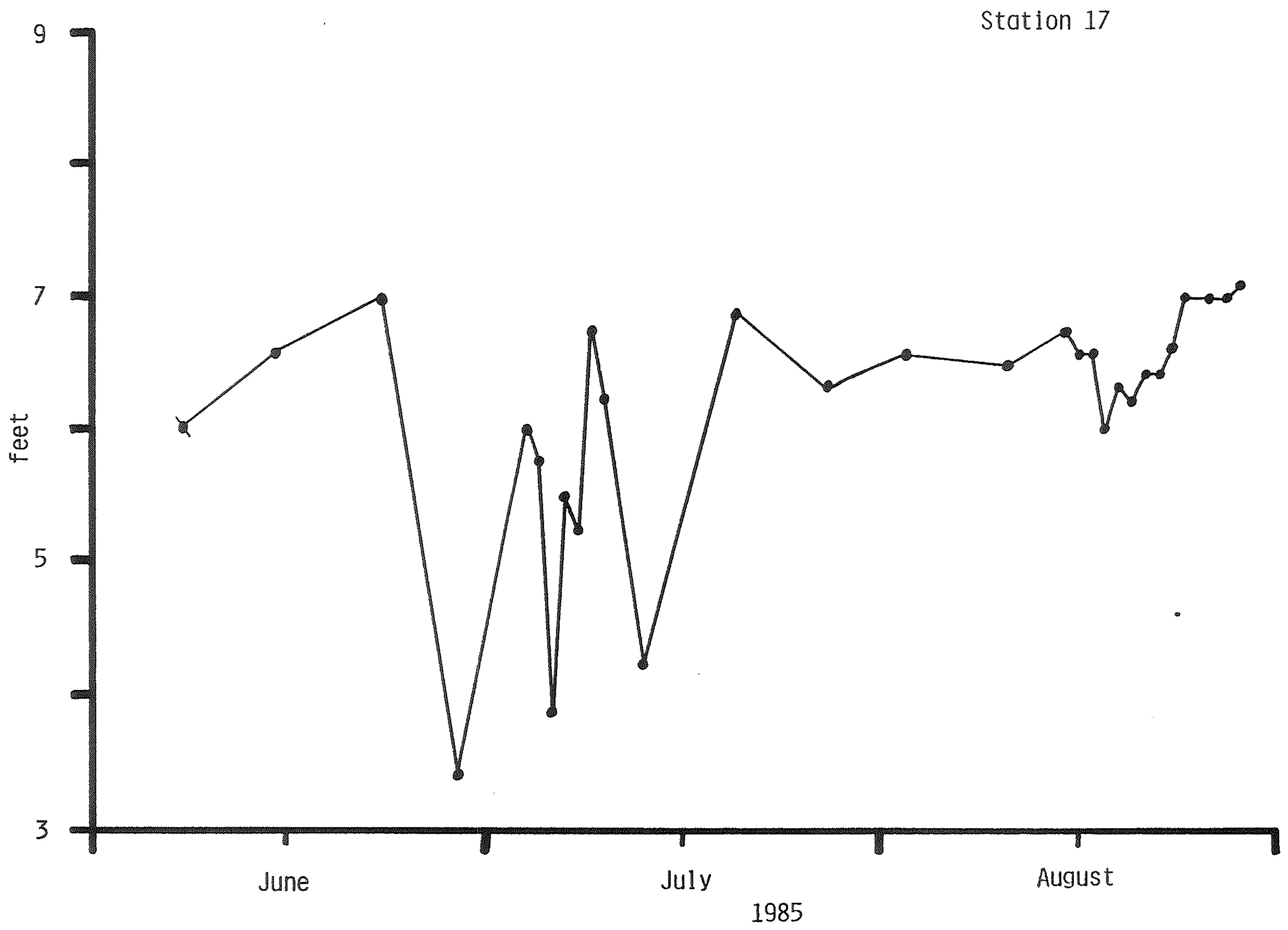


Figure 28. Secchi disc readings for individual monitoring dates of the 1985 survey at station 17 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

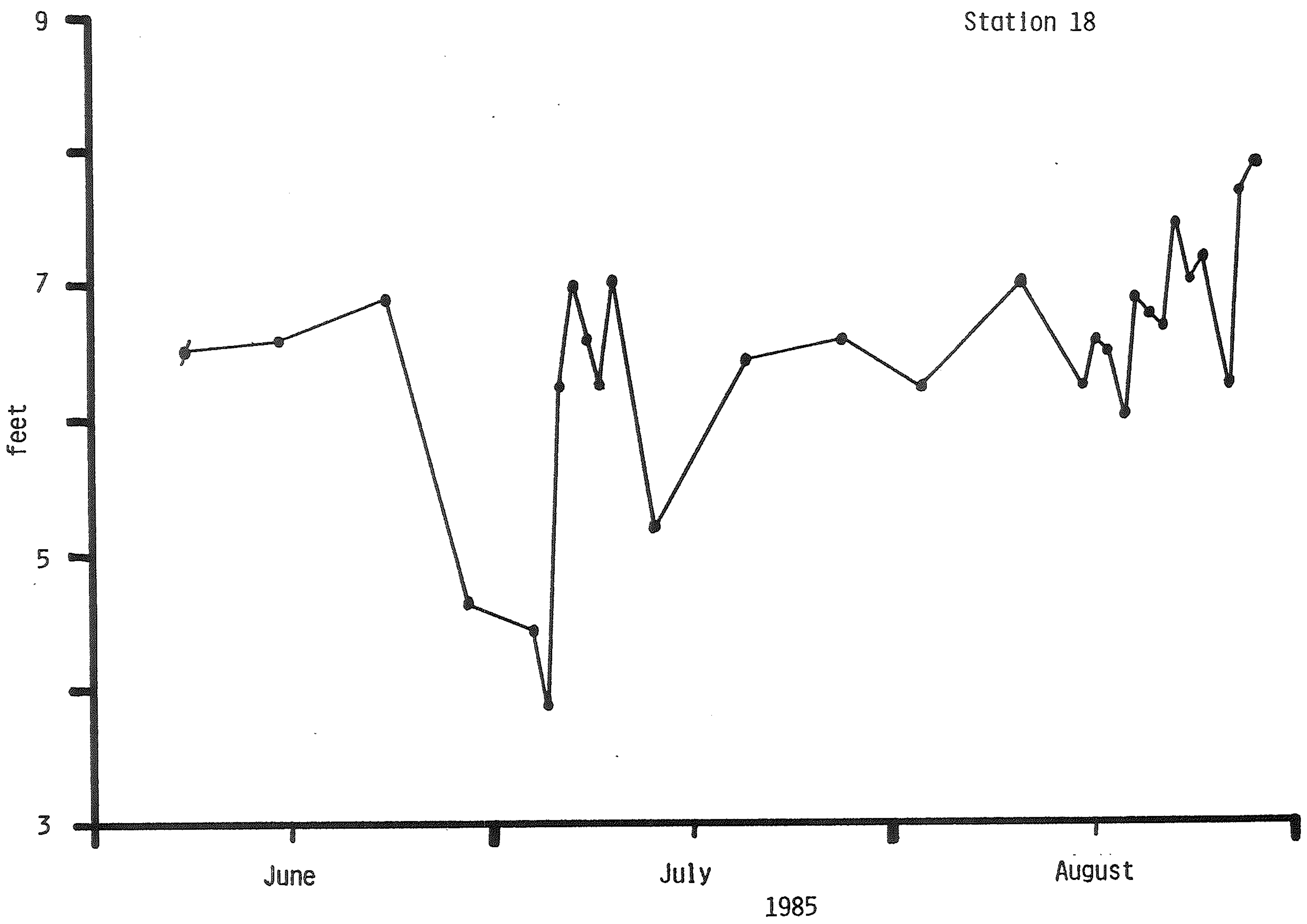


Figure 29. Secchi disc readings for individual monitoring dates of the 1985 survey at station 18 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

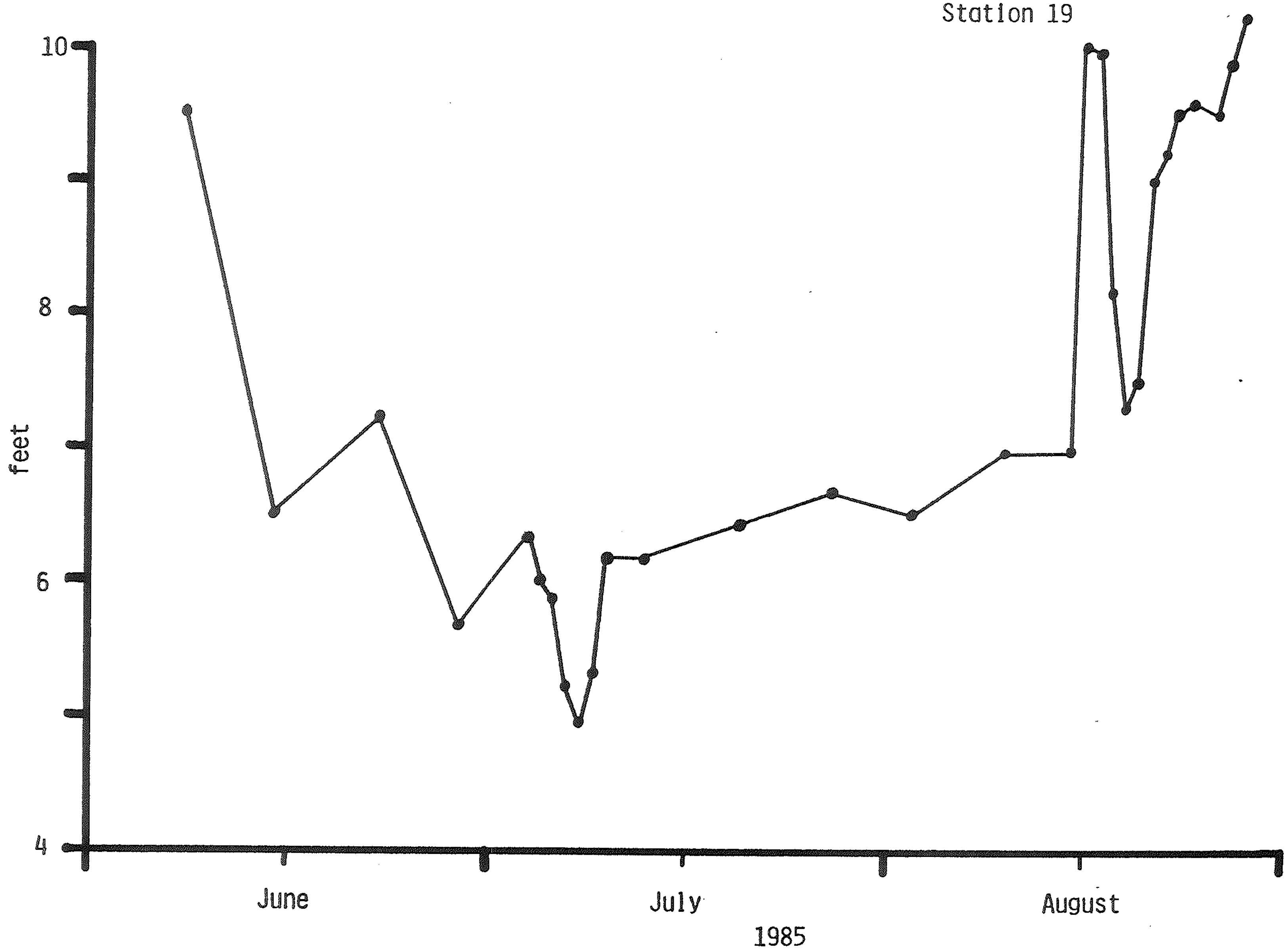


Figure 30. Secchi disc readings for individual monitoring dates of the 1985 survey at station 19 of Lake Maxinkuckee.

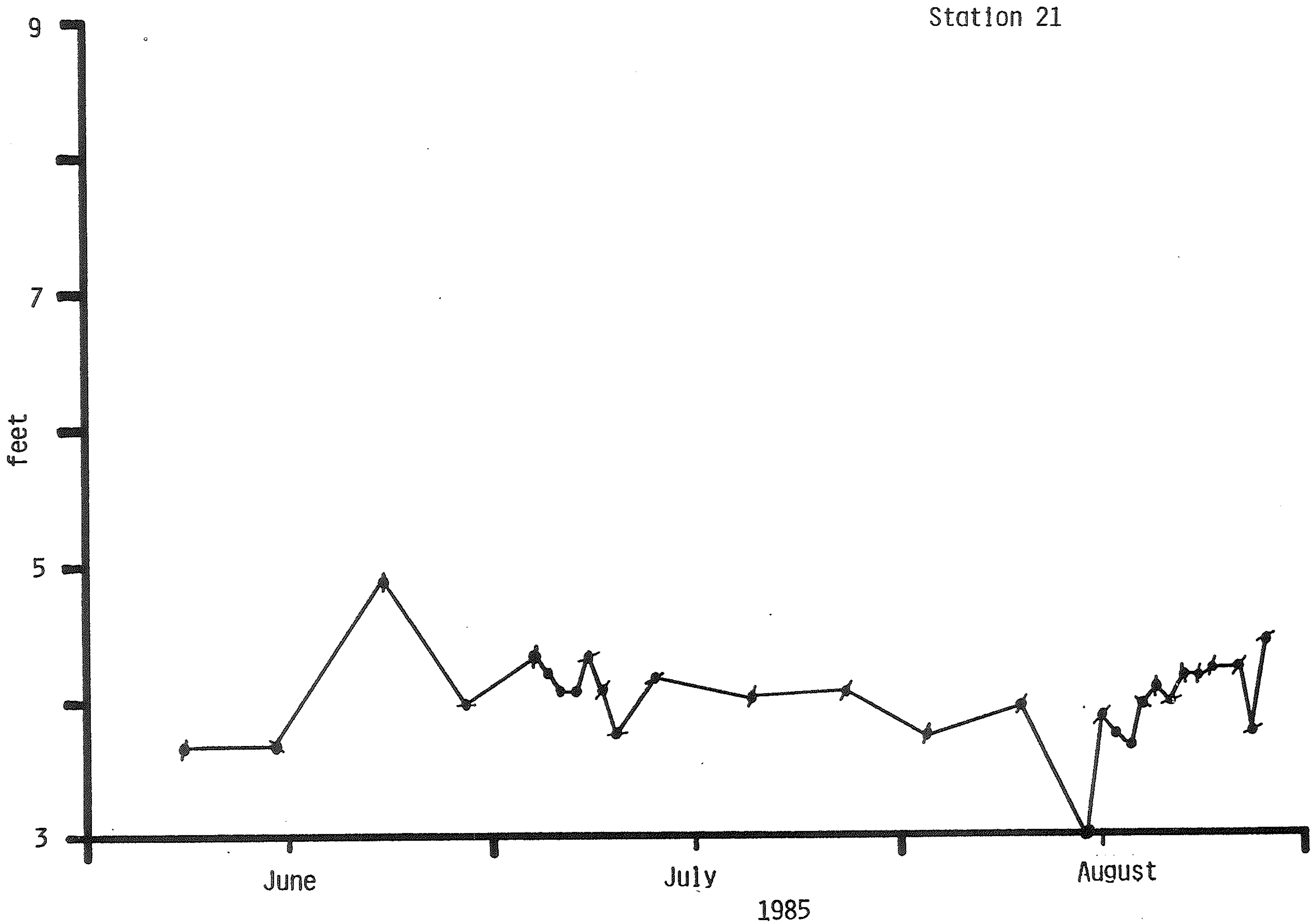


Figure 32. Secchi disc readings for individual monitoring dates of the 1985 survey at station 21 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

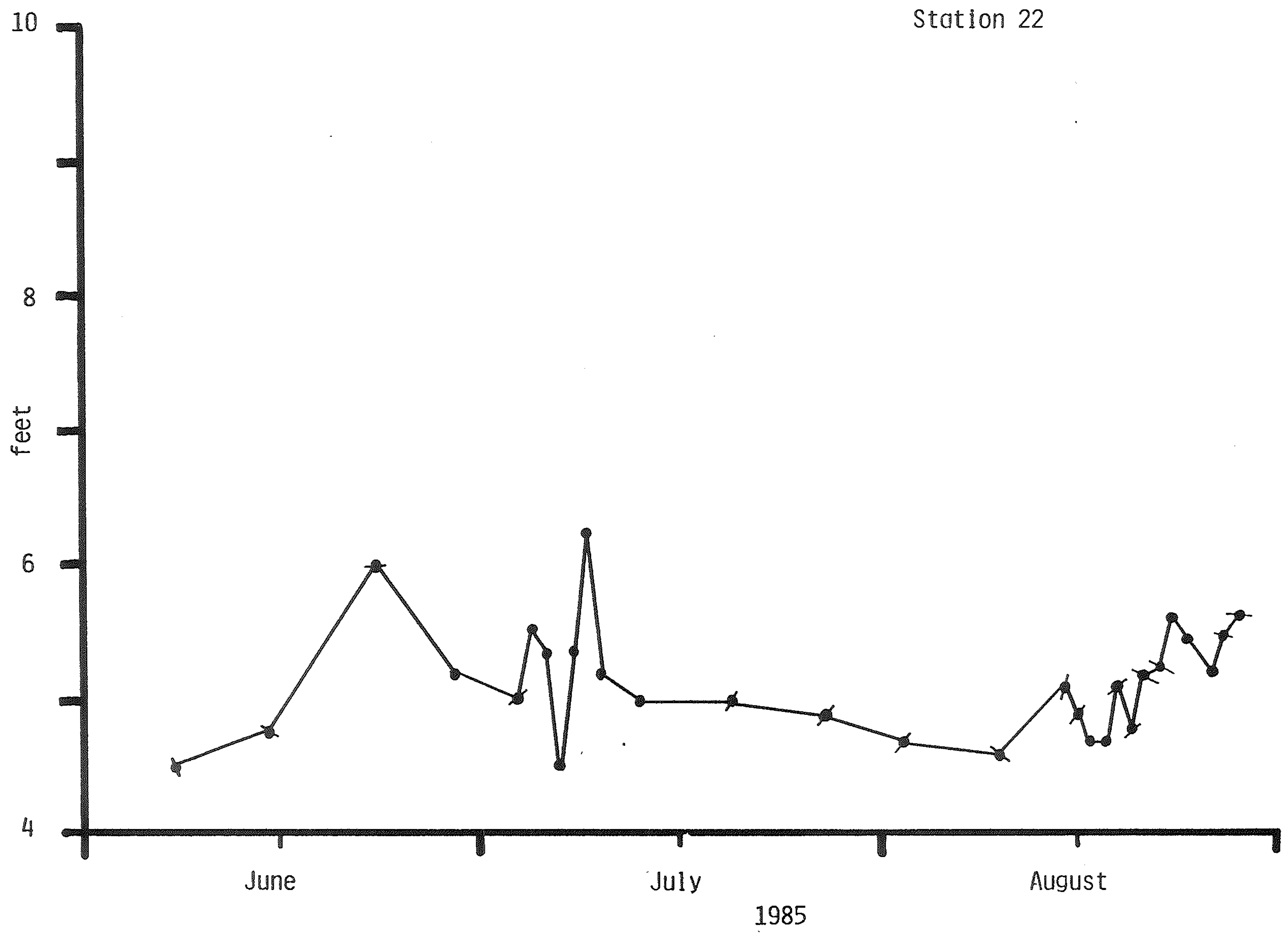


Figure 33. Secchi disc readings for individual monitoring dates of the 1985 survey at station 22 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

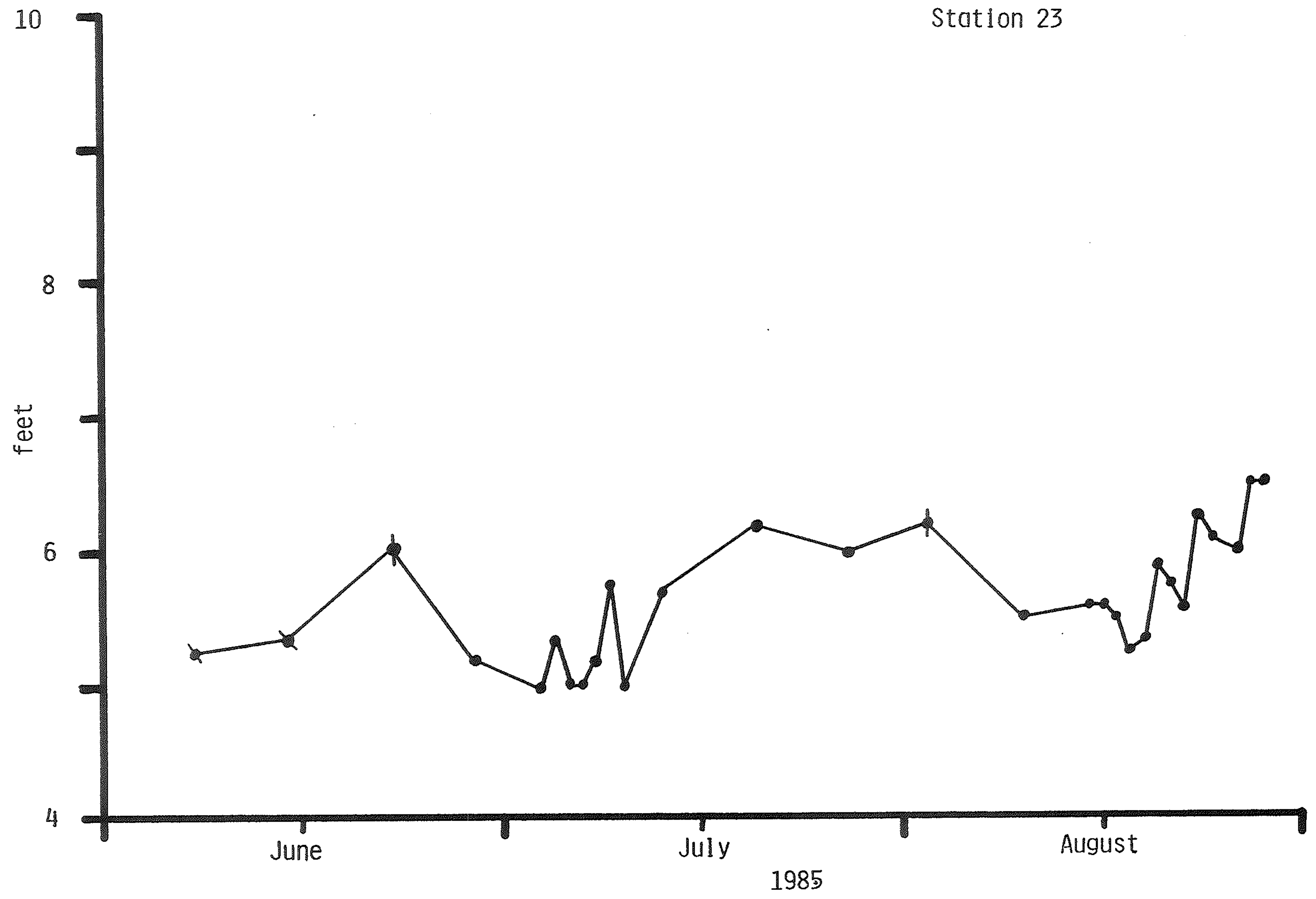


Figure 34. Secchi disc readings for individual monitoring dates of the 1985 survey at station 23 of Lake Maxinkuckee. A slash through a data point indicates that the Secchi disc was visible on the bottom.

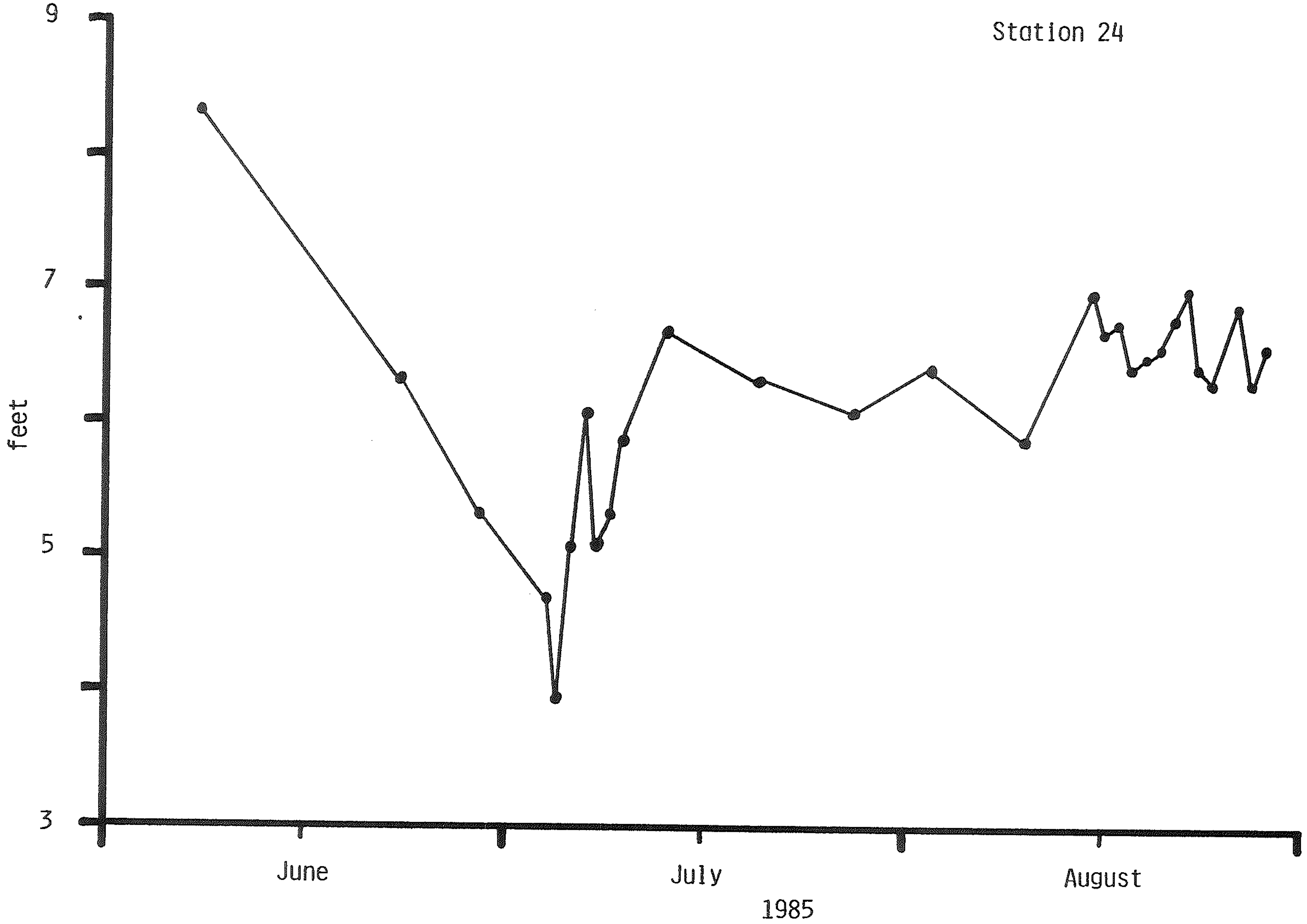


Figure 35. Secchi disc readings for individual monitoring dates of the 1985 survey at station 24 of Lake Maxinkuckee.

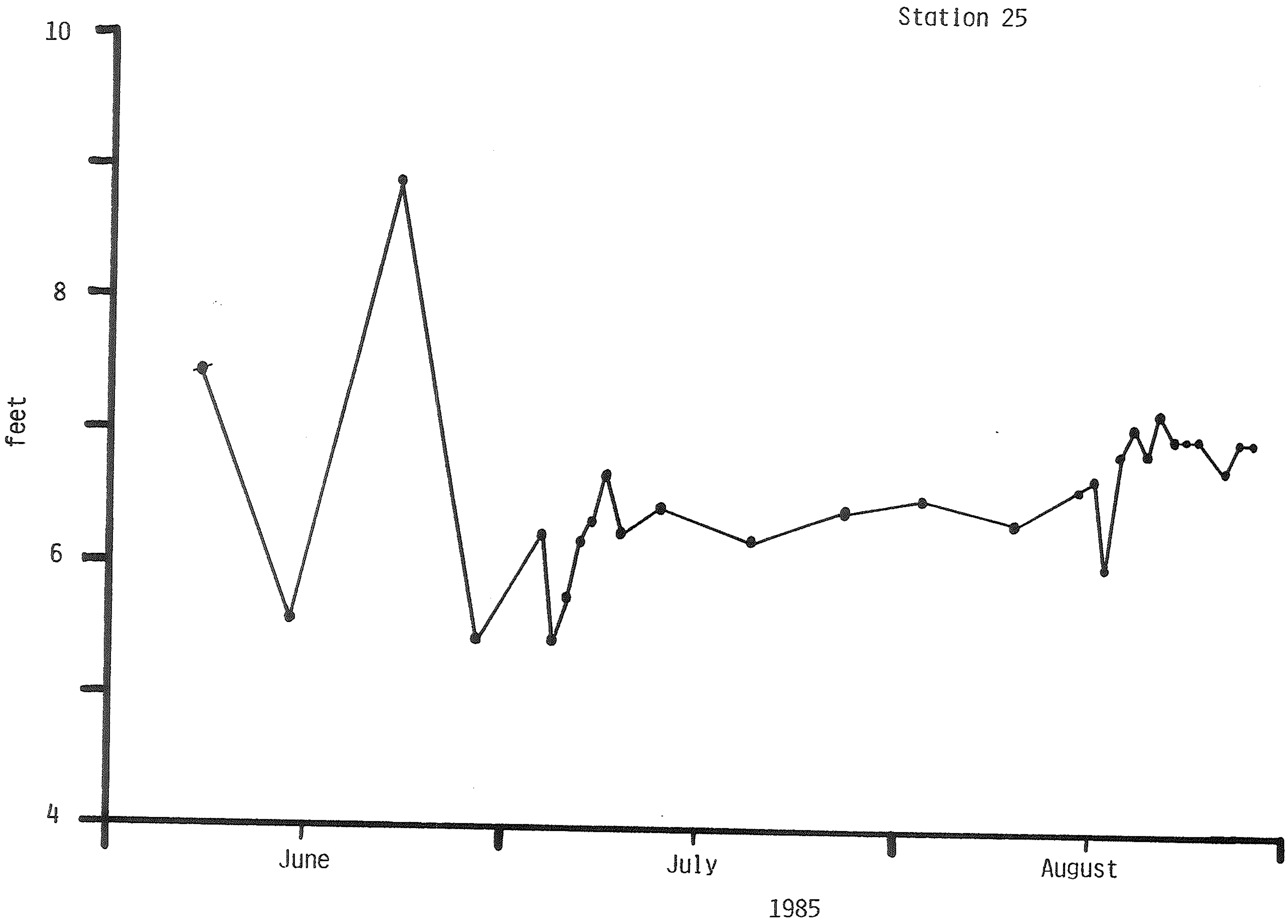


Figure 36. Secchi disc readings for individual monitoring dates of the 1985 survey at station 25 of Lake Maxinkuckee.

clarity (3.84 feet) was recorded at the mouth of the Curtiss Ditch with the second lowest mean (4.00 feet) noted near shore immediately in front of the old Farm Bureau property in the town of Culver. The best clarity value (7.50 feet) was recorded near the center of the lake immediately opposite Long Point. With the exception of station 20, the on-off shore transect data clearly show that water clarity increases progressively with increasing distance from the shore. This was especially true for transects beginning at the mouths of Wilson and Curtiss Ditches, the southeast lake corner and the Farm Bureau property.

The original hope for the 1985 Secchi program was to be able to separate power boat impact on water clarity from that of inflowing streams. Hamelink (1971) suggested that in addition to a general reduction in water clarity due to suspended algae, power boats, especially on weekends, contributed to a major short-term reduction in the transparency of Lake Maxinkuckee. He observed that on a typical weekend he would record a Secchi value of 8-10 feet in the morning, while in the afternoon following heavy boat traffic this would be reduced to 3-4 feet. He felt that this was common for all the areas of the lake within 200 - 400 feet from shore.

Most of the 26 Secchi stations of the 1985 survey displayed a pronounced reduction in water clarity on weekends with the greatest reduction taking place during the 4 July holiday period. The amount of reduction was generally greater for stations of the

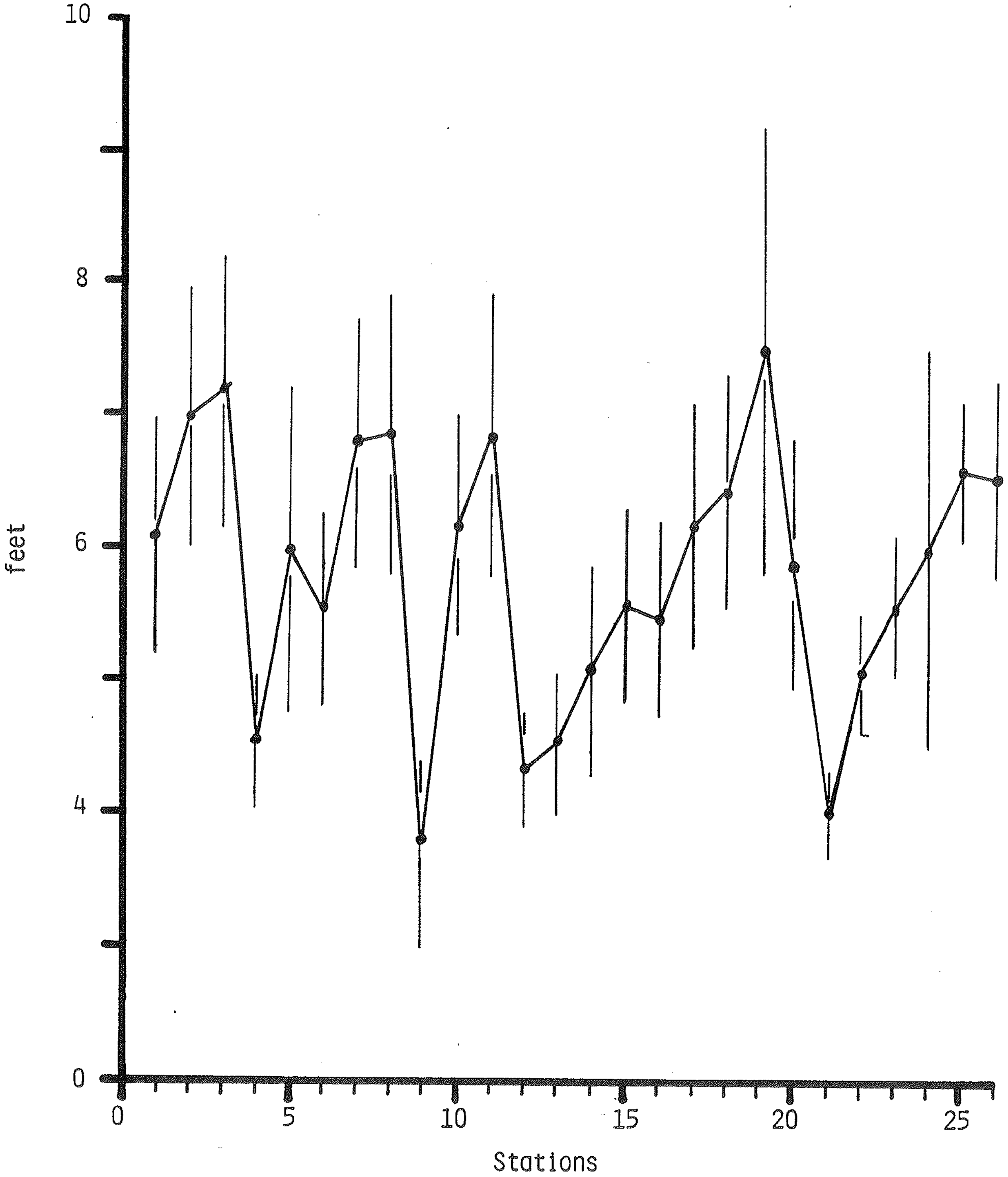


Figure 38. Mean Secchi disc transparency for individual monitoring stations of Lake Maxinkuckee for the period June to August 1985. Location of station numbers are given on Figure 10.

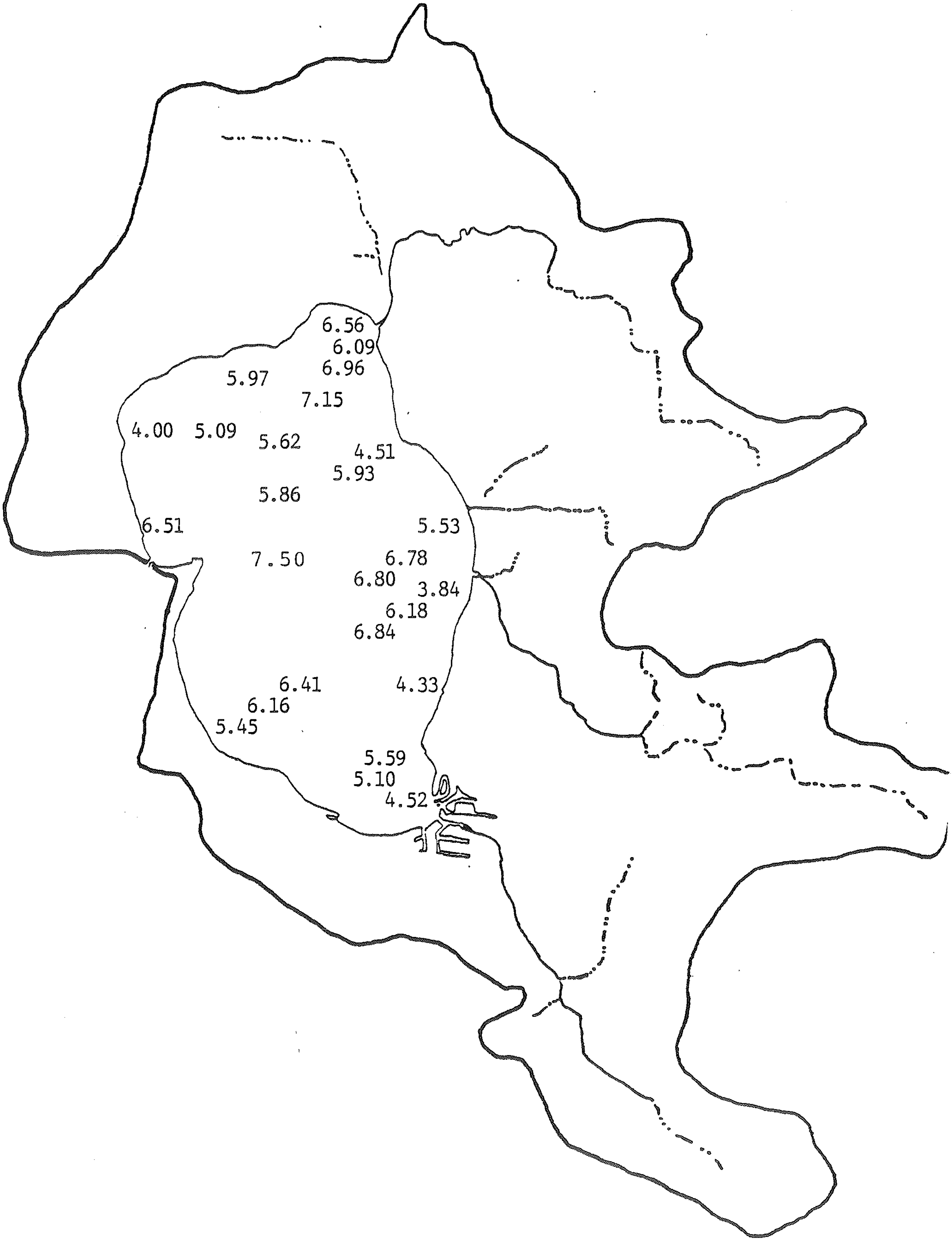


Figure 39. Map of Lake Maxinkuckee and its watershed showing mean Secchi disc transparency (feet) for individual stations of the 1985 monitoring program.

eastern half of the lake. However, no clear distinction could be made in the magnitude of change in water clarity between shallow and deep water stations.

Waves generated by power boats resuspend lake sediments and promote increased erosion of shorelines. While the silt that is suspended can reduce water clarity as observed by Hamelink (1971), it can also be an important source of nutrients, including phosphorus, for plant growth. It appears that power boats resuspended a great deal of sediment in shallow areas associated with increased weekend activity and that this affects the clarity of water throughout Lake Maxinkuckee including areas in the center of the basin overlying deep water. The immediate effect of sediment resuspension by power boats is relatively short-lived as evidenced by return of water clarity to levels considered background within two days following even such peak recreational use periods as the 4 July weekend.

While the sediment resuspension by power boats is of short temporal duration, the secondary effect of suspending fine sediments on enhancing phosphorus levels in the lake is much longer-lived and not immediately perceived by the public. It is common knowledge in limnological research that resuspending sediments into the water column enhances recycling of essential plant nutrients including phosphorus, thus making these nutrients more available for algal growth. The nutrients remain in suspension long after the sediments have settled out. Thus, the long term effect of sediment mixing by power boats every weekend will be increased cultural eutrophication of the basin by insuring that phosphorus is recycled back into the water column for algal utilization rather than being permanently buried in the sediments.

Considering Secchi stations of comparable water depth, the lowest water clarity recorded for the shallow areas of the lake were immediately offshore from the mouth of Curtiss Ditch and the Farm Bureau property. As will be discussed later, the EPA estimated that the creek at the southeastern corner of the lake contributed 26% of the phosphorus entering Lake Maxinkuckee, with the Curtiss and Wilson Ditches contributing another 20% and 8%, respectively. These inlets can be ranked in order of increasing mean water clarity immediately at their mouth as Curtiss Ditch followed by the creek at the Southeastern corner of the lake and Wilson Ditch.. While not conclusive, these data are suggestive that water clarity of the lake immediately in front of the inlet mouth is roughly proportional to the contribution of each stream to the phosphorus budget of the lake. It is important to keep in mind that with the present database it is not possible to separate the importance of near shore sediment mixing from that of stream input as factors controlling water clarity immediately offshore.

The extremely low mean Secchi value recorded immediately offshore from the old Farm Bureau is perhaps easier to explain. A number of lake residents have mentioned that during heavy rains sheets of water flow in the direction of the lake down streets that are perpendicular to Main Street often flooding low lying areas immediately adjacent to the lake. In addition, people have informed me that residents living between Main Street and the lake often experience the backup of sewer water into their basements during heavy rains. These observations coupled with the facts that: 1) a storm sewer empties into the lake near the western boundary of the Culver Military Academy, 2) the sewer system of Culver is old and combines both sanitary and storm effluents, and 3) a storm water interception system is totally lacking along the shore fronting the town of Culver leads me to conclude that the section of the lake immediately in front of the town of Culver likely experiences increased phosphorus loading from numerous non-point sources. Given the somewhat sheltered nature of this area, algae would likely have time to utilize these nutrients before they are transported offshore.

Temperature. Deep Indiana lakes such as Maxinkuckee have an annual thermal regime that is termed dimictic. This means that the entire water column theoretically mixes completely from top to bottom twice a year, once in the spring and once in the fall. For the remainder of the year, the lake is thermally and thus density stratified with bottom waters (hypolimnion) effectively isolated from mixed surface waters (epilimnion). The duration of the mixing periods (turnovers) can be as short as a day or as long as a few weeks depending in part on the rapidity of temperature change and wind intensity.

Oxygen. Since the bottom waters of a lake (hypolimnion) are effectively sealed from the surface waters (epilimnion) for a majority of the year because of temperature related density differences, the only time that oxygen is replenished in the deeper portion of the water column is during the short turnover periods of spring and fall. One way to assess whether a deeper lake is becoming or is eutrophic is to measure summer oxygen concentrations in the hypolimnion.

Algae produced in the surface waters of a lake eventually sink deeper into the water column and enter the hypolimnion where they will ultimately be decomposed using some of the oxygen that was supplied during the spring mixing period. By extension, the greater the algal population in the surface waters, the greater the quantity of organic matter entering the hypolimnion to be decomposed, and thus the faster the depletion of the finite summertime oxygen concentration of the hypolimnion. Eutrophic lakes usually have such high algal production rates that decomposition totally exhausts the hypolimnion oxygen supply (anoxia) early in summer. Oligotrophic lakes, on the other hand, have such low algal abundance that hypolimnetic oxygen levels in late summer often approximate those at the end of the mixing period in late spring.

Lake Maxinkuckee has experienced pronounced mid and late summer hypolimnetic oxygen depletion for the entire period (1907-1984) that oxygen profiles are available from the lake (Table 2). Evermann and Clark (1920) noted that at the turn of the century, the hypolimnion of Lake Maxinkuckee was normally totally anoxic for approximately two months every fall. I feel that this tendency towards anoxia can not be interpreted solely on the basis of trophic state but may in part also reflect the fact that the morphometry of the lake basin makes it difficult for wind to completely mix the entire water column, thus reducing the initial concentration of oxygen that is supplied to the deepest waters during spring mixing. As chemical and Secchi disc data both suggest that the lake is much more productive now than it was in the early part of this century, I feel that basin morphometry is an important controlling factor for deep water oxygen concentrations. A much clearer picture of historical hypolimnetic oxygen conditions has been provided by paleolimnological investigations that will be presented later in this report. Stratigraphic changes in the importance of benthic invetebrate species (determined from subfossil head capsules) that require high oxygen levels are extremely useful in determining not only when

TABLE 2. Observations of hypolimnetic oxygen depletion in Lake Maxinkuckee from 1907- 1984.

DATE	COMMENT
September 20, 1907	Anoxic below 39 feet
September 24, 1907	Anoxic below 29 feet
June 7 - 17, 1965	Minimal oxygen below 30 feet
July 27, 1970	Minimal oxygen below 36 feet
September 9, 1970	Minimal oxygen below 36 feet
August 3, 1973	Anoxic below 30 feet
June 2 - 11, 1975	Minimal oxygen below 75 feet
July 22, 1975	Minimal oxygen below 30 feet
July 1, 1977	Minimal oxygen below 29 feet
July 20, 1977	Minimal oxygen below 13 feet
August 3, 1977	Minimal oxygen below 7 feet
August 25, 1977	Minimal oxygen below 29 feet
July 24, 1978	Minimal oxygen below 41 feet
July 31, 1978	Minimal oxygen below 40 feet
August 14, 1978	Minimal oxygen below 34 feet
August 28, 1978	Minimal oxygen below 30 feet
September 6, 1983	Anoxic below 25 feet
July 17, 1984	Minimal oxygen below 30 feet
August 31, 1984	Minimal oxygen below 38 feet

hypolimnetic oxygen depletion first began in Lake Maxinkuckee but also whether it has become progressively worse.

Evermann and Clark (1920) noted that hypolimnetic oxygen depletion in Lake Maxinkuckee had an important controlling effect on both the fish community and its management as early as the 1890's. Lake trout were stocked in the lake four times between 1890 and 1894 (total fish 10,587), but not a single fish was subsequently caught. They attributed the failure of the fish introductions to the routine development of hypolimnetic anoxia in the lake. Trout and many of the other cold-water predatory fish must have a well-oxygenated cold hypolimnion where they can avoid the elevated temperatures of surface waters during summer. Elimination of this refuge area, as was apparently the case with Lake Maxinkuckee, leads to the demise of the fish population.

HISTORICAL TRENDS IN BIOLOGICAL PARAMETERS

Bacteria. The earliest data for total and fecal bacteria in Lake Maxinkuckee that I have been able to find were for 37 lake stations sampled on 22 July 1970 by the Indiana State Board of Health. On that date only one site, a discharge from the Culver Inn septic tank, exceeded the state standards (whole body contact) of 2400/100 mL for total coliforms and 400/100 mL for fecal coliforms. Hamelink (1971) on 18 June 1970 found coliform bacteria in excess of state standards at two inlets he identified as: 1) golf course inlet by Ball cottage, and 2) academy ditch by boat dock. The latter is properly called Wilson Ditch.

The Indiana State Board of Health sampled nine inlet and potential problem areas during July 1974 and found that coliform levels at all sites were well within state standards. Clyde E. Williams and Associates in 1983 sampled six stream and ditch sites and nine lake stations once each during May, July and September, 1983 (Figure 40). With one exception, fecal coliforms were greatest at all stations during July and likely reflect the increased summertime population. Fecal coliforms exceeded state standards four times in 1983: during May (600/100 mL) in the south inlet (S-4) and during July in Wilson Ditch (S-1), Maxinkuckee landing ditch (S-2), and the golf course ditch (S-3). Bacterial numbers for these stations were 1020, 6400, and 420/100 mL, respectively. Two additional sites, Culver Marina (S-6) in July and south inlet (S-4) in September, displayed high fecal coliform numbers (> 300/100 mL) but did not exceed state standards.

During August 1984 when I was coring the lake, the smell of sewage was especially strong where Wilson Ditch enters the lake. In subsequent conversations I learned that several lake residents have also smelled sewage at the same location in the past. Working with Mr. David Gaskell, a total of twelve sampling stations were chosen on Wilson Ditch, Maxinkuckee Landing Ditch

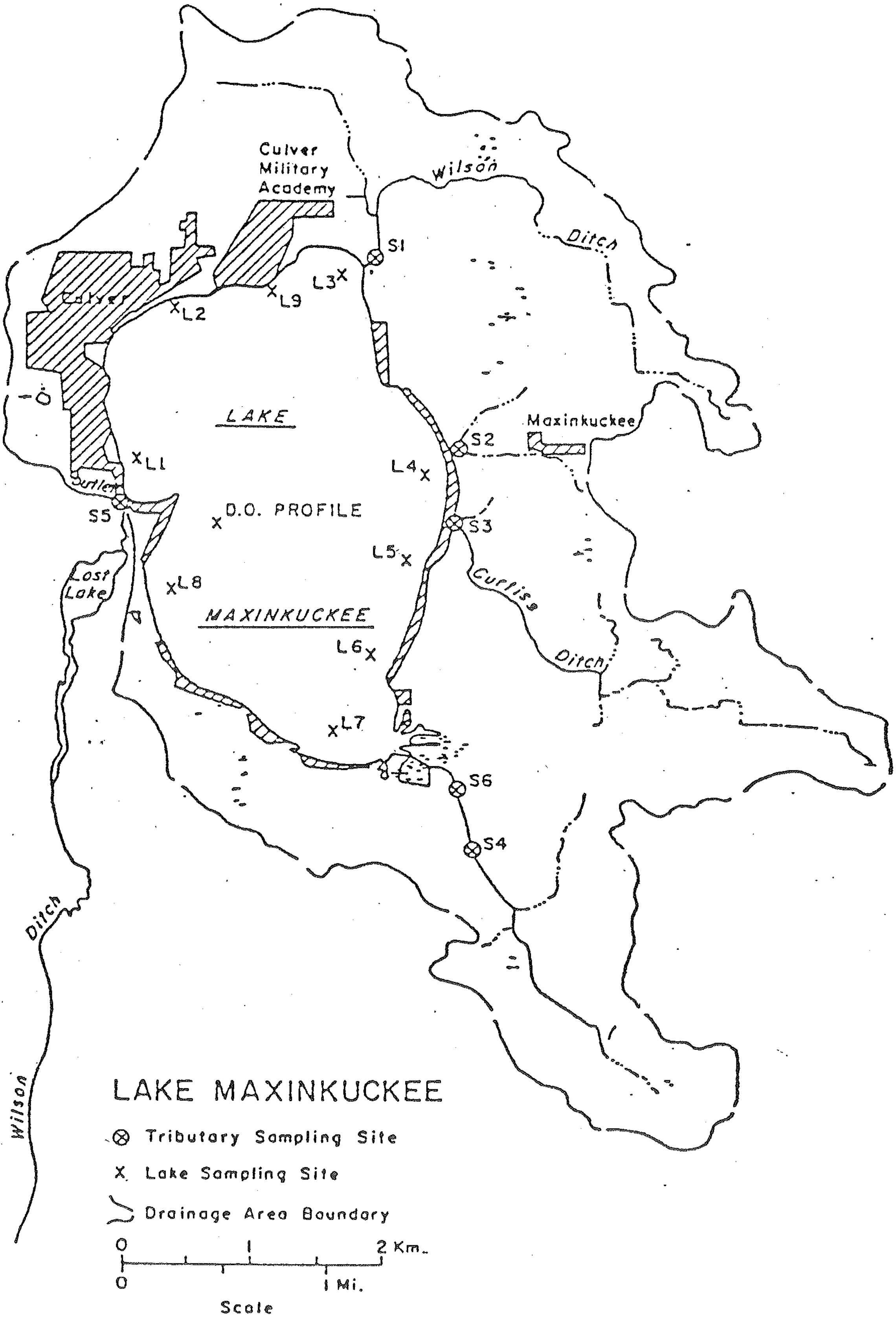


FIGURE 40. Stream (S) and Lake (L) sampling stations of Clyde E. Williams and Associates, Inc. (1983) for fecal coliform bacteria.

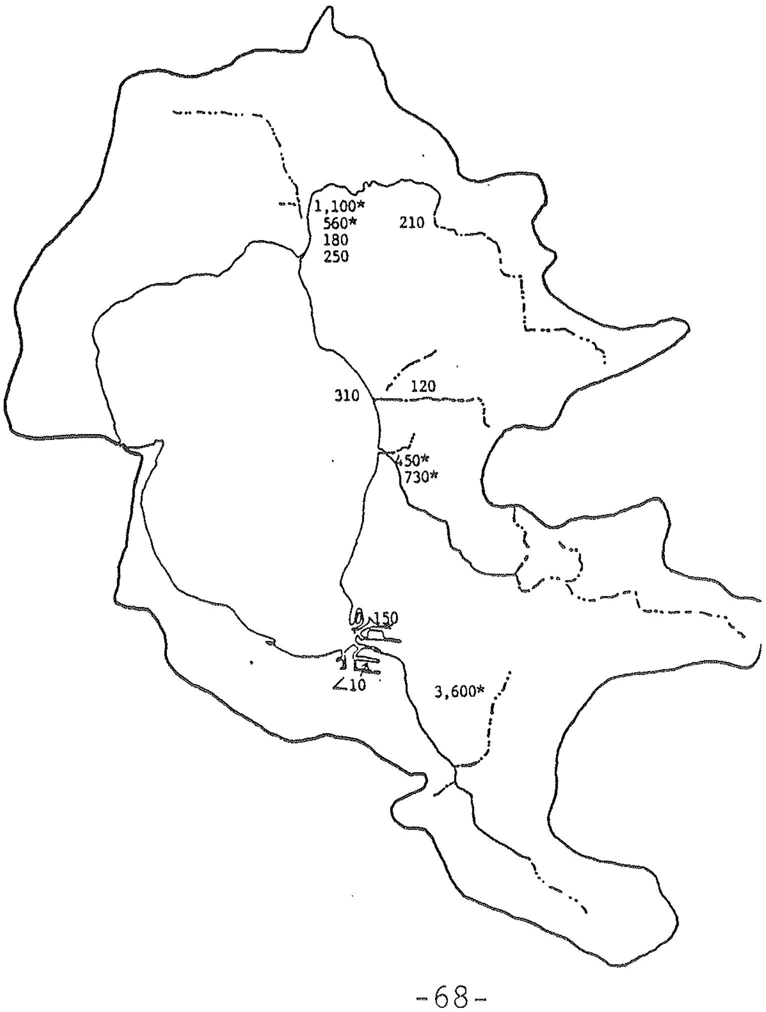
and the ditch at the southeastern corner of the lake. Samples for fecal coliform bacteria were collected at all twelve stations on 19 August 1985 according to the protocol suggested by the Indiana State Board of Health. Samples were then shipped to Indianapolis for analysis by the ISBH.

The results of the 1985 stream survey for fecal coliform bacteria are presented in Figure 41. Five of the twelve sites exceeded state standards for fecal coliform bacteria (400/100 mL). These sites included: Wilson Ditch at State Road 10, Wilson Ditch at the outlet of the Woodcraft Fishing Pond, Curtiss Ditch on the west side of State Road 117, Curtiss Ditch east of the Golf Course, and the ditch at the southeast corner of the lake at 20th B Road on the McCune farm. The Woodcraft Fishing Pond outlet and the McCune farm samples had the highest values of the survey, 1,100 and 3,600 cells/100 mL, respectively.

It appears that coliform numbers in Lake Maxinkuckee rarely, if ever, exceed state standards. Inflowing streams and ditches have exceeded state standards on numerous occasions in the past. The same streams sampled as part of the 1985 survey have exceeded state standards in all past stream surveys (1971 and 1983). Fecal coliform bacteria are restricted to warm-blooded vertebrate guts, and their presence in the levels found in these streams indicates fecal contamination from either humans or livestock.

FIGURE 41. Results of fecal coliform bacteria analyses performed by the Indiana State Board of Health on samples collected 19 August 1985 from streams and ditches entering Lake Maxinkuckee. *indicates that sample exceeded state standards of 400 cells/100 mL of sample.

	Per 100 mL
1. Wilson Ditch at Crew Sheds	250
2. Wilson Ditch, North Side of 117	180
3. Wilson Ditch at State Road 10	560*
4. Wilson Ditch, Woodcraft Fishing Pond Outlet	1,100*
5. Wilson Ditch, Along SR 10 East of Manure Pile	210
6. Maxinkuckee Landing Ditch Mouth	310
7. Maxinkuckee Landing Ditch East of Golf Course	120
8. Curtis Ditch, West Side of SR 117	450*
9. Curtis Ditch East of Golf Course	730*
10. Culver Marina Lagoon	150
11. Venetian Village Lagoon	<10
12. SE Ditch at 20th B Road on McCune Farm	3,600*



Bacterial abundance was below state standards in Wilson Ditch east of the horse manure pile of the Culver Military Academy and quickly exceeded state standards immediately downstream of the pile. It appears likely that fecal coliforms and undoubtedly nutrients essential for algal growth in the lake are leaching out of the academy horse manure pile thus contaminating the creek. The Woodcraft Fishing Pond appears to be concentrating the bacteria that are released upstream. Assuming that there are not high numbers of livestock in the upper reaches of Wilson Ditch, it is reasonable to attribute the bacterial contamination of this section of the creek to the Culver Military Academy horse manure pile. Because Wilson Ditch contributes only 6-8% of the total phosphorus loading to Lake Maxinkuckee, it appears that nutrients are being trapped effectively in the Woodcraft Fishing Pond by the extensive algal blooms that develop there during summer. Bacterial numbers decreased rapidly between the outlet of the Woodcraft Fishing Pond and State Road 117 after which they were within levels considered acceptable by the Indiana State Board of Health.

Bacteria numbers at both sites of Maxinkuckee Landing Ditch were within state standards, but both sites on Curtiss Ditch exceeded state standards. While it is likely that much of this contamination results from human sewage, I am not able to separate human from livestock influences with the database available to me.

As stated earlier, the highest bacterial numbers of the twelve stations were recorded at the McCune farm on the creek at southeastern corner of the lake. Given the low population density upstream from this site, it is likely that this contamination is attributed to livestock.

While bacterial contamination is of concern by itself, high coliform levels are also suggestive of a source of increased nutrient loading to the lake. Future studies should concentrate on estimating bacterial numbers but also on finding the source of contamination and eliminating it.

Algae. Both the biomass and species composition of algal communities are related to lake trophic state. Clear water unproductive lakes (oligotrophic) are characterized by extremely low algal abundance and dominance by species of green algae and diatoms. At the opposite end of the trophic spectrum, extremely productive lakes (eutrophic), like Lost Lake, are characterized by excessive algal abundance with species of blue-green algae dominating the assemblage. A standard way to estimate the biomass of the algal community is through analysis of chlorophyll a. All plants contain this plant pigment, and its cellular concentration is roughly proportional to cellular carbon (biomass) Thus, by measuring the concentration of chlorophyll a in a filtered sample of lake water, the biomass of living algae can be approximated. The greater the concentration of chlorophyll, the larger the algal population, and thus the more productive the lake system.

Chlorophyll _a_ data are available from Lake Maxinkuckee for only four years, 1973, 1975, 1977, and 1978. Means for these years were 5.48 ± .44, 5.5, 5.17 ± 2.01, and 2.62 ± 1.18 mg/m^3, respectively. Although actual values were not revealed, Dr. J. Bell of Purdue University stated that chlorophyll values in Lake Maxinkuckee in 1984 were "higher" than he and Dr. Spacie recorded in 1978. He also noted that algal cell concentrations were "much higher" in 1984 than he recorded in 1978. The chlorophyll means for individual years are not statistically different and suggest that lake trophic state did not change appreciably between 1973 and 1978. Further detailed interpretation based on such a limited database would be sheer speculation.

Not only does total algal biomass increase with eutrophication, but major changes occur in the species composition of the algal assemblage. Foremost among these is a replacement of green algae and diatoms by blue-green algae as dominants with increasing eutrophication. Algal data were collected for Lake Maxinkuckee periodically from 1899 to 1978 (Table 3). Blue-green algae have dominated the summer algal assemblages since at least 1899. _Lyngbya_ and _Anabaena_ were the dominant genera until the early 1970's, after which _Chroococcus_, _Microcystis_, _Anacystis_, and _Aphanocapsa_ became the major taxa. Since the dominants have always been blue-green algae, the

TABLE 3. Dominant summer algae in Lake Maxinkuckee for the period 1899 - 1978

1899	*Lyngbya* (blue-green)
1900	*Lyngbya* (blue-green) and *Anabaena* (blue-green)
1906	*Anabaena* (blue-green)
1971	*Lyngbya* (blue-green)
1973	*Fragilaria* (diatom) in May, various flagellates in early August, and *Lyngbya* (blue-green) in October.
1975	*Anacystis* (blue-green)
1977	*Aphanocapsa* (blue-green) and *Chrooroccus* (blue-green)
1978	*Microcystis* (blue-green) and *Chroococcus* (blue-green)

significance of the taxonomic shift in the mid 1970's is not clear. Blue-green algal blooms ("scums") have been causing problems in the lake including skin irritations for swimmers since as early as 1900 (Table 4). Such algal blooms are most common from mid summer through late fall and generally occur during prolonged periods of calm weather.

In summary, algal data suggest that Lake Maxinkuckee has been moderately productive since at least 1899. Blue-green algae have always dominated summer algal assemblages and major algal blooms have been observed periodically since the turn of the century. These data do not indicate any accelerated eutrophication in Lake Maxinkuckee.

<u>Macrophytes</u>. Aquatic weeds (<u>macrophytes</u>) are needed as fish habitat. Unfortunately, during the eutrophication process macrophytes often expand both aerially and vertically in the water column. Serious management problems can result when dock areas and shallow water zones become so clogged with weed growth that navigation becomes impaired. Lakes becoming progressively more eutrophic may go through a period when the biomass of both algae and macrophytes increase in response to nutrient addition. Ultimately, one or the other of these two plant communities will completely dominate the system. The most common case is exhibited by Lost Lake where the growth response of algae to nutrient enrichment was so rapid and massive that the

Table 4 . Blue-green algal blooms in Lake Maxinkuckee 1900-1971

1900	Ten episodes of algal "scums" noted between September 30 and December 12. Each was dominated by *Anabaena*.
1904-1905	Complaints of algal toxins causing skin irritations to swimmers.
1906	Nine episodes of algal "scums" noted between July 31 and November 15. Each was dominated by *Anabaena*.
1971	Algal bloom noted in early August dominated by *Lyngbya*.

submergent macrophytes were totally eliminated due to shading from the excessive concentration of algae in the water column.

The most extensive survey of the macrophytes of Lake Maxinkuckee was conducted at the turn of the century and reported by Evermann and Clark (1920). Although total plant biomass was not assessed, their accounts provide an extremely clear picture of the species composition and extent of macrophytes in individual areas of the lake. Potamogeton, Chara, Ceratophyllum, and Elodea were the dominant plant genera found. Elodea was common in many of the shallow areas, and it was mentioned that Chara dominated large areas less than 8-10 feet deep where it formed very dense carpets on the lake bottom. A very rich growth of Ceratophyllum covered the bottom of the shallow southeastern corner of the lake at Norris Inlet, the area that is today offshore from Venetian Village. Although not felt to be a management problem at the time, the authors noted that the lake appeared to be becoming more weedy every year.

The only other mention of macrophytes was in the 1965 report by the Indiana Department of Natural Resources dealing with their fish survey of that year. The report noted that most macrophytes displayed a scattered distribution in the lake and were generally limited to water less than 25 feet deep. Special mention was made of the extensive growth of Elodea in the southeastern corner of the lake. While this growth was not considered excessive in 1965, the report suggested that plant growth in this area could pose a management problem in the future.

In addition to the growth of macrophytes at the southeastern corner of the lake, Dr. Scott Holaday, a botantist at Texas Tech University and a former lake resident, supplied a number of observations (letter dated 10 February 1985) on the macrophyte community of Lake Maxinkuckee. He noted that the exotic species *Myriophyllum spicatum* (Eurasian Watermilfoil) was not in the lake in 1900 but has since become established and currently dominates most of the weed beds in the lake. Since this species only reproduces vegetatively in the lake, Dr. Holaday feels that this plant is being spread and propagated from cuttings created when power boats pass through weed beds. Finally, he suggested that extensive *Chara* beds that were present at the outlet of the lake when he was a boy but which are now gone met their demise as a result of increased boat traffic. I feel that Dr. Holaday's points are well taken.

Myriophyllum spicatum is the foremost aquatic weed problem in the northern United States today. While the presence of this potential problem species and the general expansion of the weed beds especially at the southeastern corner of the lake should cause concern, I do not feel that the macrophyte problems in the lake are serious enough at present to pose a management problem. Macrophyte beds often develop in lakes immediately offshore from major sources of nutrient input such as inlet streams. As will be discussed later, the creek at the southeastern corner of the lake is a major nutrient source for the lake, contributing at least 20-27% of total phosphorus input. The rich macrophyte bed immediately offshore from this creek inlet is undoubtedly related to the increased availability of phosphorus in this shallow-bottom area. Aquatic macrophytes are extremely efficient at trapping nutrients as they enter a lake, and excessive plant growth can result thus posing management problems for the lake residents. Macrophyte communities in Lake Maxinkuckee must be watched closely in future years especially offshore from major nutrient inputs to the lake. If it appears that weed problems are likely to develop, the Lake Maxinkuckee Association is well advised to start a weed management program before overly excessive plant growth occurs. Management of plant growth before it becomes excessive is not only less costly but also less likely to cause an impact on the lake system from decaying organic matter and nutrients released during plant control operations. Frequently, the rapid control of weed problems results in even greater problems from blue-green algal scums utilizing nutrients freed from the decay of plant tissue.

Fish. Fish were surveyed in Lake Maxinkuckee during 1899-1914 by the U.S. Bureau of Fisheries and in 1965, 1975, 1983, and 1984 by the Indiana Department of Natural Resources. The fish community at the turn of the century was dominated by yellow perch and bluegill, with rock bass being the principal subdominant. It was noted that while yellow perch was clearly the dominant species, abundance and body size were both becoming smaller in successive years. Gizzard shad apparently were not in the lake, and carp did not establish a populations in the lake until 1905.

Attempts to manage the sport fishery of the lake began as early as 1890 (Evermann and Clark, 1920). Seven fish species were stocked from 1889-1914. Stockings were often large, as evidenced by the fact that over 34 million pike perch were released during this period. Not all fish introductions were successful. Lake trout were stocked four times from 1890-1894 for a total release of 10,587 fish. Not a single fish was ever taken by an angler. Evermann and Clark (1920) attributed the complete demise of lake trout in Lake Maxinkuckee to the fact that summertime hypolimnetic anoxia (deep water deoxygenation) eliminated the fish from their habitat requirement of cold well-oxygenated water.

More recently, the Indiana Department of Natural Resources has initiated a sport fishing enhancement program through stocking Lake Maxinkuckee with walleye fry. The initial stocking of 5.6 million fry took place in April 1980 followed by additional stockings of 5.6 million and 5 million fry in May 1982 and May 1983, respectively. Unlike the early trout introductions of the late 1800's, the stockings of walleye appear to have been a success. Mr. R. Robertson in his 1983 DNR fish management report noted that by spring 1983 it was common to hear reports of walleyes being caught in Lake Maxinkuckee thus providing evidence of the survival of fry stocked in 1980 and 1981.

The percent of total fish abundance estimated for important species during 1965, 1975, 1983, and 1984 fish surveys of the Indiana Department of Natural Resources are given in Table 5. Yellow perch was the dominant species in Lake Maxinkuckee in 1965 and 1975, as it had been at the turn of the century. During both the 1983 and 1984 surveys, yellow perch had slipped from being clearly the dominant to being the third most abundant species. R. Robertson in his 1983 DNR report attributed this decline to an increase in predation pressure associated with the introduction of walleyes.

While bluegill was the second most abundant species in 1889-1914, it contributed only 12% of total abundance in 1965, and declined further to 2.8% of total abundance by 1975. During 1983 and 1984, however, bluegill importance progressively increased reaching levels (14.6%) exceeding the previous high recorded in 1965 (12.5%). As would be expected, the most

TABLE 5. Percent of total fish abundance in Lake Maxinkuckee contributed by important species.

	1965	1975	1983	1984
Yellow Perch	30.0	43.1	10.3	13.3
Rock Bass	13.0	2.8	2.5	9.3
Bluegill	12.5	2.9	8.7	14.6
Longnose Gar	10.7	12.2	6.8	4.0
White Bass	7.8	5.2	3.5	---
Gizzard Shad	5.0	10.1	3.3	11.3
Largemouth Bass	4.3	2.8	15.9	2.0
Smallmouth Bass	1.0	1.9	6.6	6.0
Carp	2.3	1.0	.8	---
Black Crappie	1.5	1.0	8.3	12.0
Walleye	.1	1.0	13.4	14.6
White Sucker	4.0	5.1	1.0	2.0
Brook Silverside	1.0	3.4	---	---
Spotted Sucker	1.0	3.3	5.6	2.6

spectacular abundance change for the 1965-1984 period was displayed by walleyes. This sport fish contributed less than 1% of total fish abundance in both 1965 and 1975 but in the 1983 and 1984 surveys increased to 13.4% and 14.6%, respectively, reflecting the success of the 1980, 1982 and 1983 stockings.

The abundance of two fish species characteristic of eutrophic lakes, gizzard shad and carp, should be watched closely in future years. Gizzard shad was not reported in the lake in the early 1900's, but in the 1965-1984 surveys contributed between 3 and 11% of total fish abundance. Carp did not become established in the lake until 1905 but has not shown signs of becoming a management problem. Only 2.3% of total fish abundance was attributed to carp in 1965. In the subsequent three surveys, its abundance dropped progressively until during the 1984 survey, it was not collected. The abundance of carp generally increases with increasing eutrophication. In spite of the fact that R. Robertson contends that Lake Maxinkuckee has become progressively more eutrophic in the past 10 years (a statement supported by the data presented in this report), the importance of carp has declined progressively since at least 1965.

Gizzard shad are of concern because an important part of their diet is algae. Gizzard shad are absent in oligotrophic lakes because there is not sufficient algae to support them. In mesotrophic and especially eutrophic lakes, algal populations are sufficient for the fish to become established. Shad feed by filtering water through their gills and ingesting the collected algae. The problem is that the acidity in the fish's stomach is insufficient to digest blue-green algae, and these unwanted algae pass through the fish gut alive, while beneficial algae such as diatoms and green algae are consumed. Thus, once shad are established in a lake, they promote dominance of algal assemblages by blue-green species.

Carp is undesired not only because it is not a sport fish, but because it mixes bottom sediments during its feeding activities, thus enhancing phosphorus release to the water column. Neither gizzard shad nor carp are considered a problem in Lake Maxinkuckee, but further eutrophication of the lake could encourage population growth of these rough fish species.

Dominant size classes and condition factors for four important fish species in Lake Maxinkuckee are presented in Table 6. Between 1975 and 1983, however, the dominant size class for yellow perch declined coincident with a reduction in the overall importance of this species in the total fish fauna. As noted earlier, these trends may reflect increased predation pressure on this species following walleye introductions in the

TABLE 6. Dominant size classes and condition factors for important fish in Lake Maxinkuckee

	Dominant Size (in.)			Condition Factor	
	1965	1975	1983	1965	1975
Yellow Perch	6 - 7	6 - 7	4.5-5.0	3.92±.72	4.88±.97
Bluegill	5.5-7.5	6.5-8.0	6.0-6.5	6.80±1.56	8.61±.67
Rock Bass	4-5.5	8.5-9.0	6.0-6.5 8.5-9.0	7.18±.78	7.3±.50
White Bass	11.5-12 14-14.5	11-11.5 14-14.5	14.0-14.5	4.35±.27	4.88±1.54

early 1980's. The dominant size class for the other three species that were examined did not change appreciably from 1965 to 1983. The relationship of body weight to body length (condition factor) was also calculated for individual age classes by the Indiana Department of Natural Resources for the 1965 and 1975 surveys. Mean condition factors for individual species summing all size classes are presented in Table 6. As with dominant size, the condition factor for each of the species examined did not change significantly between 1965 and 1975.

In summary, the species composition of the fish community of Lake Maxinkuckee has not changed appreciably since the turn of the century. Rather, the relative dominance ordering has changed. The latter is a reflection of both the general response of individual species to increasing trophic state and hypolimnetic deoxygenation and an alteration in predation intensity associated with fish management programs, especially the recent stockings of walleye. With the current database it is impossible to separate the influence of these two factors. While additional fish data for the lake would be highly desirable, the public must realize that detailed fish surveys require great expenditures of both manpower and money.

NUTRIENT LOADING TO LAKE MAXINKUCKEE

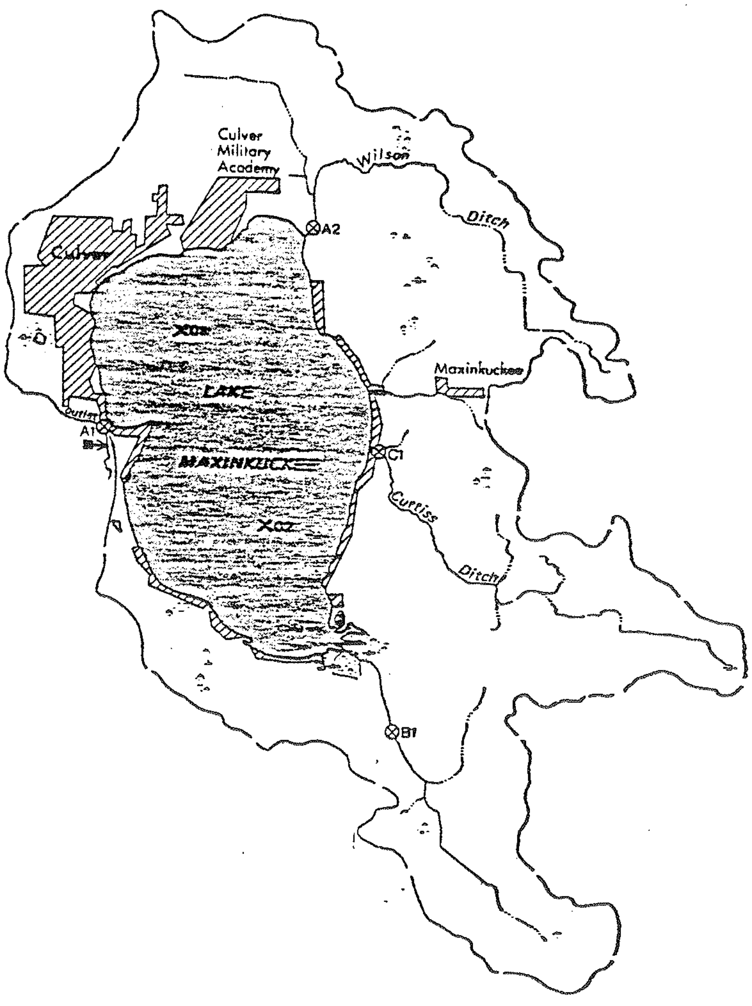
Two recent studies have constructed nutrient loading models for Lake Maxinkuckee aimed at identifying the principal sources of phosphorus input to the lake (Table 7). The United States Environmental Protection Agency (1976) constructed a loading model based on 1973 monitoring data for stream and lake stations. They estimated that 56% of total phosphorus loading to the lake was contributed by three streams with the greatest source being the creek entering at the southeastern corner of the lake. Watershed runoff from shoreline property contributed an additional 29% of the phosphorus input, but EPA admitted that this estimate was considered very conservative because they did not include the contribution of lawn fertilizer. Direct precipitation striking the lake surface was the third most important nutrient source (11.2%) followed by septic tanks (3.5%).

Howard Consultants, Inc. (1982) revised the 1976 model of the EPA. The two models are nearly identical, except Howard Consultants felt that EPA underestimated the precipitation contribution by approximately 14%. Again, the contribution of septic tanks was considered to be of little importance (2.6%).

A third and final estimate of phosphorus loadings to Lake Maxinkuckee was constructed by Clyde E. Williams and Associates (1983) based on water chemistry that they collected during 1983. Although the detailed model was not provided in their report, they noted that EPA data on the contribution of both dry fallout from the atmosphere and septic tanks were in error. Thus,

TABLE 7 . Estimates of percent of total phosphorus loading to Lake Maxinkuckee contributed by major sources

		EPA 1976	Howard Consultants 1982
A)	Tributaries		
	Wilson Ditch	8.7	6.4
	Unnamed Creek B-1	26.8	19.8
	Curtiss Ditch	20.8	15.3
B)	Immediate Drainage	29.0	30.4
C)	Septic Tanks	3.5	2.6
D)	Direct Precipitation	11.2	25.5
		100	100



they agreed with Howard Consultants, Inc. (1982) that EPA miscalculated atmospheric input. This study does differ from earlier estimates of septic tank loadings, 6% versus 3.5% for EPA and 2.6% for Howard Consultants.

All past investigations agree that Lake Maxinkuckee is becoming progressively more eutrophic. All of the investigations prior to 1983 felt that while the lake was still mesotrophic, it was dangerously close to becoming eutrophic. Only Clyde E. Williams and Associates (1983), based on water chemistry that they collected during that year, felt that the lake was already eutrophic.

Hamelink (1971) felt that if phosphorus concentrations were increased three times over 1971 values, the lake would be in "trouble", and a fifteen-fold increase would spell "ruin" for the system. He projected that the first condition would be reached in 20 years and the second condition in 220 years. The EPA (1976) felt that a 30% increase in phosphorus over 1973 values would cause the lake to become eutrophic.

Bell and Spacie (1977) compared physical, chemical and biological data collected during 1973 and 1977. By means of a statistical technique called trend analysis, they showed that in spite of a maximum decline of phosphorus loading to the lake of only 3% following the January 1973 state ban on phosphorus detergents, the lake still became significantly more eutrophic from 1973 to 1977. A second analysis of their data, where each parameter was assigned "eutrophy points", provided further support for their interpretations. The most pessimistic prediction was offered by Howard Consultants, Inc. (1982) who felt that only a 5% increase in phosphorus loading to the lake would cause a shift from mesotrophic to eutrophic conditions.

The cultural eutrophication of Lake Maxinkuckee is not the direct result of any single perturbation. The process is additive. The general setting for Lake Maxinkuckee and its watershed in 1900 is depicted in Figure 42. With the exception of the town of Culver, the shoreline was only sparsely populated. An extensive marsh existed at the southeast corner of the lake. The stream that entered the upper end of the marsh lacked a distinct channel through the wetland but rather percolated through the vegetation, entering the lake at an area called Norris Inlet. A similar marsh was located between the outlet from Lake Maxinkuckee and Lost Lake proper. Some degree of dredging at the beginning of this marsh was mentioned by Evermann and Clark (1920).

The situation in 1986 is dramatically different (Figure 43). The marsh at the southeast corner of the lake has been largely drained, the stream has been channelized so that it now flows unimpeded into the lake, and an extensive system of finger canals

FIGURE 42. Map of Lake Maxinkuckee and immediate shoreline in 1900. Adapted from Evermann and Clark (1920).

FIGURE 43. Lake Maxinkuckee and its watershed in 1984.

has been dredged through the old marsh to provide lake access for new residences and a marina. Stream channelization is also extensive through the Lost Lake marsh. In addition, the number of buildings standing in the watershed, exclusive of the town of Culver, increased from 81 in 1900 to 359 in 1962 to 429 in 1980 (Table 8).

Hamelink (1971) warned that nutrient loading to the lake would be greatly increased if the marsh at the southeastern corner of the lake was developed. He suggested that this area be left undisturbed. In addition, Hamelink felt that construction of canals in the marsh would be disastrous. Although after the fact, Howard Consultants, Inc. (1983) noted that draining this marsh was a mistake.

The channelized stream that formerly percolated through the marsh now contributes 20-27% of the total phosphorus input to Lake Maxinkuckee. The area drained directly by this stream approximates 20% of total watershed area. There is a wealth of information indicating that marshes such as formerly existed at Lake Maxinkuckee are extremely efficient at removing nutrients from inflowing stream water. The city of Clermont, Florida now discharges its sewage into a marsh fringing a lake. Nutrients are trapped by the marsh vegetation and sediments and have not contributed to the eutrophication of the adjoining lake.

Without a doubt, marsh drainage at Lake Maxinkuckee greatly

TABLE 8. Major construction activity in the Lake Maxinkuckee watershed from 1900-1980.

LAKE MAXINKUCKEE WATERSHED DISTURBANCE

I) Houses

Year	Total	Increase
1900	81	
1962	359	278
1980	429	70

II) Dredging

Finger canals constructed in marsh at SE corner of lake between 1962 - 1980.

increased both water inflow and phosphorus loading to the lake system. It is likely that the increased growth of aquatic macrophytes near Norris Inlet observed by the Indiana Department of Natural Resources in 1965 is the direct result of increased phosphorus loading associated with dredging activities in the adjacent watershed. Similarly, the fact that Secchi disc transparency was lowest in 1984 at stations nearest Norris Inlet is likely associated with algal uptake of stream delivered phosphorus in combination with increased inorganic turbidity arising from watershed erosion.

Hamelink (1971) warned against further residential development in the watershed, especially second and third tiers of homes along the shore. We know now that diffuse runoff (exclusive of septic tanks) from shoreline residential development contributes at least 29-30% of the total phosphorus loading to Lake Maxinkuckee. EPA (1976) admits that this figure is considered extremely conservative as it does not include an estimate of the contribution from lawn fertilizers. Again, Hamelink (1971) argued both that lawn fertilizers were an important nutrient source for the lake and that their use should be stopped.

ESEI (1982) argued against any change in rules governing land use restrictions in the Maxinkuckee watershed. They estimated that only a 3% increase in the urban area along the shore would be sufficient to cause the lake to shift from a mesotrophic to a eutrophic state. Their predictions were based on nutrient delivery via enhanced surface runoff. Specifically, they suggested that if the Cove West Development was permitted, projected phosphorus loading from the area would be increased by 1800% over background values.

Past models of nutrient loading to Lake Maxinkuckee have considered septic tanks to be only a minor contributor (2.6-6%) to the total phosphorus loading. Howard Consultants, Inc. (1982) estimated that even a 100% increase in the number of septic tanks would only increase phosphorus loading to Lake Maxinkuckee by 2.5%. Given that they estimated that only a 5% increase in total phosphorus loading will be sufficient to change the lake to a eutrophic condition, further population expansion should be discouraged, especially in shoreline areas. Given the additive nature of man-induced nutrient sources, even a seemingly insignificant additional nutrient source may be the "straw that breaks the camel's back" leading to a possibly irreversible eutrophic condition.

Finally, human recreational activities may be as great as or greater than human sewage as a contributor to the cultural eutrophication of Lake Maxinkuckee. Hamelink (1971) suggested that power boats are a significant factor in the cultural eutrophication of the lake. He noted that for lake areas within 200-400 feet of shore, he would record a Secchi value of 8-10 feet on a typical weekend morning, but following a day of heavy boat traffic, this would be reduced to 3-4 feet in the afternoon. The same argument was presented by ESEI (1982), and data from the 1985 Secchi program conclusively showed the influence of power boats.

Waves generated by power boats resuspend lake sediments and promote increased erosion of shorelines. While the silt that is suspended can reduce water clarity as observed by Hamelink (1971) and ESEI (1982), it can also be an important source of nutrients, including phosphorus, for algal growth. Eutrophication is caused not only be increased nutrient loading to a lake but also by enhanced nutrient cycling within the system. One of the ways to reduce cultural eutrophication and restore lakes is to reduce nutrient release from lake sediments into the overlying water column. Further discussion of nutrient sources contributing to the eutrophication of Lake Maxinkuckee and ways to curb their impact appears later in this report.

PALEOLIMNOLOGICAL PERSPECTIVE ON EUTROPHICATION

The value of paleolimnological techniques in applied ecological research has been reviewed by Crisman (1978) and Binford et al. (1983). In particular, this research approach has been invaluable in understanding lake responses to eutrophication and acid rain. The premise of the paleolimnological approach is simple. Each year a record of the current chemical and biological status of a lake is deposited in the top layer of sediments collecting on the lake bottom. The progressive sediment accumulation of successive years caps this annual record, thus preserving it much like the individual pages of a history book. By isotopically dating sediment cores so that the year of deposition of any level in the core can be determined, the researcher can use information gathered from physical, chemical, and biological markers at any core level to reconstruct lake conditions at the time of deposition. Changes in the past condition of the lake can then be related to known historical records of human activity that may have been responsible for the change in lake condition. For a majority of lakes in the world, the history of water quality is either not extensive or lacks sufficient quality control as to not supply a database sufficient to delineate factors responsible for perceived or actual environmental degradation of a lake. In such cases, the paleolimnological approach is the only feasible way both to reconstruct the environmental history of a lake and to relate it to known human activity.

Six sediment cores were collected at three stations (two cores at each station) in Lake Maxinkuckee on 2 August 1984

(Figure 44). The northern site was immediately offshore from the Culver Inn where cores were collected in 20 m of water. The central lake site was offshore from Long Point, again in 20 m of water. The southern site was shallower than the other two (12.4 m). Two cores were collected at each site to insure that backup material was present in case of loss of core samples during laboratory analysis. All cores were collected in meter-long plexiglass tubes attached to a piston corer. All cores were sectioned at 1-cm intervals, and sediment material from each level was placed in plastic bags and frozen for transport to Florida. Analyses were performed in my laboratory at the University of Florida.

The paleolimnological research was undertaken to determine if Lake Maxinkuckee has become progressively more eutrophic in the last 100 years, and if so, has there been an acceleration in the process recently that can be related to known human activity in the watershed. The study concentrated on four parameters: 1) 210-Pb dating of sediment cores, 2) changes in the deposition of inorganic and organic sediment fractions, 3) changes in the accumulation of phosphorus in the sediments, and 4) changes in the species composition and accumulation rates of major benthic invertebrate groups living on the lake bottom. The 210-Pb analyses were essential for establishing a

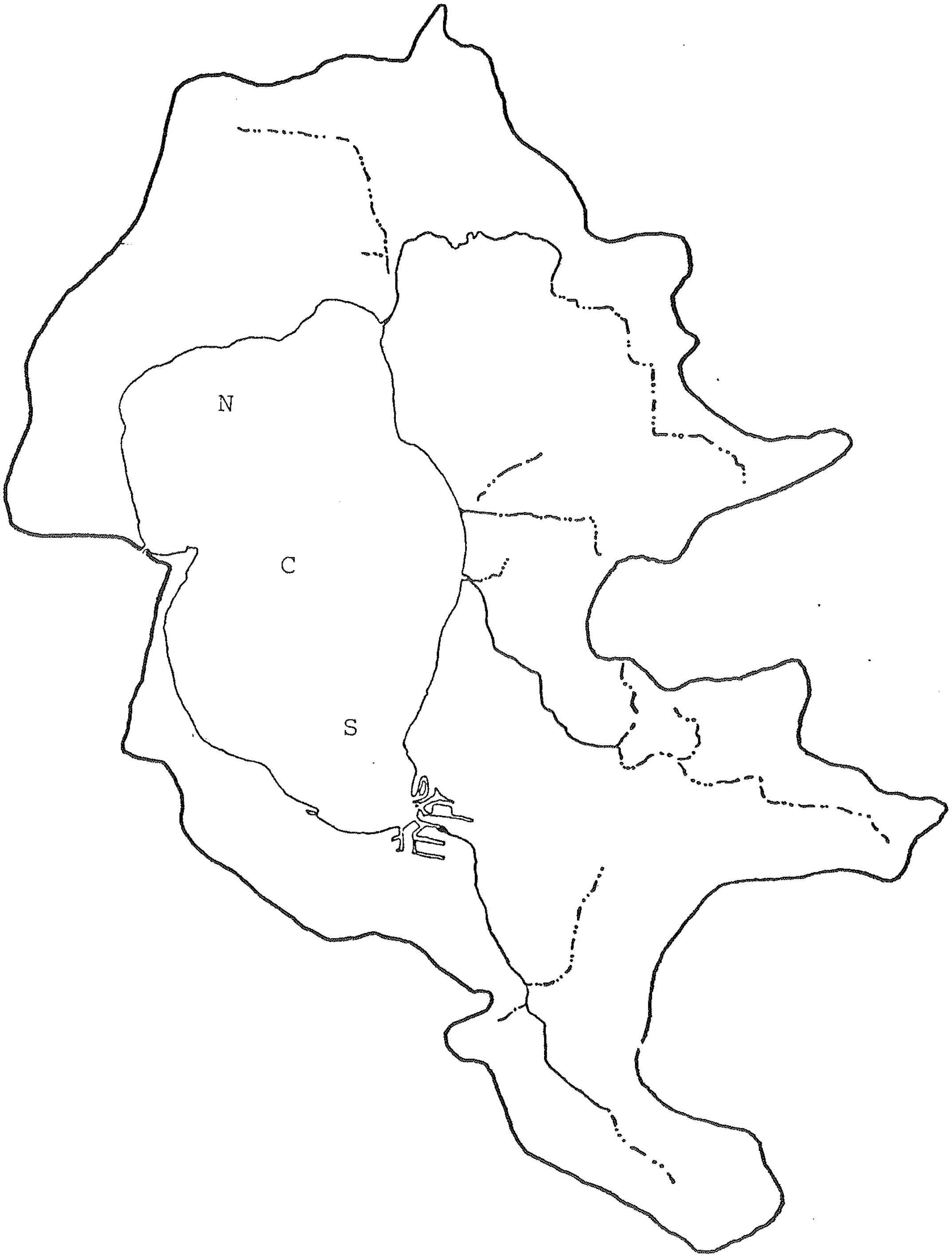


Figure 44. Sediment coring sites of August 1984 in the northern (N), central (C), and southern (S) basins of Lake Maxinkuckee.

time stratigraphy for each core. Inorganic and organic sediment fractions and their rates of annual accumulation on the bottom provide valuable information on watershed erosion and lake productivity, respectively. As phosphorus has been determined to be the limiting nutrient for algal production in Lake Maxinkuckee, changes in the deposition rate of this most important nutrient for lake eutrophication reflect both the general history of eutrophication of the lake as well as alterations in the phosphorus input to the lake from the watershed. Finally, historical chemical and biological data all suggest that the lower reaches of the water column of Lake Maxinkuckee have always been devoid of oxygen during mid and late summer since at least the late 1800's. As this can be a consequence of either the eutrophication process or hinderance of water column mixing due to the morphometry of the lake, it was important to determine the importance of each as controlling factors for summer oxygen levels in the lake. Benthic invertebrate subfossils were examined in the present cores because the distribution of individual taxa, especially chironomid midges, living in the bottom sediments is directly related to water column oxygen levels.

All paleolimnological data in this report are presented in a standard format that may be unfamilar to the reader. On all figures, the vertical axis denotes time as a function of depth in the core. The most recently deposited material (1984) would be at the top of the core labelled "0", which represents the water column/sediment boundary. Progressively older sediments are thus at depth in the core. Accumulation rates for individual parameters are given as the amount of a given parameter deposited per square centimeter of lake bottom per year (# or $mg/cm^2/yr$). Such accumulation rates have been calculated for that section of the core that is within the limits of the 210-Pb dating procedure and are always accompanied by the calculated chronological dates for the core profile. The horizontal scale on all figures denotes changing concentrations or number of a particular paleolimnological parameter.

210-Pb Dating. After examining cores from all three sampling sites it was decided that the best paleolimnological record would be obtained from the northern and central sites. In part this decision was made due to the extremely sandy nature of the sediments at the southern site. All paleolimnological discussion in this report has therefore been restricted to cores of the northern and central sites. 210-Pb is a naturally occurring radionuclide in the uranium-238 series and has a half-life of 22.26 years. It is the accepted technique for dating lacustrine sediments deposited within the past 120 years. Fifteen stratigraphic samples were collected from one core each from the northern and central basins and analyzed for 210-Pb using the technique of Eakins and Morrison (1978) and an alpha-spectrometer as a detector.

The age/depth relationships for cores from the northern and central basins are given in Figure 45. The northern basin has had a much faster sediment accumulation rate than the central basin, 16 cm versus 8 cm of sediment accumulation since 1840, respectively. Prior to 1949, each 1 cm of sediment accumulation represented between 10 and 16 years of deposition, but between 1949 and 1974 sediment accumulation increased by 37% so that each centimeter of sediment represented only 6.2 years of accumulation. The most dramatic increase in the sedimentation rate in the northern basin of Lake Maxinkuckee has taken place between 1974 and 1984. During this period sediment accumulation rates increased by 60% over rates for 1949-1974 and by a minimum of 76% over pre-1949 rates. Each centimeter of sediment accumulation between 1974 and 1984 only represented 2.49 years of sedimentation. As mentioned previously, the sedimentation rate in the central basin was approximately half of that of the northern basin, thus hindering the type of detailed chronological resolution presented for the northern basin.

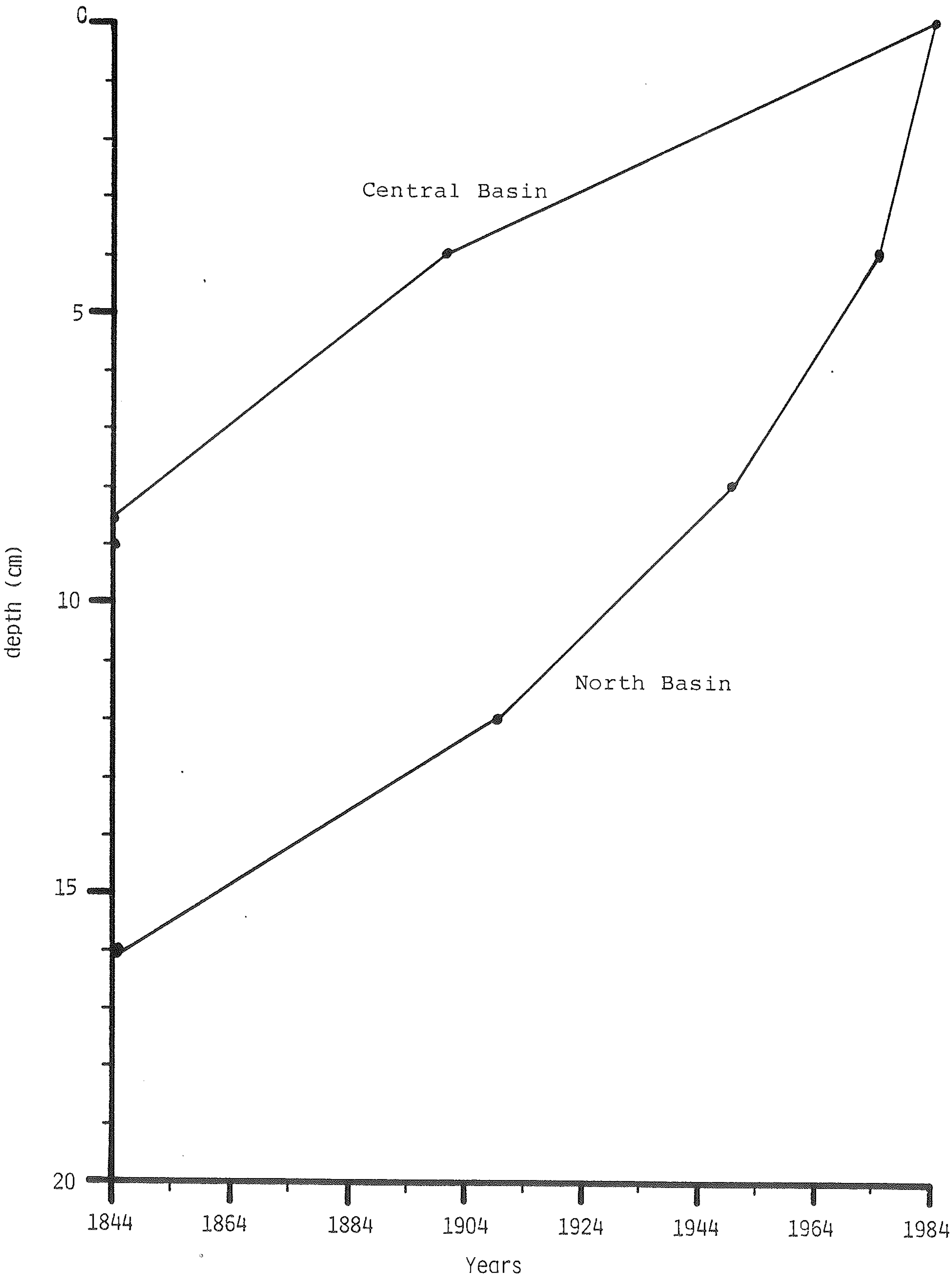


Figure 45. Depth/year profiles for cores from the northern and central basins of Lake Maxinkuckee.

Organic and Inorganic Sediment Fractions. Depth profiles for percent water and ash are presented for cores from the north and central basins in Figure 46 and 47, respectively. Percent water is a measure of the degree of sediment compaction, and percent ash is equivalent to the percent of the dried sediment that is contributed by the inorganic fraction. Cores from both the northern and central basins were somewhat flocculent at the core top, but the central basin was generally less flocculent than that of the northern basin. Both cores displayed a general reduction in the percent ash toward the core top with the decline taking place above 45 cm in the northern core and above 16 cm in the central core.

Annual accumulation rates ($g/cm^2/yr$) for total dry sediment and its organic and inorganic fractions in the northern basin of Lake Maxinkuckee are presented in Figure 48. The accumulation of total dry sediment in the northern basin increased progressively from land clearance in the 1800's until approximately 1960 with values ranging from .03 to .05 $g/cm^2/yr$. In the past 24 years, annual sediment accumulation rates have increased by 39% to .008 $g/cm^2/yr$.

Unlike total dry sediment, the accumulation of organic sediment was relatively constant at approximately .006 $g/cm^2/yr$ before 1960, but like total sediment accumulation increased

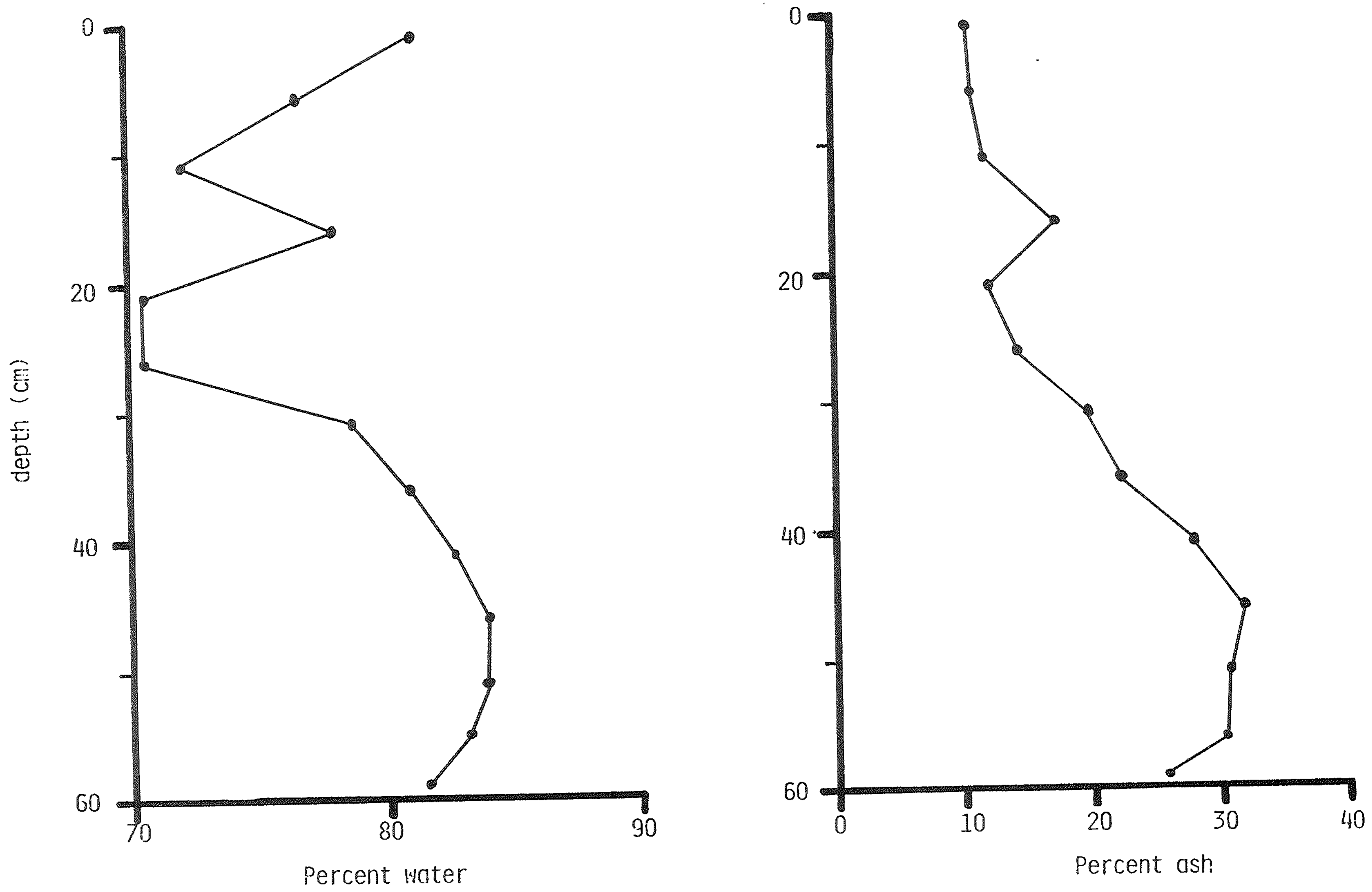


Figure 46. Percent water and ash for select levels of the sediment core from the northern basin of Lake Maxinkuckee.

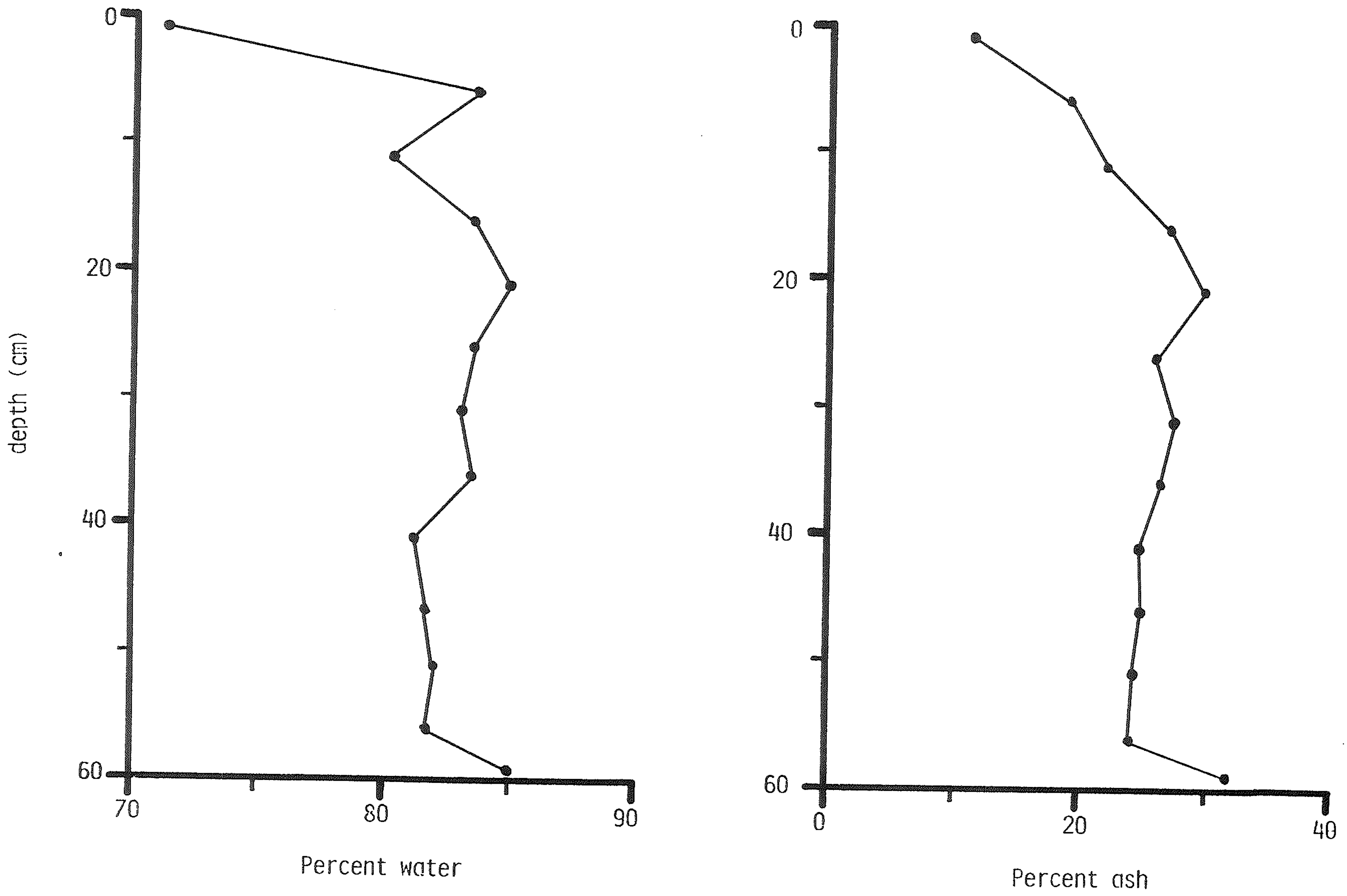


Figure 47. Percent water and ash for select levels of the sediment core from the central basin of Lake Maxinkuckee.

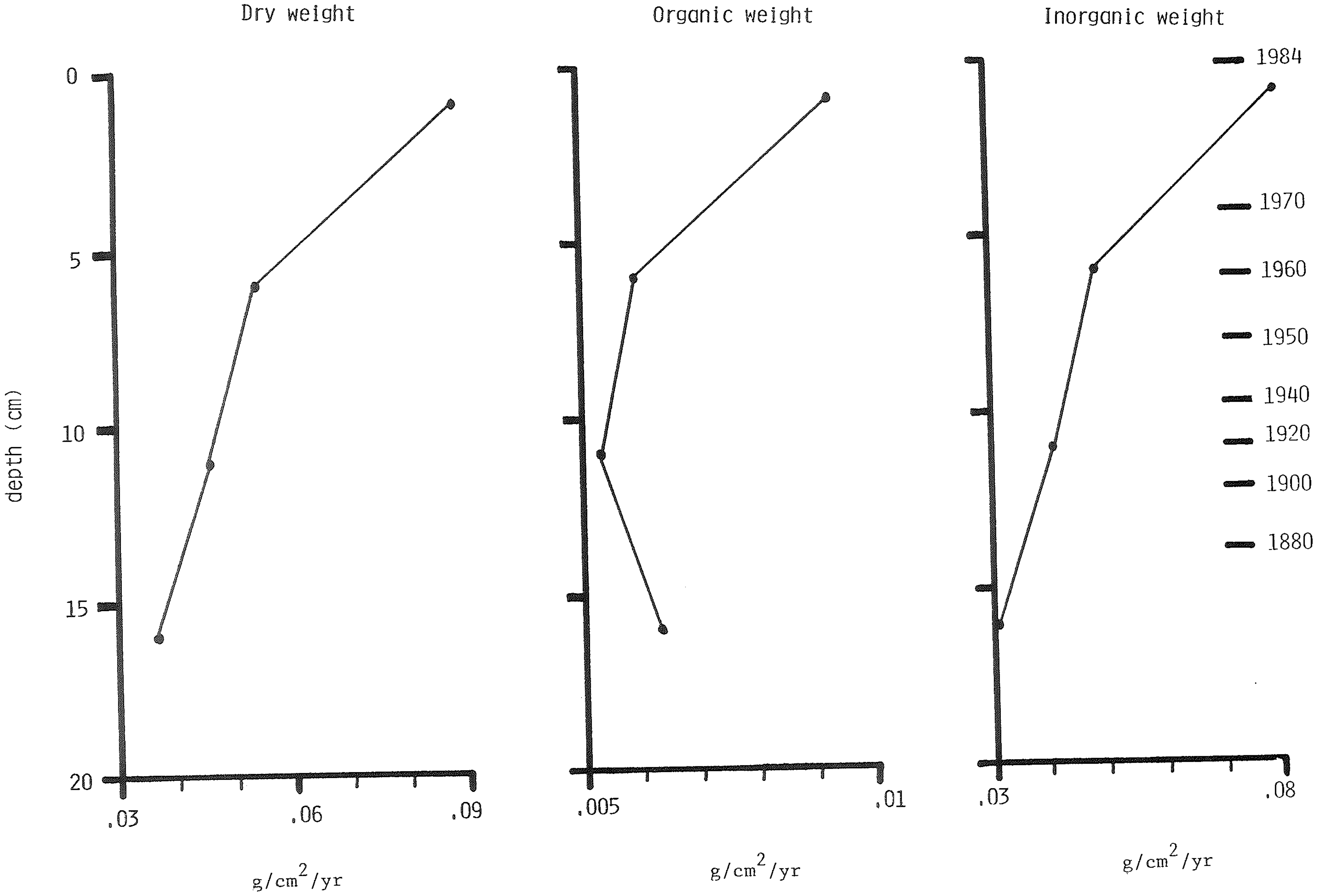


Figure 48. Annual accumulation rates of total dry, organic, and inorganic sediment in the sediment core from the northern basin of Lake Maxinkuckee.

sharply (33%) to .008 g/cm^2/yr during the past 24 years. The pattern for the accumulation of inorganic sediment is identical to that of total sediment with a sharp increase (39%) in the annual accumulation rate after 1960.

These data suggest that the delivery of erosional material from the Lake Maxinkuckee watershed has increased by approximately 39% during the past 24 years. Such an increase in the deposition of inorganic sediments can result from increased erosion of material from the watershed and/or facilitation of sediment delivery from the watershed. The latter can conceivably occur without an increase in the total watershed erosion rate.

The first European settlers came to the Lake Maxinkuckee watershed in 1835-1836, the town of Culver was laid out in 1844, and the Culver Military Academy was established in 1894 (McDonald 1905). A total of 81 cottages and other structures were built along the lake shore pre 1900 (Figure 42), and presumably maximum land clearance for agriculture took place prior to 1870. With peak land clearance for the town of Culver, the Culver Military Academy, and agriculture taking place before 1900, one would expect erosion rates to be greater then than post-1960, a period with little change in pre-established land clearance patterns. The erosion rate could have increased post 1960 as a reflection of changing farm practices, but this can not be assessed with the present database. Even if this were true, it is unlikely that modern erosion rates would exceed rates in the past when the native forests were being cut totally for development pre-1900.

What is more likely is that the delivery rate of inorganic material to the lake has increased recently much more than the actual erosion rate. Pre-1960 there was an extensive marsh at the southeastern corner of Lake Maxinkuckee (Figure 42) that trapped erosional material carried by the creek that drains approximately 23% of the lake watershed. Since 1960 (Figure 43) the effective filtering capacity of this marsh has been drastically altered by dredging and draining activities that have acted to speed the delivery of watershed runoff water to the lake without filtering it slowly through the marsh. The increase in organic matter accumulation rates in the sediments of Lake Maxinkuckee post-1960 (Figure 48) are closely linked to increased delivery of erosional material during this period and its stimulation of algal growth to increase the rate of lake eutrophication.

Phosphorus. Phosphorus concentrations were determined according to the ascorbic acid colorimetric method (APHA 1980) using the filtrate collected from the HCl digestion technique of Andersen (1976) using 2 cc of sediment from each core level examined. Trends in organic accumulation rates closely match those of phosphorus associated with the period of maximum land clearance, but stabilized at much lower levels between 1910 and 1960. As noted previously for both organic and inorganic sediment fractions, phosphorus accumulation rates increased sharply post-1960 approaching or exceeding the previous high rates recorded pre-1900 (Figure 49).

The United States Environmental Protection Agency (1973) estimated that the accumulation of phosphorus in the sediments of Lake Maxinkuckee is .15 $g/m^2/yr$. Williams and Associates (1973) constructed their own phosphorus input model for the lake and estimated the sediment deposition value for phosphorus at .17 $g/m^2/yr$. Phosphorus accumulation rates calculated for the northern and central basins as part of the current paleolimnological study are 2.7 $g/m^2/yr$ and .16 $g/m^2/yr$, respectively. The value for the central basin is remarkably similar to that of the EPA and Williams and Associates, while the value for the north basin is an order of magnitude higher than past estimates for the lake as a whole. The central basin is closer to the three creeks on the eastern shore that contribute approximately 56% of the calculated phosphorus loading to the lake and because of its location is likely to represent an integrated value for the lake as a whole. The

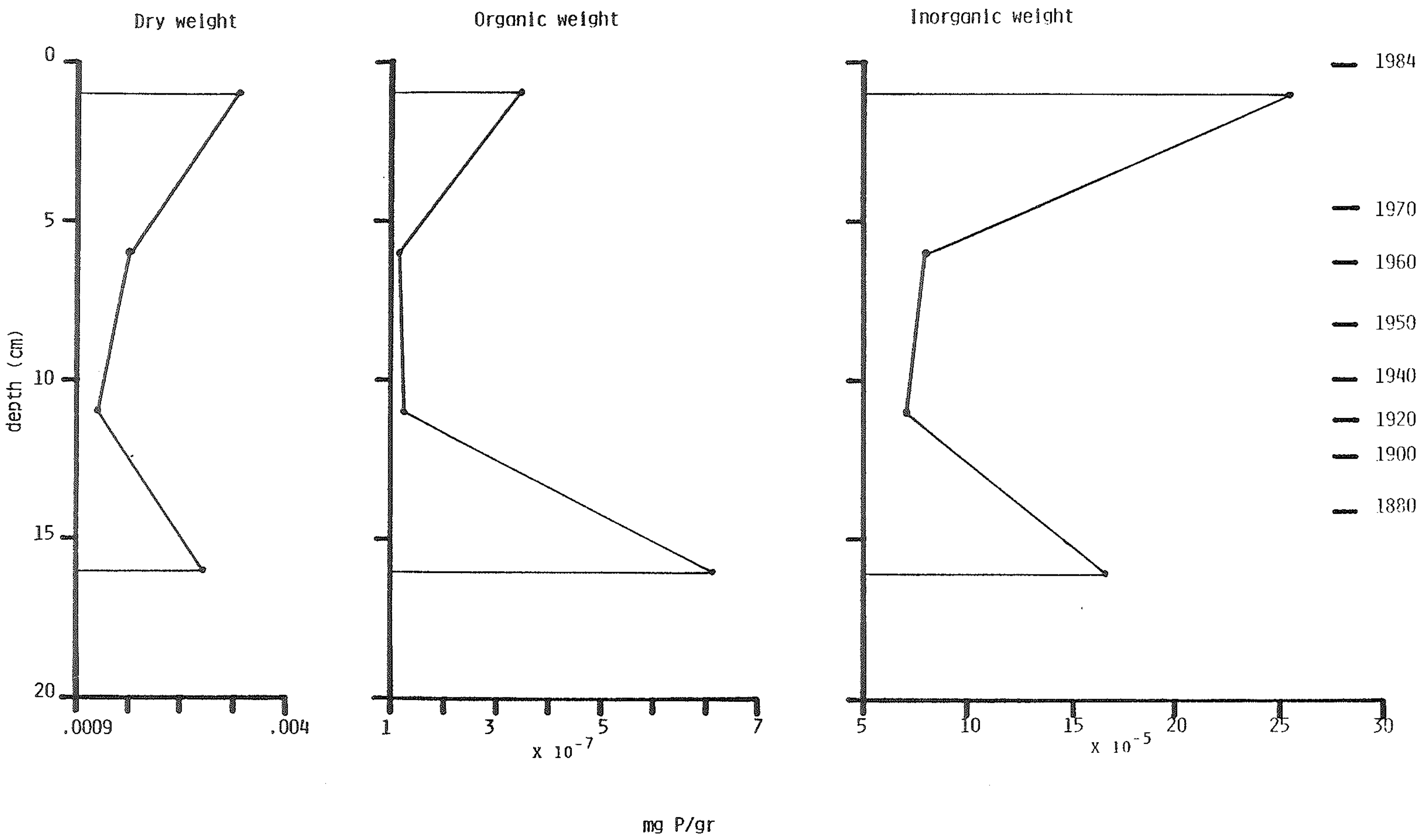


Figure 49. Annual accumulation rates (mg $P/cm^2/yr$) of phosphorus expressed on the basis of dry, organic and inorganic fractions in the sediment core from the northern basin of Lake Maxinkuckee.

northern basin site is more remote from these inputs and more likely to reflect nutrient loading from sources in the northwestern quadrant of the watershed.

All past nutrient loading models for Lake Maxinkuckee have concentrated on point-source loadings such as creeks and largely have omitted any potential contributions from the town of Culver in their calculations. The assumption of all models was that both the Culver Military Academy and the town of Culver were connected to a sewage treatment plant, thus were not contributing to the nutrient loading of Lake Maxinkuckee. This was undoubtedly in error. As noted earlier, Culver has an old sewer system that combines sanitary and storm effluents and often becomes greatly overloaded during peak storm events. During such periods, water sheet flows downhill from Main Street in the direction of the lake and pools in the low lying areas along the shoreline. In addition to this potentially nutient rich non-point source of pollution, a large storm water line outflow pipe is located along the northern lake shore near the boundary with the Culver Military Academy. It is thus not surprising that sediments in the somewhat sheltered northern lake basin are accumulating phosphorus at a rate 10 times greater than the center of the lake. The northern basin lying offshore from the town of Culver is one of the most eutrophic areas of the lake as evidenced by the fact that the mean Secchi disc value for 1985 in this area was lower than 24 of the other 25 stations sampled in the lake. As will be discussed later in this report, the potentially large but as yet unquantified nonpoint nutrient loading from the town of Culver must be addressed in any future lake management plan.

Benthic Invertebrates. As noted previously, benthic invertebrates, especially chironomid midges, are good biological indicators of general lake productivity (degree of eutrophication) as well as the concentration of oxygen in the lower levels of the water column. All past studies at Lake Maxinkuckee have reported a major reduction in the oxygen level of the lower water column during mid and late summer. Anoxic conditions have been reported during many summers. The failure of early lake stockings with trout in the late 1800's is most certainly related to the lack of high oxygen levels during summer in the lower colder segments of the water column.

Benthic invertebrate subfossil remains were examined for multiple levels of the north basin core representing a time chronology from the present to pre-1800. I was particularly interested in determining: 1) if the lake has always developed profundal anoxia during summer or whether such conditions are the direct result of human activities, and 2) if major changes have taken place in the abundance and taxonomic composition of the benthic invertebrate community as a result of lake eutrophication.

For each core level, 2 cc of sediment was cooked in 10% KOH for 15 minutes after which the residue was filtered through an 80 um screen. The entire fraction retained by the screen was examined under a microscrope, and each subfossil remain was isolated individually from the sediment matrix with an Eppendorf pipet and placed on a glass microscope slide containing a drop of silicon oil. After all individuals were thus isolated, a coverslip was added to the slide, and this permanent mount was examined under a microscope at 200x for detailed taxonomic work.

The major invertebrate groups identified in the present study were: bryozoans, Chaoborus, and chironomid midges. Bryozoans are colonial jelly-like animals that attach to aquatic weeds, docks, and other hard objects and filter water to feed on algae. They are represented in the subfossil record by their resting eggs called statoblasts. Crisman et al. (1986) related the abundance of bryozoan statoblasts in lake sediments to known environmental variables including lake water chemistry, degree of eutrophication, and extent of weed beds and noted that bryozoan abundance in sediments is positively correlated with the extent of weed beds in the lake.

Chaoborus is a large invertebrate predator that lives as a benthic invertebrate during the day but swims to the upper portions of the water column at nite to prey on microcrustaceans and rotifers. It is represented in the sedimentary record by its mandibles. This organism is of particular interest in the present study because in lakes that develop severe oxygen depletion in deeper waters during summer, whether by progressive eutrophication or some one-time catastrophic event, *Chaoborus* is no longer able to retreat to the dark cool bottom waters in order to avoid predation by fish, but is trapped in the well lit upper portions of the water column. Lacking a predation refuge during the day, *Chaoborus* is often eliminated from such lakes by fish predation. The disappearance of *Chaoborus* subfossils from the sedimentary record thus can provide a valuable chronological marker for the initiation of summertime anoxia in deep water.

The third and final benthic invertebrate group examined in the present study is chironomid midges. Midges are represented in the sedimentary record by their chitinous head capsules. As most taxonomy of the group is based on features of the head capsule that are preserved upon death of the organism, a great deal of information can be obtained from the sedimentary record. Midges are used by the EPA and state environmental regulatory agencies as the preferred biological indicator organism for defining both the degree of lake productivity (eutrophication) and mid summer oxygen levels in the deeper portions of a lake's water column.

Bryozoan and Chaoborus abundance profiles for the north basin core are given in Figure 50. Bryozoans have always been present in the lake, but the abundance of Chaoborus has changed markedly in recent history, displaying a sharp decline above 37 cm and eventual elimination from the subfossil record above 7 cm. The initial decline occured long before the area was settled by Europeans, but the extinction of Chaoborus occured between 1920 and 1950.

Accumulation rates for bryozoans, Chaoborus, and total chironomid midges for the post-settlement period are given in Figure 51. Bryozoan annual accumulation rates increased sharply in the 1800's and peaked about 1910. Since that time they have remained relatively constant. These data suggest that the extent of weed beds in at least the northern sections of the lake have remained at about the same level since at least 1910. Before that, there appears to have been an expansion in weed beds associated with land clearance by settlers and the resulting stimulation of lake productivity by enhanced nutrient inputs.

As noted earlier, Chaoborus was not encountered in the sediment record post-1950. The fact that Chaoborus began to

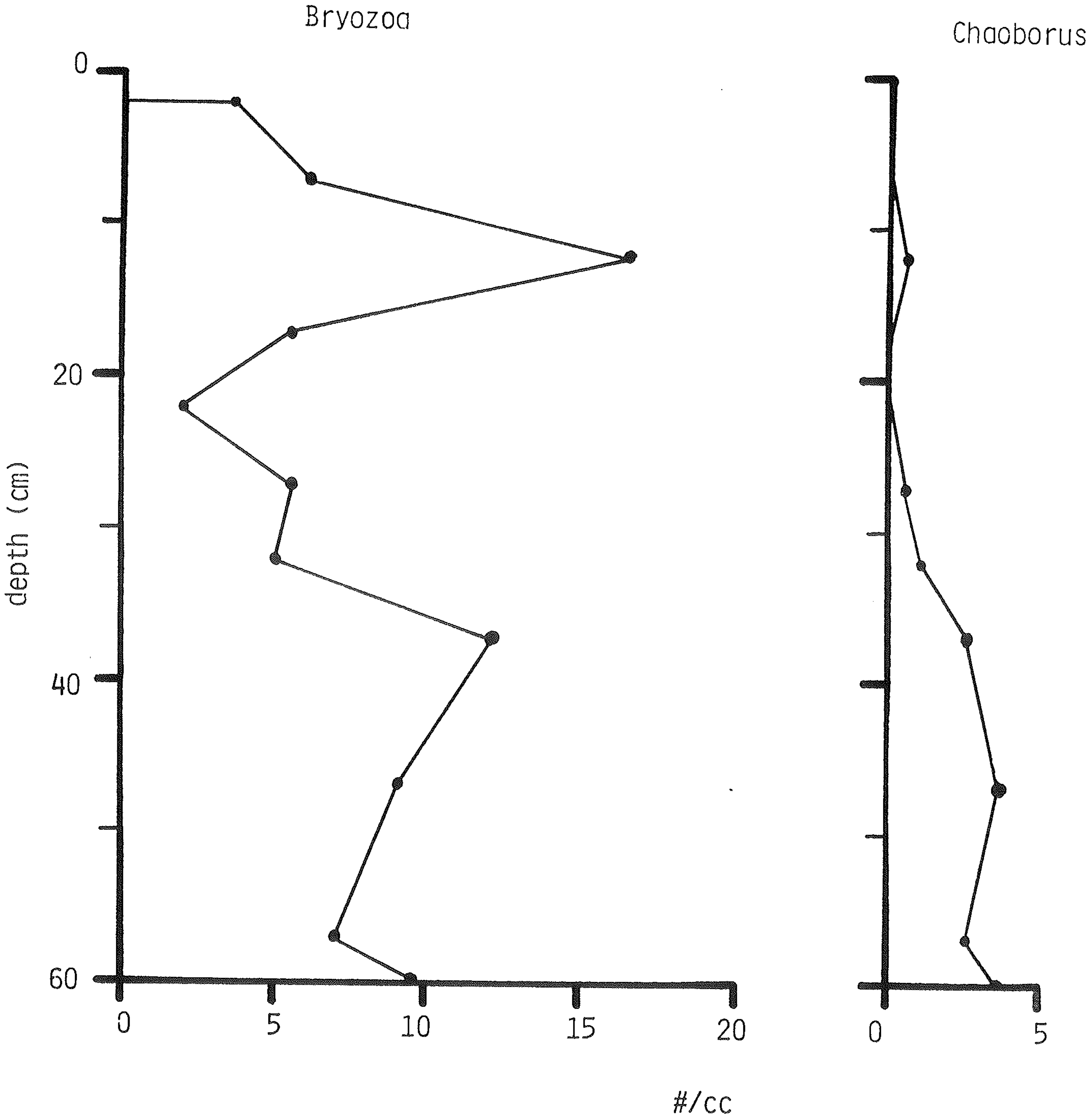


Figure 50. Abundance of bryozoan statoblasts and *Chaoborus* mandibles in a core from the north basin of Lake Maxinkuckee

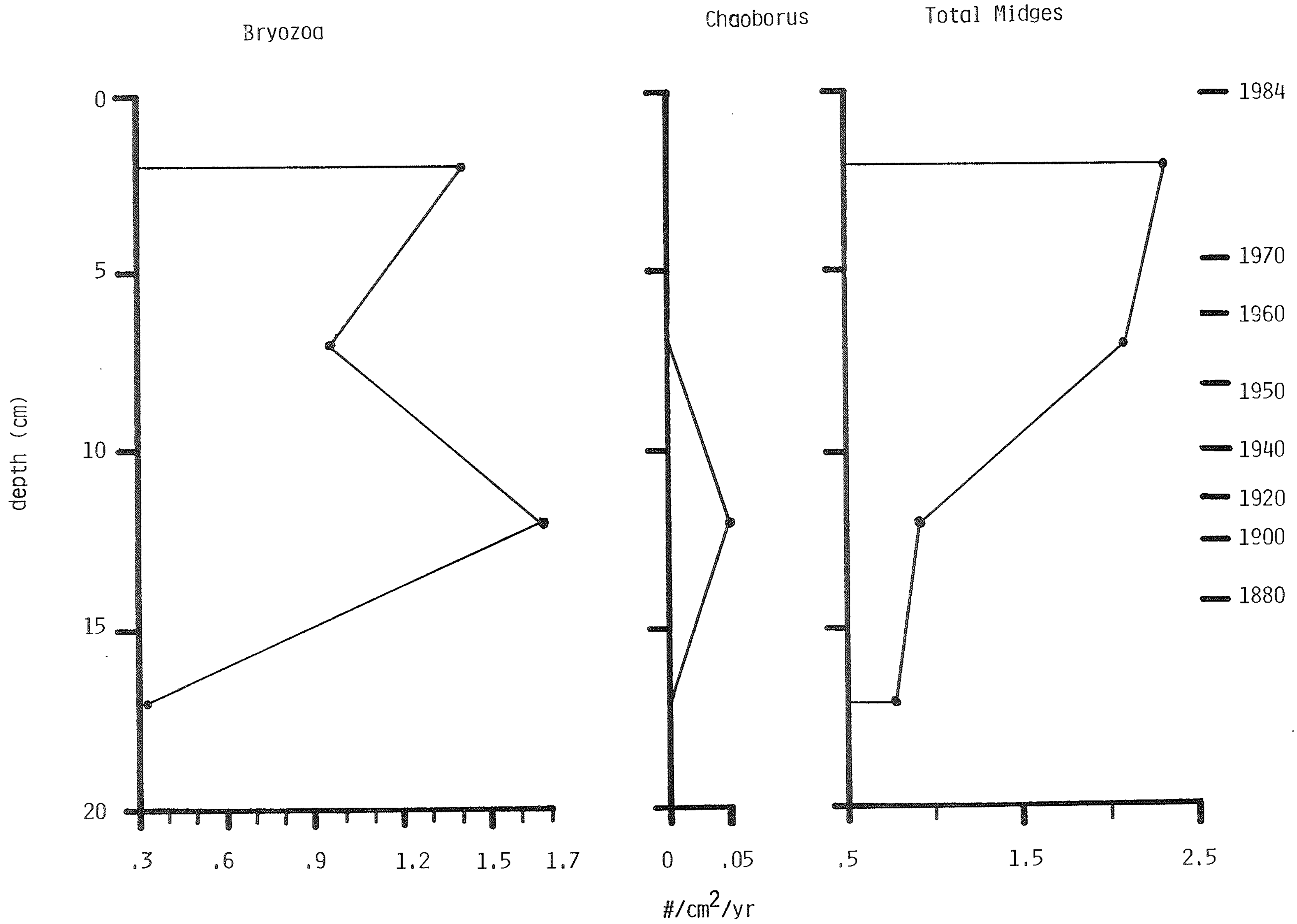


Figure 51. Annual accumulation rates of the three major benthic invertebrate groups examined in the sediment core from the northern basin of Lake Maxinkuckee.

decline long before European colonization coupled with observations of summer anoxia in the lower water column as early as 1900 suggest that deoxygenation of deep waters is largely a function of basin morphometry and the precultural background productivity level of the system. The effect of the recent eutrophication in Lake Maxinkuckee likely has been to expand the temporal extent of the anoxic period to encompass most of the summer and early fall. While *Chaoborus* could tolerate relatively brief anoxic periods, it likely would be eliminated, as observed, with enhanced eutrophication and the associated temporal expansion of summertime anoxia. *Chaoborus* would then no longer have its deeper water refuge during the day and thus be restricted to well lit surface waters where fish predation could eliminate it from the lake.

The annual accumulation rates of total chironomid midges remained at low levels until approximately 1910 when they began to increase. Accumulation rates post-1955 have remained at least four times greater than pre-1910 levels. The increase in midge abundance post-1955 reflects the progressive eutrophication of the lake during the past thirty years. By 1980 midge accumulation rates had increased by 11% over 1955 values.

Four major midge groups are represented in the Lake Maxinkuckee core (Figure 52). The midge assemblage from

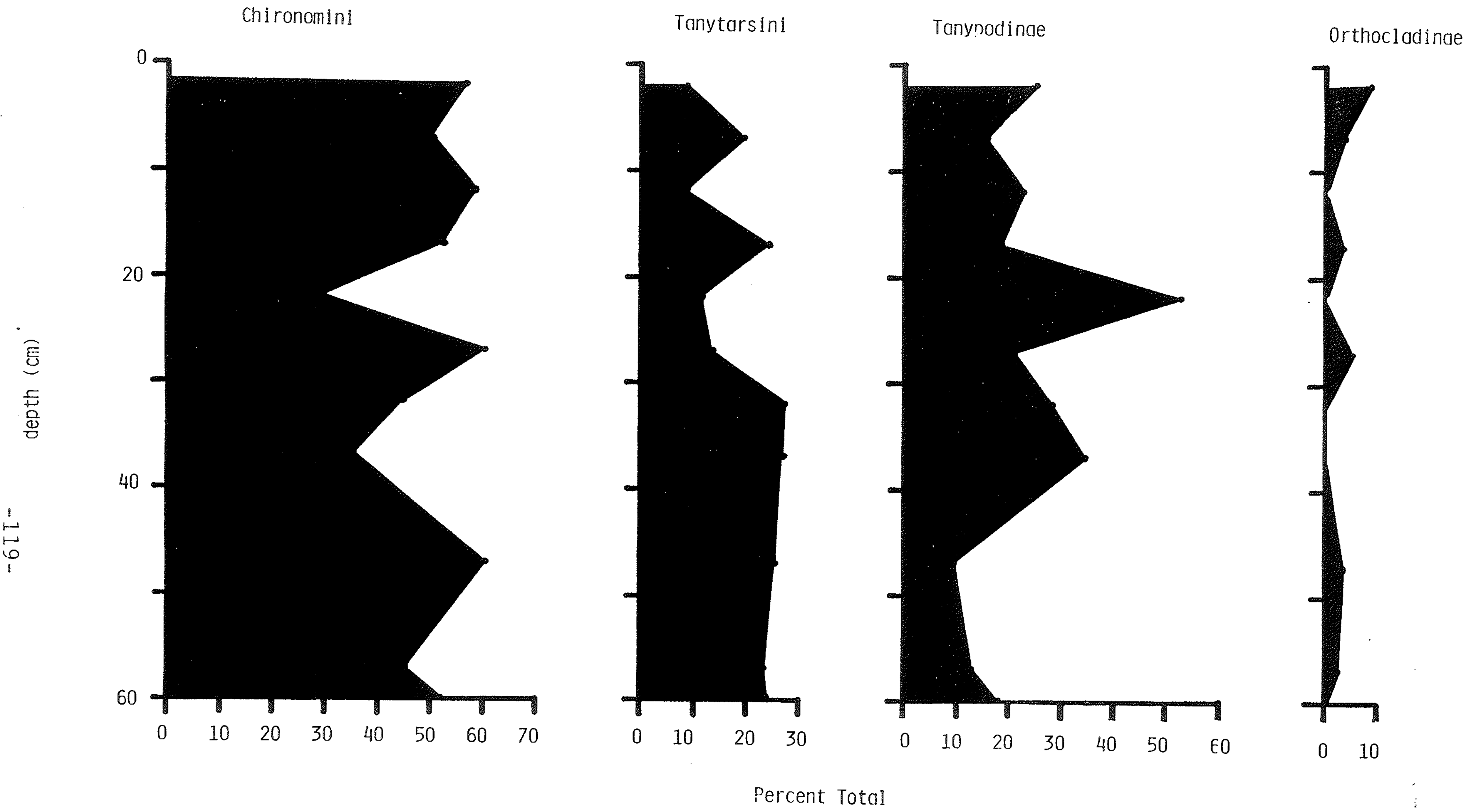


Figure 52. Percent contribution of major groups to the total chironomid assemblage at select levels of the core from the northern basin of Lake Maxinkuckee.

pre-settlement to the present has always been dominated by the Chironomini with the remaining groups ranked in order of decreasing dominance as Tanytarsini, Tanypodinae, and Orthocladinae. With the exception of a tendency towards replacement of Tanytarsini by the Tanypodinae as the second most dominant element in the post-settlement period, the rank ordering of the groups has remained relatively constant for at least the past 300 years.

Accumulation rates for the major midge groups are presented in Figure 53. The accumulation rates of all groups remained relatively constant until approximately 1910. The Chironomini and Tanytarsini sharply increased in abundance between 1910 and 1955, with the former displaying the greatest increase. Between 1955 and the present, the Tanytarsini have declined from their peak core abundance in 1955, while the numbers of Chironomini, Tanypodinae and Orthocladinae have continued to increase. It is clear that much of that much of the increased abundance of total midges observed in recent years is a direct result of the major expansion in the Chironomini.

A number of changes have taken place in the taxonomic composition of the midge assemblage of Lake Maxinkuckee in recent years (Figure 54). Chironomus has dominated the assemblage throughout the core with Tanytarsus as the principal subdominant. The percentage contribution of the latter to the

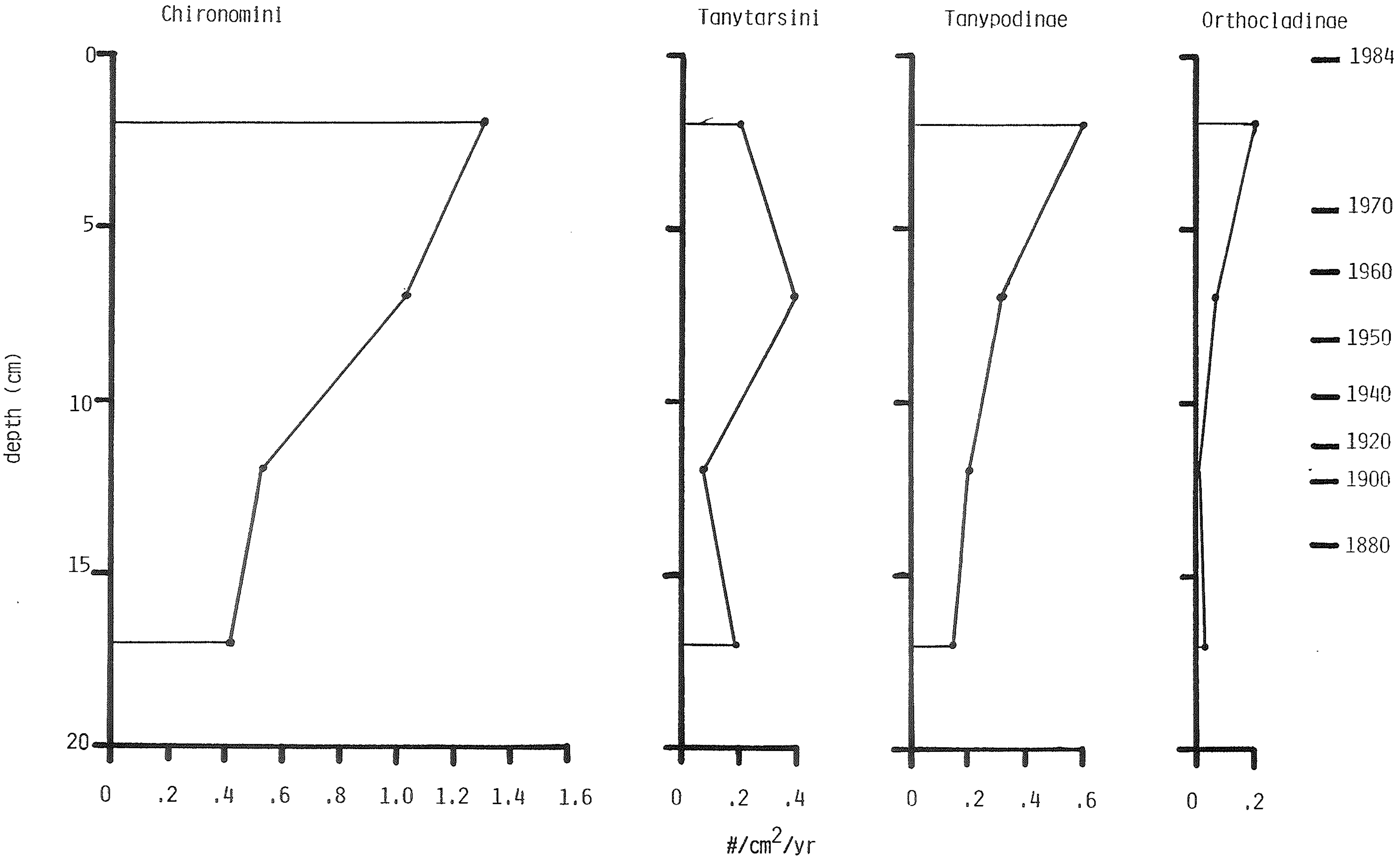


Figure 53. Annual accumulation rates of major chironomid groups in the sediment core from the northern basin of Lake Maxinkuckee.

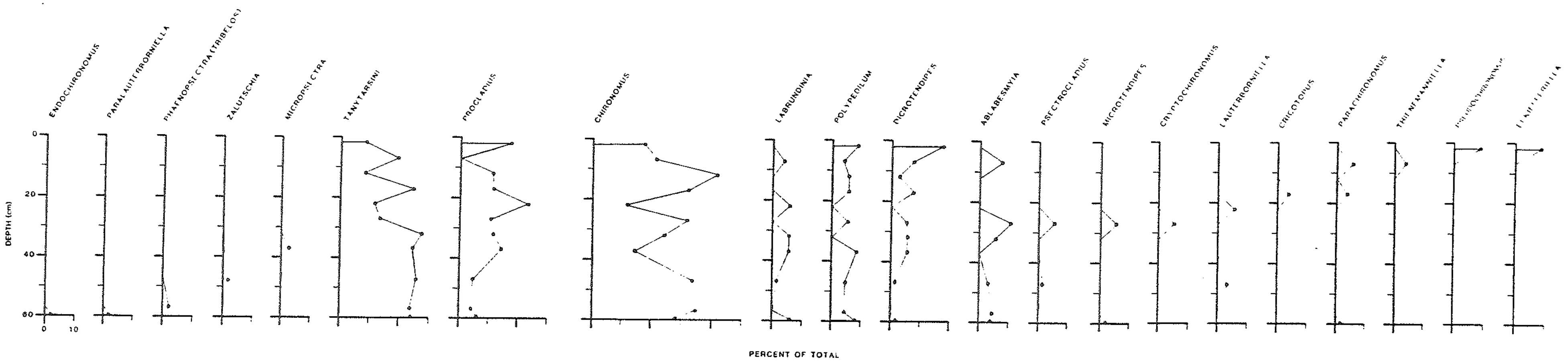


Figure 54. Percentage contribution of major taxa to the chironomid assemblage of the Lake Maxinkuckee core from the northern basin.

total fauna has been declining progressively since the 30 cm level (well before European colonization). In the past ten years, the abundance of *Dicrotendipes*, *Parachironomus*, *Pseudochironomus*, *Eukiefferiella*, and *Thienemaniella* have risen sharply.

Accumulation patterns for major midge taxa are given in Figure 55. While the accumulation rates of most taxa have changed little since the pre-settlement period, those of three taxa, *Chironomus*, *Dicrotendipes*, and *Procladius*, increased 5.79, 16.6, and 35.5 times, respectively, between 1955 and 1979. All three taxa are used as bioindicators of increasing lake eutrophication.

The significance of the midge data for Lake Maxinkuckee is extremely clear. Oligotrophic lakes are characterized by a dominance of Orthocladinae and Tanytarsini, but dominance shifts to Chironomini and Tanypodinae in highly eutrophic lakes. At the generic level, *Tanytarsus* is replaced by *Chironomus* with increasing eutrophication.

Orthoclads have never been an important element in the midge fauna of Lake Maxinkuckee. Rather, Chironomini and secondarily Tanytarsini dominated the pre-settlement assemblage. The absence of a group indicative of oligotrophic (low productivity) lakes and the importance of a group (Chironomini) characteristic of moderately-excessively productive lakes (mesotrophic-eutrophic)

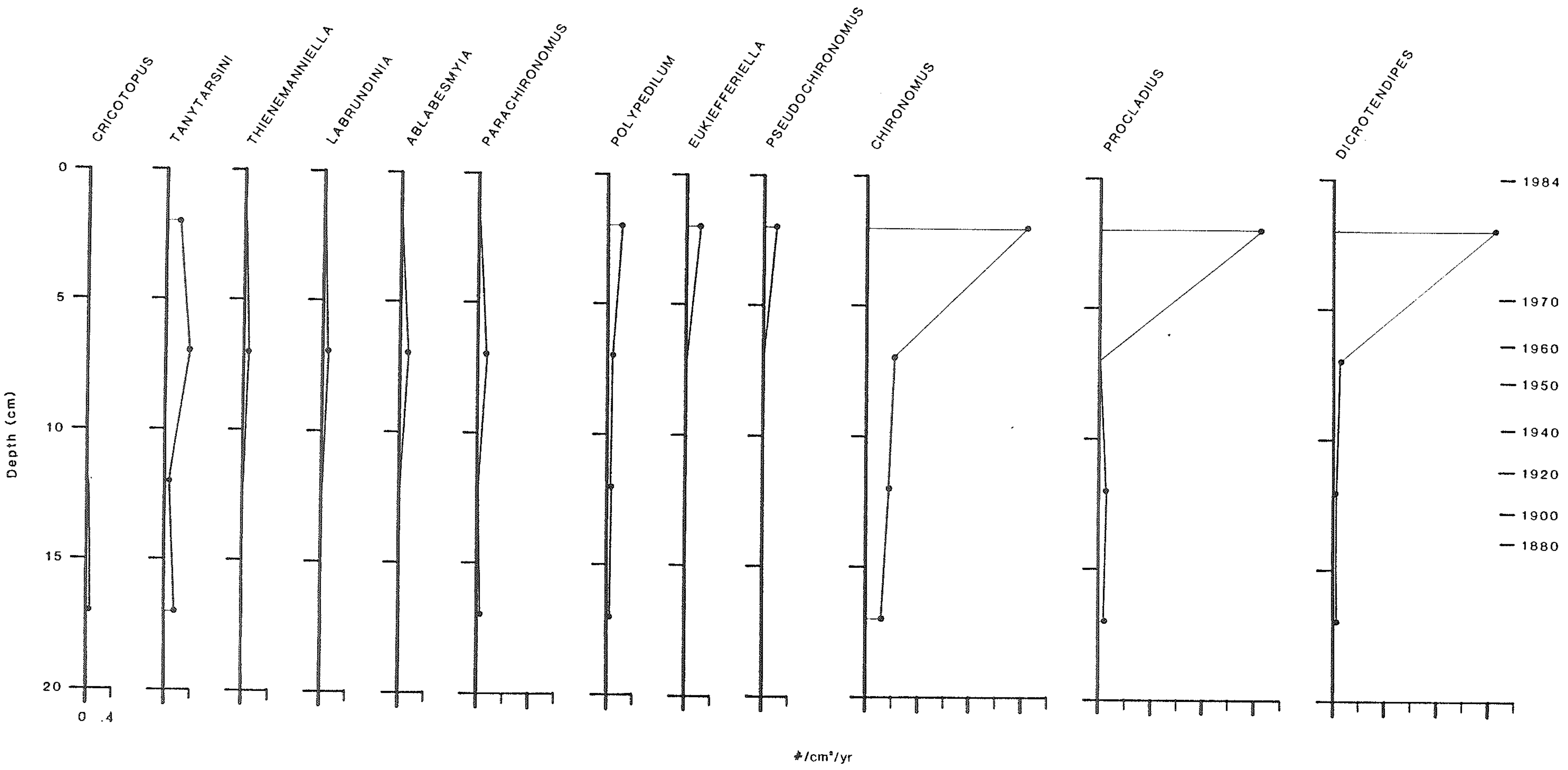


Figure 55. Annual accumulation rates of major chironomid taxa in the sediment core from the northern basin of Lake Maxinkuckee.

suggests that Lake Maxinkuckee has always been moderately productive (mesotrophic). Further, the midge assemblage clearly shows that the eutrophication process has greatly accelerated since 1955. The midge fauna existing in the lake today is one characteristic of eutrophic lakes with prolonged periods of deep water anoxia.

CONCLUSIONS AND RECOMMENDATIONS

The present investigation on Lake Maxinkuckee consisted of three distinct phases. First, all historical data from the first investigations in the late 1800's to the present were compiled (Table 1) and interpreted. Second, a Secchi disc monitoring program and a bacteriological survey of inlet streams were instituted to gather data essential for a sound lake management plan. Third, a paleolimnological analysis of sediment cores from the lake was conducted to estimate historical changes in both the inputs of phosphorus and material eroded from the watershed and the general history of lake eutrophication.

Based on this three phase approach, the following conclusions regarding the cultural eutrophication of Lake Maxinkuckee have resulted:

1) Lake Maxinkuckee has always been moderately productive. Algal blooms (scums) were common as early as 1900 (Table 4), and both the algal (Table 3) and benthic invertebrate (Figures 52,54) assemblages have always been dominated by taxa characteristic of moderately to excessively productive lakes.

2) The lower water column of the lake has been largely devoid of oxygen in late summer since at least 1900 (Table 2). Early stockings of trout in the late 1800's were unsuccessful principally due to water column anoxia. This condition undoubtedly has been exacerbated by recent lake eutrophication.

3) Nutrient models (Figures 2,3) indicate that Lake Maxinkuckee currently is at the mesotrophic/eutrophic trophic state boundary. If the lake has not already slipped into the eutrophic category,

it should definitely do so within the next 5-10 years. Once this happens, the cost of lake restoration will rise exponentially with each incremental increase of lake fertility.

4) Phosphorus is the nutrient limiting algal production in the lake as determined by the EPA in 1973. Thus, eutrophication is accelerated by increased delivery of phosphorus to the lake. Detailed nutrient input models agree that approximately 56% of phosphorus entering the lake is contributed by three creeks, Wilson Ditch, Curtiss Ditch, and the creek at the southeastern corner of the lake (Table 7). In addition to farming runoff, the horse manure pile of the Culver Military Academy is likely one of the principal sources for Wilson Ditch. The Curtiss Ditch sources are farm runoff and improperly functioning septic systems, while farm runoff is likely the principal source for the southeastern creek.

5) While the contribution of the town of Culver was largely overlooked in past nutrient models (Table 3), results of the current investigation suggest that the old sewer system that combines both sanitary and storm effluents becomes overloaded during peak storm events and is a significant nutrient loader to Lake Maxinkuckee. Phosphorus accumulation rates are 10 times greater offshore from the town of Culver than in the center of the lake (Figure 49).

6) The deposition rate of inorganic sediments in the lake has increased by 39% in the past 24 years (Figure 48). Such siltation reflects a combination of increased erosion rates in the watershed and increased delivery of erosional material to the lake. While changing farming practices contribute to part of the change, it is

felt that a significant amount of this increased siltation is related to stream dredging and the destruction of the marsh at the southeastern corner of the lake in the past 20 years. This marsh collected water from the major agricultural area of the watershed and filtered out inorganic sediments and phosphorus before the water was delivered to the lake. Since the marsh has been dredged, this kidney effect has been eliminated. Today this stream contributes between 20 and 26% of the phosphorus entering the lake (Table 7). Coincidental with the period of marsh destruction, phosphorus accumulation rates in the sediments of Lake Maxinkuckee increased by 32%, and all chemical (Figures 48,49) and biological (Figures 51,53,55) parameters indicate a marked increase in the eutrophication of the lake.

7) Power boats are a significant source of water column turbidity especially on weekends. This conclusion is based on the intensive database of the 1985 Secchi disc program. Although water clarity always returned to levels considered background by Tuesday following a weekend depression of clarity (Figure 11), resuspension of sediments into the water column by power boats is considered a significant source for recycling phosphorus in the lake. Such phosphorus is then available for algal utilization.

8) Lake Maxinkuckee has become significantly more eutrophic since 1970 and is or soon will be considered eutrophic (Figures 2, 3). The lake changed little between initial European settlement and the mid-1950's. The general productivity of the lake increased during the 1960's but this increase pales by comparison with that of the post-1970 period. Water concentrations of total phosphorus

(Figure 1) and alkalinity (Figure 4) and annual accumulation rates in the sediments of organic and inorganic matter (Figure 49) and remains of three chironomid genera (*Chironomus*, *Procladius*, *Dicrotendipes*) characteristic of eutrophic lakes (Figure 55) all increased markedly post-1970. Secchi disc values declined after 1965, but between year differences in the 1970's and 1980's may not be significant (Figure 5). This eutrophication is an additive process resulting from a combination of factors including increased recreational use of the lake, dredging of sensitive wetland areas, increased farmland erosion rates, and runoff from the town of Culver. The influence of each is magnified due to the slow flushing rate or water renewal time (6.7 years) of the lake.

9) In spite of progressive eutrophication, recent stockings of walleye by the Indiana DNR have proven successful and have greatly enhanced the sport fishing potential of the lake.

Specific recommendations resulting from the current investigation that are considered a framework upon which to build a comprehensive management plan for Lake Maxinkuckee are given in Table 9. Within each of the four general classes of recommendations, individual recommendations have been ranked roughly in order of decreasing urgency. As eutrophication is considered an additive process, any effective future management plan for Lake Maxinkuckee must, in due course, address each of the recommendations provided. The rationale for each recommendation is provided below according to the ordering scheme of Table 9.

TABLE 9. Recommendations for management of Lake Maxinkuckee

Class I: Immediate Action at Little Cost

1. Institute a regional environmental management plan linking Lake Maxinkuckee, Lost Lake, and Culver into a sound watershed approach.
2. Survey the old Farm Bureau property for chemical pollution prior to any commercial or residential development.
3. Relocation of the horse manure pile of the Culver Military Academy away from Wilson Ditch.
4. Initiation of a stream survey incorporating monitoring of water quality with location of pollution inputs to the streams.
5. Institute a public education program.
6. Consider restricting the number, maximum horsepower, speed, and use area within the lake for powerboats.

Class II: Immediate Action at Moderate Cost

1. Construction of retention pond or restoration of the marsh near the mouth of the creek at the southeast corner of the lake.
2. Construction of a retention pond near the mouth of Curtiss Ditch.
3. Construction of an interceptor sewer system along the shoreline bordered by the town of Culver.

Class III: Long-term at Great Cost

1. Construction of a regional sewer system to service the town of Culver and all developed areas of the Lake Maxinkuckee Watershed.

Class IV: Periodic Long-term at Low Cost

1. Maintainence of the Secchi disc monitoring program.
2. Maintainence of DNR walleye stockings.
3. Periodic survey of the aerial extent and composition of aquatic weeds.

I-1: Institute a regional environmental management plan linking Lake Maxinkuckee, Lost Lake, and the town of Culver into a sound watershed approach. Not only is this the most important recommendation to implement, it may be the most difficult to realize. Such a plan must concentrate on land use management for reduction of phosphorus export from the Lake Maxinkuckee watershed, the need for the town of Culver to address: 1) their nutient contribution to Lake Maxinkuckee, 2) elimination of sewage discharge to Lost Lake, and 3) the much needed restoration of Lost Lake. Currently, communication links among representatives of Lake Maxinkuckee, Lost Lake, and the town of Culver are sporadic and weak. In addition, it is often difficult to ascertain which lake association committee is entitled to speak for the non-Culver lake residents of Lake Maxinkuckee. I suggest the formation of a regional board consisting of two representatives each from Lake Maxinkuckee, Lost Lake, the town of Culver, and the often overlooked agricultural community. This board should then be empowered to speak for the combined Maxinkuckee-Lost Lake watershed in matters of regional environmental significance. Existing boards and associations would still function to handle matters of local concern to each of the separate entities comprising this regional board. Without such a unified approach, any future hope of securing state and/or federal funding to stop the cultural eutrophication of Lake Maxinkuckee or to restore Lost Lake will be seriously impaired. Recommendations provided in the present report on Lake Maxinkuckee and a similar report on Lost Lake that I will complete in spring 1986 should form the basis of a sound regional watershed management plan. The mandate of the regional board that I outlined above is both to see that these recommendations are implemented and to serve as a watchdog for further environmental degradation of the watershed's water quality.

I-2: Survey the old Farm Bureau property for chemical pollution prior to any commercial or residential development. Both fertilizers and herbicides/pesticides were formerly stored on this property. The potential exists that soils at former storage and handling areas have been contaminated with these chemicals. Future residential or commercial development of the property could promote leaching of these chemicals into the lake from soils that might be disturbed during construction activities. Any future developer of the property must be required to perform detailed soil testing of the old Farm Bureau property for EPA priority pollutants, herbicides, pesticides, nitrogen, and phosphorus prior to issuance of construction permits.

I-3: Relocation of the horse manure pile of the Culver Military Academy away from Wilson Ditch. Wilson Ditch currently contributes 6-8% of total phosphorus loading to Lake Maxinkuckee (Table 7). This is the lowest contribution of any of the creeks of the eastern shore. Although all creeks drain large agricultural areas, the phosphorus loading of Wilson Ditch to Lake Maxinkuckee is minimized because the existing retention pond traps much of the watershed phosphorus export. The phosphorus loading of Wilson Ditch can be further minimized through removal of the manure pile of the Culver Military Academy. While the manure pile is an obvious phosphorus source, it is an even more serious source of bacterial contamination in the creek.

Results of the 1985 creek bacteriological survey (Figure 41) indicated severe bacterial contamination immediately downstream from the manure pile. Luckily, the retention pond trapped much of this contamination before it entered the lake. The manure pile must be relocated away from Wilson Ditch to minimize leaching of nutrients and bacteria into the creek.

I-4: Initiation of a stream survey incorporating monitoring of water quality with location of pollution inputs to the streams. Streams entering the lake along the eastern shore contribute approximately 56% of total phosphorus loading to Lake Maxinkuckee (Table 7). The first step in minimizing this stream contribution is to identify sources of stream contamination. The 1985 stream bacteriological survey indicated serious bacterial contamination on Wilson Ditch, Curtiss Ditch, and the stream at the southeastern corner of the lake (Figure 41). I suggest a survey of each creek that incorporates analyses of benthic invertebrates, water chemistry, and bacteria at multiple stations along the stream length. In addition, an attempt should be made to locate point sources of pollution including improperly functioning septic systems.

I-5: Institute a public education program. Lake residents need to be encouraged to implement the following measures both to decrease nutrient input to the lake and its recycling in the water column:

A) Do not fertilize lawns. Routine watering with lake water will contain sufficient nutrients to support lawn growth.

B) Properly maintain septic tanks. Do not allow septic tanks to fill. Keep wastes pumped out. Inspect drain fields especially potential discharge points along the lake shoreline.

C) Report all sewage smells to the Indiana State Board of Health. This includes not only along the shoreline, but also anywhere in the watershed. Not only is this a potential health hazard, it is a source of unwanted nutrients in the lake.

D) Reduce garbage disposal use. Any organic matter that enters your septic system is a potential source of nutrients for the lake. Bag all food wastes for trash pickup.

E) Do not remove shoreline vegetation. The emergent grasses and cattails that grow along the shore not only reduce shoreline erosion by waves generated by powerboats but also trap nutrients before they enter the water column of the lake.

F) Do not dredge around docks and shoreline frontage. Mechanical mixing of sediments promotes release of trapped nutrients.

G) Minimize wave generation by boating activities. Do not ski within 200 feet of shore and lower boat speed within 400 feet of shore to a speed that minimizes wave generation. Not only do waves promote shoreline erosion, they increase the general mixing depth of the lake thus increasing the recycling of nutrients.

I-6: Consider restricting the number, maximum horsepower, speed, and use area within the lake for powerboats. The 1985 Secchi disc survey clearly demonstrated that powerboats are a significant factor affecting water clarity of Lake Maxinkuckee especially during weekends (Figures 11-37). Because turbidity that is generated near shore is transported quickly off shore, it was impossible in the 1985 survey to determine the minimum distance from shore needed to minimize its generation. It is obvious that either boat operators are ignoring speed restrictions near shore or current speed restriction zones need to be extended farther from shore.

II-1: Construction of a retention pond or restoration of the marsh near the mouth of the creek at the southeast corner of the lake. This creek currently contributes 20-26% of total phosphorus loading to Lake Maxinkuckee (Table 7). It is interesting to note that increased loadings of inorganic sediment (Figure 48) and phosphorus (Figure 49) occurred following channelization and draining of the marsh at the creek mouth in the 1960's. The filtering capacity that was once afforded by the marsh must be restored. I suggest the creation of retention ponds and/or an artificial marsh near the mouth of this creek. It is entirely feasible to retain runoff water near the creek mouth so that silts will settle out and phosphorus will be taken up by marsh vegetation without adversely affecting the drainage requirements of local farmers. Such a system would also be effective at trapping bacterial comtamination such as was observed in the creek during the 1985 bacteriological survey (Figure 41).

II-2: Construction of a retention pond near the mouth of Curtiss Ditch. This ditch contributes 15-20% of total phosphorus loading to Lake Maxinkuckee (Table 7). In addition, state bacteria standards were exceeded at both stations sampled in the creek during the 1985 survey (Figure 41). With the current database it is not apparent whether a similar retention pond is needed for Maxinkuckee Landing Ditch. This decision must await completion of the detailed stream survey proposed as recommendation I-4. The effectiveness of retention ponds for trapping nutrients is obvious. Although Wilson Ditch drains a watershed area and land use comparable to Curtiss Ditch and the creek at the southeast corner of the lake, it contributes only 6-8% of total phosphorus loading to the lake as compared to the 15-20% and 20-26% contribution of the latter two systems (Table 7).

II-3: Construction of an interceptor sewer system along the shoreline bordered by the town of Culver. Paleolimnological evidence suggests that sediment phosphorus accumulation is 2.7 $g/m^2/yr$ immediately offshore from the Culver shoreline as compared to .16 $g/m^2/yr$ for the center of the lake. Much of this 6-fold phosphorus enrichment is likely attributed to runoff from the town of Culver. In order to stop this significant phosphorus loading from runoff, I suggest ringing the shoreline of Culver with an interceptor sewer system beginning at the undeveloped shore adjacent to the Culver Inn and extending to the southern town limits. Storm sewers dumping directly into the lake would be connected, and the system would trap all storm water currently flowing down the hill east of Main Street. All collected water could then be moved to a retention pond near the sewage treatment plant for subsequent treatment during non-peak flow periods. No further development of the Culver town shoreline should be permitted without the assurance that the interceptor system be installed as part of the plan.

III-1: Construction of a regional sewer system to service the town of Culver and all developed areas of the Lake Maxinkuckee Watershed. This is the icing on the cake for controlling the cultural eutrophication of Lake Maxinkuckee. While septic tanks have been estimated to contribute only 2-6% of total lake phosphorus, the contribution of the immediate drainage, defined as the phosphorus contributed as part of diffuse overland and subsurface drainage along the shore, exceeds 30% of total lake phosphorus (Table 7). The principal sources of this component include fertilizer from lawns and runoff from roofs, parking lots, and streets during storms. At the very least, a storm sewer system to collect runoff should be proposed. This could be tied in with the retention ponds proposed for the major creeks draining the eastern shore. Although expensive, I feel that a complete sanitary sewer system is needed for all developed areas of the Maxinkuckee watershed. The expense involved with construction of such a system pales by comparison with the potential cost of restoring Lake Maxinkuckee in the future if cultural eutrophication is allowed to continue.

IV-1: Maintainence of the Secchi disc monitoring program. The Secchi disc program should be continued in future years. As demonstrated by the present investigation, this is one of the cheapest ways both to get data on the trophic state of the lake and to address important factors that may be affecting it. Even if not continued every year, the Secchi disc program provides a yardstick against which to measure if the lake condition continues to worsen.

IV-2: Maintainence of DNR walleye stockings. Strong support should be given to the Indiana Department of Natural Resources efforts to stock the lake with predatory fish such as they are currently doing with walleye. Since introduction of walleye fry into the lake in 1980, 1982, and 1983, perch contribution to total fish abundance has declined from approximately 40% pre to 10% post stocking. Reduction in perch abundance decreases predation on large zooplankton, the principal grazers of algae in temperate zone freshwater lakes. Both Shapiro and Wright (1984) in Minnesota and Crisman et al. (1986) in Florida have demonstrated how enhanced zooplankton populations following removal of their principal fish predators have proven effective at eliminating algal blooms even in highly eutrophic lakes. Such biomanipulation using fish may help to lessen the consequences of cultural eutrophication by keeping algal biomass low in spite of high nutrient levels.

IV-3: Periodic survey of the aerial extent and composition of aquatic weeds. A study to quantify the extent and species composition of weed beds in Lake Maxinkuckee should be initiated. We need a database against which future changes in the aerial extent of weeds can be compared. *Myriophyllum spicatum* is an exotic plant that has spread throughout the northern United States and has often caused serious lake management problems associated with its often excessive growth. This plant is established in the lake and if nutrient loadings to the lake continue to increase could pose a management problem in the future.

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