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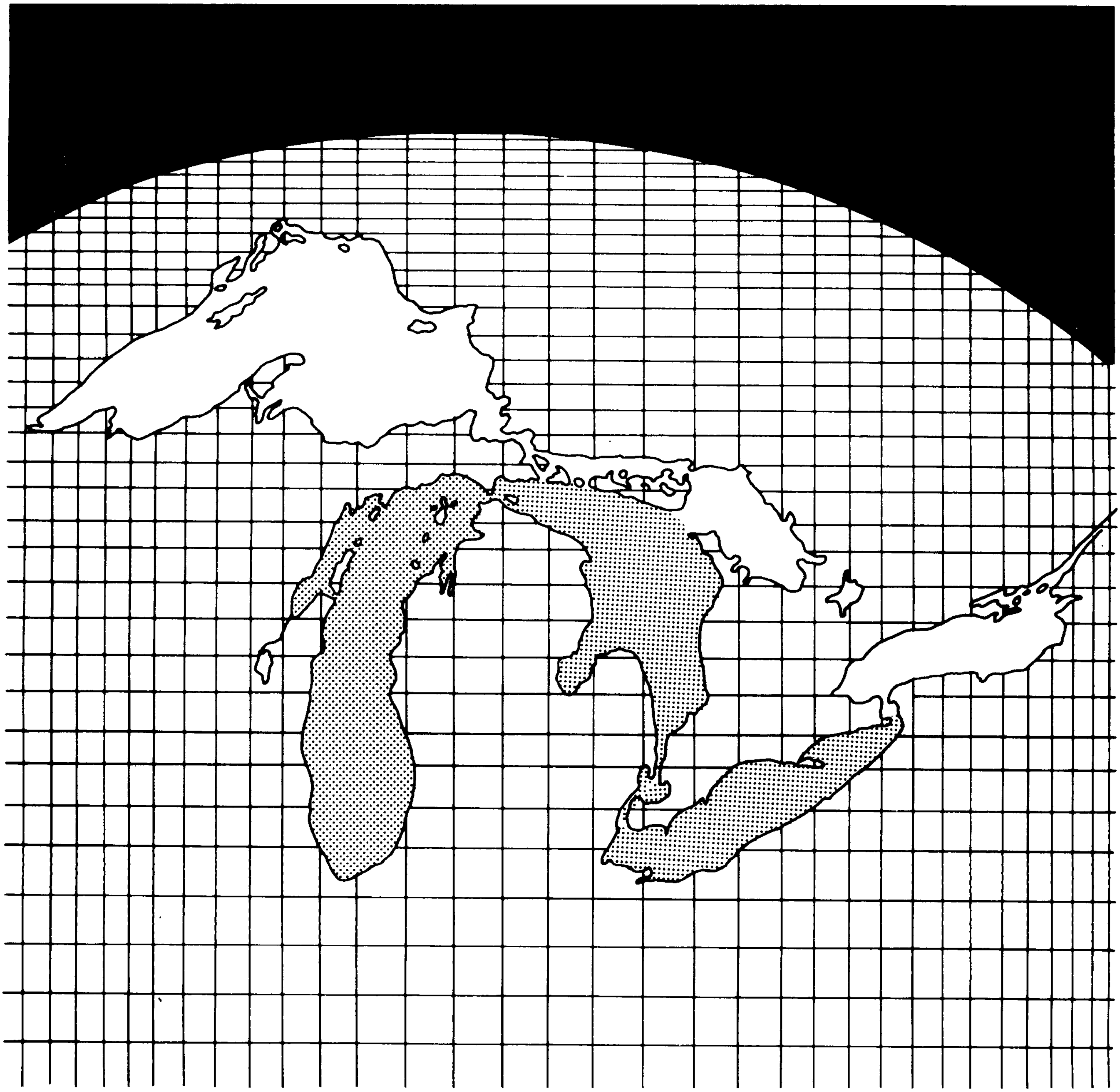
Water Quality in the Middle Great Lakes: Results of the 1985 U.S. EPA Survey of Lakes Erie, Huron and Michigan



WATER QUALITY IN THE MIDDLE GREAT LAKES: RESULTS OF THE 1985 USEPA SURVEY OF LAKES ERIE, HURON AND MICHIGAN[1]

by

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FOREWORD

The Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency was established in Region V, Chicago, Illinois to focus attention on the significant and complex natural resource represented by the Great Lakes.

The GLNPO implements a multidisciplinary environmental management program drawing on a wide range of expertise represented by universities, private firms, state, federal, and Canadian governmental agencies, and the International Joint Commission. The goal of the GLNPO program is to develop programs, practices, and technologies necessary to achieve a better understanding of the Great Lakes basin ecosystem and to eliminate or reduce to the extent practicable the discharge of pollutants into the Great Lakes system. The GLNPO also coordinates U.S. actions in fulfillment of the Agreement between Canada and the United States of America on Great Lakes Water Quality of 1978.

This report presents some of the results of the water quality surveillance program conducted on Lakes Michigan, Huron, and Erie (the middle Great Lakes) in 1985 by the GLNPO. This surveillance program is a continuation of the program begun in 1983. The 1983 and 1984 results are reported by Lesht and Rockwell (1985 and 1987). Since many of the procedures and protocols, both in sampling and analysis, were similar in the three years, this report includes much of the same background information contained in the reports on the 1983 and 1984 survey. The present report contains an analysis of the 1985 data, which is then compared with the 1983 and 1984 results.

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ABSTRACT

Continuing a limited annual program begun in 1983, the U.S. Environmental Protection Agency's Great Lakes National Program Office surveyed the water quality of Lakes Erie, Huron and Michigan (the Middle Great Lakes) in 1985. A helicopter survey was completed in winter during January and February, and three ship surveys were conducted in spring, summer, and fall. The samples were analyzed for the traditional limnological parameters and for nutrients. The data were compared with the results of the 1983 and 1984 surveys. Although many measurements of water quality were unchanged from 1983 to 1985, the physical conditions, notably temperature, were much different; 1983 was a mild year, while 1984 and 1985 were much colder. In 1985 the stratification for each lake spanned a longer period than in 1983 and 1984. All three lakes exhibited a pattern of nutrient depletion from the epilimnion and concurrent enrichment of the hypolimnion during the summer. However, in 1985, the magnitude of the depletion for some parameters was greater than observed in 1983 and 1984. During the fall survey before and after "fall overturn" measurements of chemical concentrations were obtained. Concentrations of total phosphorus continue to be low in Lakes Michigan and Huron, and seem to be declining in Lake Erie. Nitrate + nitrite nitrogen concentrations are consistently increasing in all three lakes. Chloride concentrations are increasing in Lakes Huron and northern Lake Michigan, but continue to decrease in Lake Erie. The chloride concentration in southern Lake Michigan was unchanged between 1984 and 1985 which may be a significant change from the previous years of constant increases. The Great Lakes Mass Balance Model illustrates how the lakes might be expected to respond to recent historical changes in phosphorus loading. In Lake Michigan, Lake Huron and the three basins of Lake Erie predicted concentrations of total phosphorus decreased over the modeled period.

TECHNICAL SUMMARY

The water-quality surveillance program begun in 1983 to sample the open waters of Lakes Michigan, Huron and Erie (the middle Great Lakes) was continued in 1985. The principal objectives of the program were (1) to determine the water quality of the three lakes, especially with regard to the concentration of nutrients in the open waters; (2) to continue the program of annual sampling so as to provide data necessary for detection and evaluation of both trends and annual variability in water quality; and (3) to provide data relevant to the ongoing verification and modification of the nutrient-based eutrophication models that have been developed in conjunction with previous Great Lakes surveillance. The major findings of the 1985 survey are summarized below; the details of the analyses and statistical summaries (SAS, 1982 and 1985) and tables presenting the results are included in later sections.

GENERAL FINDINGS

Sampling

The sampling network that had been used in the first two years of the program (1983 and 1984) was modified in response to recommendations made by the International Joint Commission's Lake Task Forces (IJC, 1986). Analysis of historical data, including data from previous intensive surveys, shows that the 1985 sampling network is comparable to the 1983/1984 network and is representative of the well-mixed, open-lake areas that the program was designed to sample.

Surveys were conducted during the spring (April-May), summer (August), and fall (November-December). In general, the lakes were warmer in 1985 than in 1984 but cooler than in 1983. As expected, Lake Michigan, Lake Huron and the eastern basin of Lake Erie were isothermal during the spring survey. However, the western basin of Lake Erie was stratified and the western part of the central basin of Lake Erie was beginning to stratify during the spring sampling.

Spatial variability of the sampled parameters during the spring survey was smaller in 1985 than in 1984 and 1983. This variability was similar to the analytical uncertainty estimated as part of the quality control program in all basins, except western Lake Erie, indicating the relative homogeneity of the open waters and the adequacy of the sampling program. The criterion of detection (COD) established using the quality control data was well below environmental levels for almost all parameters during every survey. The COD for dissolved reactive phosphorus was near environmental levels and the COD for dissolved reactive silicon was above environmental levels during the fall survey.

Spatial Segmentation

The ascription of stations to the traditional lake basins was essentially the same in 1985 as in previous years. However, in order to conform more closely with basin definitions used in some numerical models (Rodgers and Salisbury, 1981a and b; DiToro and Matystik, 1980), two stations, L. Mich 27 and L. Huron 27, were considered to be in the southern basins of each lake rather than in the northern basins.

With the exception of Lake Erie, consistent differences in parameter values in adjacent basins were not found in 1985. This is in contrast to the findings of the 1984 survey, when all three lakes exhibited consistent differences in some parameters, notably dissolved reactive silicon and dissolved nitrate+nitrite nitrogen. The pattern of the differences found in 1984 suggested that the rate of phytoplankton growth and nutrient uptake was higher in the southern basins of Lakes Huron and Michigan than in the respective lakes's northern basins during the periods of sampling. In 1985 the southern basins showed slightly higher biomass (chlorophyll-a) than the northern basins, but lower rates of nutrient uptake (silica and nitrogen) during the summer and Fall-1 surveys. The observations of basin differences in many parameters are probably related to the annual patterns of lake warming, which differ from year to year.

Vertical Segmentation

As was the case in 1983 and 1984, vertical concentration gradients were observed in all the deeper basins after stratification. Nutrients were depleted in the epilimnion of each lake during the summer. Summer silica depletion observed in 1985 in Lakes Huron and Michigan was greater than in either 1983 or 1984.

All of the deep (>50 m) basins developed turbid nepheloid layers that contained high concentrations of dissolved nutrients and particles. The concentrations of many nutrients were significantly higher in the nepheloid layers than in the hypolimnion of Lakes Huron and Michigan during the summer survey (Table 20), while in Lake Erie's eastern basin the differences were not as great. The magnitude of dissolved nutrient enrichment in the nepheloid layer in Lakes Huron and Michigan was greater in 1985 than in the previous years.

NUTRIENT CONCENTRATIONS

Phosphorus

Lake Michigan: The surface concentrations of total phosphorus measured in the spring in the well-mixed, open waters of Lake Michigan were 4.8 ± 0.7 ug/L south and 5.6 ± 1.7 ug/L north (mean ± one standard deviation); these values are virtually the same as those measured in the spring of 1984 (4.8 ± 0.9 ug/L south, 6.2 ± 3.0 ug/L north). Total phosphorus concentrations in the epilimnion declined during the year until the Fall-2 survey when mixing throughout the water column redistributed nutrients. Increases in the concentration of total phosphorus in the nepheloid layer mirrored the decreases in the epilimnion.

Total phosphorus concentrations have remained stable in Lake Michigan since the late 1970s. Since the inception of the annual monitoring program in 1983, the spring open lake total phosphorus levels have been as much as 30% below the International Joint Commission (1980) target concentration of 7 ug/L in both the northern and southern basins.

Lake Huron: Springtime surface concentrations of total phosphorus in Lake Huron were 10% to 20% lower in 1985 (3.0 ± 0.5 ug/L) than in 1983 (3.6 ± 0.7 ug/L). The 1985 levels are the lowest values measured in the last fifteen years. Epilimnion concentrations decreased during the summer to 2.8 ug/L north and 2.3 ug/L south, while the southern basin nepheloid layer concentration increased to 4.2 ug/L. During the winter (January-February 1985) the highest concentrations observed were 3.5 ug.L north and 4.0 ug/L south. These values are well below the IJC (1980) target level of 5 ug/L.

Lake Erie: Spring-averaged, volume-weighted (by strata), open-lake total phosphorus concentrations in all three basins of Lake Erie were observed at their lowest levels since the start of the annual surveillance program. On an annualized basis, the 1985 total phosphorus concentrations were virtually unchanged from 1984 in the western (23.5 ug/L) and central (15.0 ug/L) basins. The concentration in the eastern basin (11.0 ug/L) was lower than measured in 1984. Assuming a linear trend, the rates of decrease in total phosphorus concentration over the last three years in both the central and eastern basins were statistically significant and estimated to be 0.65 ug/L/yr (central) and 0.95 ug/L/yr (eastern).

Nitrate + Nitrite

Lake Michigan: Springtime nitrate + nitrite nitrogen concentrations in the surface waters of Lake Michigan were higher in 1985 than in either 1983 or 1984. Mean concentrations in 1985 were higher (alpha = 0.05) both in the southern (287 ug/L) and northern (297 ug/L) basins than in 1983 (259 ug/L south, 262 ug/L north). There is a step increase in concentration in 1985 over the apparent rate of increase of 2 ug/L per year from 1977 through 1984.

In both basins, the 1985 epilimnetic depletion of nitrate + nitrite nitrogen from spring survey maxima, resulted in a 46% decrease in both basins (minima were 156 ug/L northern and 159 ug/L southern). During the summer survey, maximum observed enrichment occurred in the nepheloid layer in the northern basin (314 ug/L) and in the southern basin (330 ug/L) during the fall survey. In both basins, increased nitrate + nitrite nitrogen concentrations were observed in the hypolimnion in the fall survey.

Lake Huron: The concentration of nitrate + nitrite nitrogen in the open-lake surface waters of Lake Huron was 302 $\pm$ 24 ug/L during the spring of 1985. This is a lower concentration, but is virtually unchanged from 1983 and 1984. Epilimnetic depletion of nitrate + nitrite nitrogen from observed spring survey concentrations resulted in a 12% decrease in the northern basin to 267 ug/L and a 9% decrease in the southern basin to 276 ug/L. Maximum observed enrichment of nitrate + nitrite nitrogen occurred in the nepheloid layer (354 ug/L in the northern basin and 363 ug/L in the southern basin). Hypolimnion concentration increases were noted in both basins during the summer survey.

Lake Erie: In 1985, spring surface open-lake nitrate + nitrite nitrogen concentrations in the western and central basins of Lake Erie were at intermediate values between those found in 1983 and 1984. Western Lake Erie 1985 annual average (3 ship surveys) concentration was 446 ug/L. This compares with 502 ug/L (1984) and 321 ug/L (1983). Central Lake Erie 1985 annual average survey concentration was 178 ug/L. The corresponding concentrations were 219 ug/L in 1984 and 147 ug/L in 1983. Eastern Lake Erie 1985 annual average survey concentration was 256 ug/L. The corresponding annual concentrations were 266 ug/L in 1984 and 219 ug/L in 1983. The spring nitrate + nitrite nitrogen concentrations were comparable in all basins with the helicopter winter surveys, except in the western basin. In the western basin the spring average nitrate + nitrite nitrogen concentration was 699 ug/L, which represents an unusually high concentration for Lake Erie in 1985. Similar high concentration levels were observed in spring 1984 (818 ug/L to 962 ug/L).

Silica

Lake Michigan: Concentrations of dissolved reactive silica[a] in the open waters of Lake Michigan in 1985 were slightly higher than 1984 levels in the southern basin and unchanged in the northern basin. Concentration levels have stayed within a 0.3 mg/L range (0.9 to 1.2 mg/L) in both

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[a] Analytical determinations of dissolved reactive silicon were made in 1985. These values have been converted to dissolved reactive silica (SiO_2) when appropriate for comparison with previously reported data.

basins since the late 1970s. Based on spring surface samples, the 1985 concentrations were found to be 1.21 ± 0.04 mg/L (south) and 1.16 + 0.06 mg/L (north). Maximum average observed dissolved reactive silicon was measured in the Fall-1 survey nepheloid layer inboth basins: 2.49 mg/L in the northern basin and 2.00 mg/L in the southern basin.

Epilimnetic depletion of dissolved reactive silica was 83% from the spring survey (1.20 mg/L in the northern basin and 1.21 mg/L in the southern basin) to the summer survey (0.20 mg/L in the northern basin and 0.21 mg/L in the southern basin). Enrichment of the hypolimnion and nepheloid layers occurred in both basins.

Lake Huron: Spring surface dissolved reactive silica levels measured in the open waters of Lake Huron in 1985 (1.66 ± 0.04 mg/L) were between the 1983 levels (1.64 ± 0.05 mg/L) and 1984 levels (1.68 ± 0.12 mg/L). These mid-1980 levels are higher (alpha = 0.05) than previously found in the early 1970s and suggest an annual rate of increase between 0.01 to 0.02 mg/L/year from the early 1970s.

Epilimnetic depletion of dissolved reactive silica was 52% in the southern basin, with the observed summer survey measured at 0.72 mg/L. In the northern basin the epilimnetic depletion was 45%, with the observed summer survey measured at 0.90 mg/L. The nepheloid and hypolimnion were enriched in both basins with dissolved reactive silica increasing to a maximum in the nepheloid layer in the Fall-1 survey in the northern basin (2.21 mg/L) and in the summer survey in the southern basin (2.27 mg/L).

Lake Erie: Except in the western basin, Lake Erie dissolved reactive silica concentrations in 1985 were found to be lower than levels found in 1984. Western basin spring surface samples showed a large increase averaging 1.30 ± 0.28 mg/L in 1985 as compared to 0.80 ± 0.60 mg/L in 1984 and 0.89 ± 0.59 mg/L in 1983.

Dissolved reactive silica concentrations remained extremely low in the central basin at 0.02 ± 0.01 mg/L in 1985, returning to levels observed in 1983. The eastern basin average silica concentration of 0.14 ± 0.02 mg/L in 1985 was lower than 1984 (0.22 ± 0.06 mg/L) but higher than 1983 (0.04 ± 0.01 mg/L).

Western basin dissolved reactive silica concentrations decreased during 1985 and were measured during the summer survey at 0.70 mg/L or 48% lower than spring levels. However, central and eastern basin silica concentrations increased in the epilimnion as the season advanced.

Evidence of hypolimnion and nepheloid layer enrichment was observed in both the central and eastern basins. The maximum observed dissolved reactive silica concentration (3.31 mg/L) occurred in the central basin hypolimnion during summer anoxia and in the eastern basin nepheloid layer (0.73 mg/L).

MAJOR ION CONCENTRATIONS

Anions -- Chloride, Sulfate, and Carbonate

Lake Michigan: Chloride concentrations in 1985 were observed to be lower in the surface waters of southern Lake Michigan at 8.72 ± 0.23 mg/L from 8.90 ± 0.28 mg/L in 1984. In the surface waters of northern Lake Michigan, chloride remained virtually unchanged at 8.83 ± 0.41 mg/L in 1985 from 8.84 ± 0.22 mg/L in 1984. Corresponding values in 1983 were 8.78 ± 0.33 mg/L southern basin and 8.68 ± 0.23 mg/L northern basin.

The 1985 spring concentrations of sulfate in Lake Michigan (22.1 ± 0.08 mg/L southern basin and 22.2 ± 0.3 mg/L northern basin) were higher in the southern basin and virtually unchanged in the northern basin compared to 1983 and 1984. Corresponding mean values in the southern basin were 21.8 mg/L (1984) and 21.4 mg/L (1983) and in the northern basin were 22.2 mg/L (1984) and 21.2 mg/L (1983).

Alkalinity values were virtually the same in the northern basin at 107.7 ± 1.8 mg/L $CaCO_3$ and in the southern basin at 108.4 ± 1.5 mg/L $CaCO_3$. Corresponding values were 108.7 mg/L (1984) and 108.1 mg/L (1983) in the northern basin and 107.7 mg/L (1984) and 109.0 mg/L (1983) in the southern basin.

Lake Huron: Chloride values continue to be low in Lake Huron. The mean northern basin concentration (5.39 ± 0.11 mg/L) and the mean southern basin concentration (5.35 ± 0.14 mg/L) are the lowest mean spring values measured during the annual program since 1983. Corresponding northern basin values were 5.49 ± 0.14 mg/L in 1984 and 5.54 ± 0.25 mg/L in 1983, and southern basin values were 5.87 ± 0.34 mg/L in 1984 and 5.79 ± 0.36 mg/L in 1983.

As with chloride, both sulfate and alkalinity concentrations were low in Lake Huron. Spring 1985 sulfate concentrations were 15.89 ± 0.41 mg/L and 15.69 ± 0.48 mg/L in the northern and southern basins, respectively. These are statistically unchanged from the 1984 values of 15.97 ± 0.42 mg/L and 16.94 ± 2.07 mg/L in the northern and southern basins, respectively.

Alkalinity values in 1985 averaged 76.50 ± 1.05 mg/L and 77.56 ± 1.11 mg/L in the northern and southern basins. These can be compared with 1984 results of 77.45 ± 1.71 mg/L and 77.21 ± 1.29 mg/L, respectively. These values remain virtually unchanged from 1983.

Lake Erie: Chloride levels in Lake Erie continue to be the highest of the three sampled lakes. On an annual basis, volume weighted average (VWA) concentrations were the lowest and most variable in the western basin over the last three years 11.74 ± 1.95 mg/L (1983), 12.62± 3.39 mg/L (1984), and 11.10 ± 1.75 mg/L (1985) due to the inflow of Lake Huron water, which has low chloride concentrations. Concentration levels tend to increase from west to east during 1983 through 1985. In 1985, chloride VWA concentrations were not significantly different between the central (14.65 ± 0.02 mg/L) and eastern (14.82 ± 0.18 mg/L) basins. Historical data show a steady decline in chloride concentrations since 1966 (~24.0 mg/L) in the central basin. The 1985 central basin VWA annual average is lower than the 1984 VWA average (14.80 ± 0.12 mg/L).

Sulfate VWA concentrations are virtually unchanged from concentrations reported in 1984. The 1985 concentration values of 19.14 ± 0.81 mg/L, 23.00 ± 0.31 mg/L and 23.17 ± 0.06 mg/L in the western, central, and eastern basins can be compared with 20.35 ± 1.71 mg/L, 23.18 ± 0.13 mg/L and 23.71 mg/L measured in 1984. Sulfate concentrations have not declined from average levels reported throughout the seventies (22.6 ± 0.4 mg/L).

Measurements of 1985 VWA alkalinity concentrations of 84.11 ± 1.65 mg/L, 92.65 ± 0.56 mg/L and 93.30 ± 0.89 mg/L in the western, central, and eastern basins are not significantly lower than 1984 measurements (86.29 ± 2.05 mg/L, 93.69 ± 0.77 mg/L and 96.45 ± 0.68 mg/L).

Cations -- Calcium, Magnesium, Sodium, and Potassium

Lake Michigan: Cation concentrations were determined during the summer survey in 1985. The epilimnion concentration of calcium, the major cation present, was 35.2 ± 0.2 mg/L and 36.0 ± 0.2 mg/L in the northern and southern basins, respectively. Comparable mean values measured in 1984 were 35.2 mg/L in both basins.

Of the other cations measured, magnesium measured 11.2 ± 0.1 mg/L and 11.0 ± 0.00 mg/L in the northern and southern basins, respectively (11.0 mg/L in both basins in 1984 and 11.7 mg/L north, 12.0 mg/L south in 1983). Sodium averaged 5.5 ± 0.03 mg/L and 5.4 ± 0.02 mg/L in the northern and southern basins, respectively (4.8 mg/L north and 4.7 mg/L south in 1984 and 5.0 mg/L north and 5.2 mg/L south in 1983). Potassium averaged 1.21 ± 0.004 mg/L and 1.23 ± 0.003 mg/L in the northern and southern basins, respectively (1.30 mg/L north, 1.29 mg/L south in 1984 and 1.20 mg/L north, 1.23 mg/L south in 1983).

The cation concentrations are little changed from previous years except for sodium concentrations which were higher in both basins. The large year-to-year variation in sodium concentrations in the northern and southern basins was not expected and may be due to analytical problems. Only calcium appeared to be enriched within the nepheloid layer (35.9 mg/L north and 36.4 mg/L south).

<u>Lake Huron</u>: Lake Huron's cation concentrations are lower than Lake Michigan's. Calcium concentrations were 26.2 ± 0.3 mg/L and 27.8 ± 0.2 mg/L in the northern and southern basins, respectively (26.1 mg/L north and 27.5 mg/L south in 1984 and 28.0 mg/L north and 29.3 south in 1983). The epilimnion concentrations of the other cations were: magnesium in 1985 was 7.3 ± 0.03 mg/L north and 7.4 ± 0.04 mg/L south (7.0 mg/L north, 7.4 mg/L south in 1984), (7.3 mg/L north, 7.7 mg/L south in 1983); sodium in 1985 was 3.4 ± 0.02 mg/L north and 3.6 ± 0.02 mg/L south (3.0 mg/L north, 3.3 mg/L south in 1984), (3.2 mg/L north and 3.4 mg/L south in 1983); and potassium in 1985 was 0.87 ± 0.01 mg/L north and 0.90 ± 0.01 mg/L south (0.93 mg/L north, 0.97 mg/L south in 1984) (0.88 mg/L, 0.93 mg/L south in 1983).

Cation concentrations in 1985 were intermediate between 1983 and 1984 observations except for sodium concentrations which were higher in both basins in 1985. All cation concentrations appeared to be elevated within the nepheloid layer in the northern basin while in the southern basin there was no apparent enrichment.

<u>Lake Erie</u>: Calcium is the major cation in Lake Erie, as in the other lakes, with concentrations in the western, central and eastern basins measured in the epilimnion in summer at 29.9 ± 0.4 mg/L 35.0 ± 0.1 mg/L, and 35.5 ± 0.2 mg/L, respectively. These values were 31.2 mg/L, 34.4 mg/L, and 35.8 mg/L in 1984 and 34.9 mg/L, 38 mg/L, and 34.9 mg/L in 1983.

No consistent patterns were observed in magnesium with 1985 concentrations at 8.1 ± 0.7 mg/L, 8.4 ± 0.2 mg/L, and 8.3 ± 0.1 mg/L. These values in 1984 were at 8.0 mg/L, 8.2 mg/L, and 8.2 mg/L and were at 8.3 mg/L, 8.3 mg/L and 7.4 mg/L in 1983.

Sodium concentrations in 1985 were 6.0 ± 0.2 mg/L, 8.6 ± 0.1 mg/L, and 8.9 ± 0.1 mg/L. These values in 1984 were 5.9 mg/L, 7.6 mg/L, and 7.8 mg/L and in 1983 were 6.4 mg/L 8.0 mg/L, and 7.4 mg/L.

Potassium concentrations in 1985 were 1.18 ± 0.03 mg/L, 1.33 ± 0.004 mg/L, and 1.35 ± 0.008 mg/L. These values in 1984 were 1.24 mg/L, 1.42 mg/L, and 1.49 mg/L and in 1983 were 1.20 mg/L, 1.26 mg/L, and 1.35 mg/L.

Most cation concentrations in 1985 were at intermediate levels when compared to 1983 and 1984 except for sodium which was higher in 1985 in the central and eastern basin when compared to the two previous years.

OTHER PARAMETERS

Specific Conductance

Combined changes in the concentrations of major ions are reflected in changes in the measured specific conductance, or conductivity. In accordance with the small changes in the concentration of major ions, conductivity measurements in 1985 were virtually unchanged from 1983 and 1984 levels in most basins. Spring mean epilimnetic conductivities were 279.8 ± 0.8 uS/cm and 279.3 ± 0.9 uS/cm in the southern and northern basins of Lake Michigan, respectively (1984 mean levels were 280.0 uS/cm and 277.1 uS/cm and 1983 mean levels were 279.1 uS/cm and 278.2 uS/cm); 202.7 ± 1.2 uS/cm in the southern and northern basins of Lake Huron combined (1984 mean levels were 203.1 uS/cm and 1983 mean levels were 204.2 uS/cm); and 254.5 ± 10.5 uS/cm, 276.2 ± 2.9 uS/cm, and 276.4 ± 1.84 uS/cm in the western, central, and eastern basins of Lake Erie, respectively (1984 values were 273.0 uS/cm, 276.0 uS/cm, and 281.7 uS/cm; 1983 values were 259 uS/cm, 278.1 uS/cm, and 289.1 uS/cm).

Dissolved Oxygen

Historically, anoxia has been a problem both in the western and central basins of Lake Erie. In the western basin, anoxia events are episodic, while in the central basin anoxia has occurred regularly. In August 1985, the average dissolved oxygen concentration was a minimum in the central basin hypolimnion layer at 1.3 mg/L. This value is much lower than those measured in 1983 (3.7 mg/L) and 1984 (3.9 mg/L). The hypolimnion thicknesses in 1985 was estimated at 1.6 meters. Previous hypolimnion thickness were 4.3 m (1984) and 5.4 m (1983). The anoxic condition observed in 1985 resulted from the on going oxygen depletion, the thin hypolimnetic layer, and the longer than normal period of stratification.

TROPHIC STATUS

Dobson et al. (1974) established a simple set of criteria for trophic classification of the Great Lakes. These criteria are based on the amount of particulate phosphorus and chlorophyll-a in the surface waters, as well as the Secchi depth. Using the Dobson criteria for the ship-borne surveys, the open waters of Lakes Michigan and Huron may be classified as oligotrophic, and Lake Erie waters are evaluated over the entire range from eutrophic-mesotrophic-oligotrophic depending on the parameter involved.

The most frequent classification for the western basin is eutrophic and the most frequent classification for the central basin and eastern basins is oligotrophic. When other classifications are used (International Joint Commission, 1976a; Rast and Lee, 1978), the most frequent classification for Lake Erie's central basin would be either mesotrophic or oligotrophic. The classifications based on phosphorus, chlorophyll-a, and Secchi depth are different for some basins than a classification scheme based on aerobic heterotrophs (Rockwell et al., 1980). Using aerobic heterotrophs, the southern basin of Lake Michigan and the eastern and central basins of Lake Erie would be classified mesotrophic. The aerobic heterotroph evaluations are not changed from previous years for most basins. Using this system, the classification of the central basin of Lake Erie has changed from eutrophic to oligotrophic in 1983 to mestrophic to oligotrophic in 1985, suggesting overall that the central basin appears to be improving.

RESPONSE TO LOADS -- MODEL COMPARISONS

Surveillance data were compared to the predictions of two types of mathematical models, one a simple, multi-segment, mass-balance model for total phosphorus (Chapra, 1977), and the other a dynamic eutrophication model relating several water-quality variables to phosphorus loading (DiToro and Connolly, 1980; DiToro and Matystik, 1980; Rodgers and Salisbury, 1981a). The mass balance model, GLMB, was used to hindcast annual averages of total phosphorus concentrations from 1974 to 1985. The GLMB model predicts the decreasing long-term trends observed in the surveillance data very well. The simple GLMB model readily provided the ability to confirm trends observed in the annual total phosphorus surveillance data. The dynamic eutrophication model, WASP, was used to hindcast station averages of ortho and total phosphorus and chlorophyll-a concentrations collected by the GLNPO during 1983, 1984 and 1985. The ability of the WASP model to predict the temporal trends and the concentration magnitudes of the surveillance data varied between the segments and parameters. The complex WASP model allowed examinations of the effect on related parameters resulting form varying the settling velocity of particulate in Lake Michigan and the phosphorus loadings in Lake Huron.

INTRODUCTION

SCOPE

Continuing the open lake surveillance begun in 1983 to establish a long-term, annual water quality data base for the Great Lakes, the Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency (USEPA) conducted an optimized program of water quality monitoring in the relatively homogeneous offshore water of Lakes Michigan, Huron, and Erie during 1985. This surveillance program is designed to provide information to evaluate the progress of the phosphorus remedial control efforts.

The GLNPO program is an outgrowth of the Great Lakes International Surveillance program (GLISP), (International Joint Commission (IJC), 1975), which is designed to comply with the provisions of the 1978 Canada-United States Water Quality Agreement that calls for periodic monitoring of the Great Lakes to determine the degree to which the objectives of the agreement are being met. More specifically, the 1985 program was intended to collect water quality data for use in nutrient-based lake eutrophication models and to add to the annual water quality database for these lakes. The current GLNPO surveillance program incorporates the major open-lake surveillance features of the 1986 GLISP plans for Lake Huron and Lake Erie. The GLNPO plan is less extensive (fewer stations) than the GLISP plan for Lake Huron and less frequent (fewer surveys) than the GLISP plan for Lake Erie. The GLNPO plan focuses exclusively on the relatively homogenous waters of each lake during the isothermal periods and the stable, stratified summer period. By explicitly excluding nearshore areas from consideration and by limiting the surveys to three distinct periods during the year, the program makes efficient use of the limited resources available.

GENERAL PLAN AND RATIONALE

The 1985 GLNPO monitoring program follows the general GLNPO survey design developed for the 1983 program. The major difference of the 1985 plan is the station pattern alteration to include sites recommended by the Lake Michigan and Lake Erie task forces. The current GLNPO surveillance plan is conceived as an annual program. This change from the 1975 GLISP design is based on the recognition that the annual variability in water-quality observations made in the Great Lakes may far exceed any trend discernable from less frequent measurements.

This effort is focused on chemical eutrophication and the whole lake response to changes in phosphorus loading, therefore, sampling is restricted to lakes considered susceptible to eutrophication (Lake Superior is not affected by eutrophication) and to the offshore waters. (Lake Ontario is excluded since Canada conducts annual monitoring of its water quality.) Resource limitations required a reduction in both the spatial extent and the within-year frequency of sampling (relative to the 1986 GLISP). For the long-term objectives of the GLNPO plan these are not serious restrictions. Over a period of years, each lake will be sampled more frequently under this plan than under the 1975 GLISP.

The GLNPO plan is based on three sampling periods during the year - spring isothermal, summer stratified, and after the fall water column overturn. The later sampling period used a ship in late fall/early winter (November - December) and/or a helicopter in mid-winter (January-February).

Each of the sampling surveys consists of as many runs (legs) from the Lake Michigan western end of the survey track (Chicago, IL) to the Lake Erie eastern end (Dunkirk, NY) as are possible in the three-week period allowed for each survey. Multiple survey legs provide a form of replication ensuring that some of the data collected is not biased by transient events. In 1985 a steering motor defect interrupted and delayed the spring survey for four days. Only two legs were run because spring warming had advanced in Lake Erie's central basin causing partial stratification. As planned, three legs were completed during the summer survey and two legs were completed in the fall.

The GLNPO surveillance program is unique in that all three lakes were sampled by one agency, used one vessel, and used one principal analytical laboratory. Thus, interlake comparisons based on the data collected during the program are not complicated by differences in sampling procedures, collection times, interlaboratory differences, or analytical techniques.

Although the sampling network used in 1983 and 1984 was modified in 1985 in Lakes Michigan and Erie, and the 1983-1985 program is reduced in areal scope from previous intensive surveillance programs based on the original Great Lakes Intensive Survey Plan, the results of 1985 efforts were comparable with the 1983 and 1984 efforts and the earlier intensive programs. The 1985 efforts are shown to be representative of the well-mixed, open-lake areas that the program was designed to sample.

Surveys

Each survey period has a specific purpose within the context of the objectives of the program. The first ship survey is conducted as early as possible after ice out conditions in the Straits of Mackinac while the water column is still isothermal and both vertically and horizontally well-mixed. This provides data to establish estimates of the initial concentrations of substances of interest. The second ship survey is conducted during the summer period of lake stratification to determine epilimnetic nutrient depletion and hypolimnetic enrichment of nutrients.

The third ship survey, conducted in the fall, is intended to survey isothermal conditions after fall overturn. This goal was accomplished in the shallower basins of Lakes Michigan and Huron and in Lake Erie. The helicopter-borne surveys are conducted to provide data during the mid-winter when ship-borne sampling is restricted by weather and ice conditions. The mid-winter data provide estimates of water quality after "fall overturn" mixing is complete. Nutrient concentrations are expected to be highest during winter before nutrients are utilized by diatoms during the spring (Schelske, 1975). The helicopter surveys are conducted when the annual ice cover is expected to be of the greatest extent. If the annual ice cover inhibits sediment resuspension due to winter storm mixing, the water column may be least affected by biological activity due to low temperatures and outside influences from tributary loadings.

Parameters

The water quality parameters measured as part of the 1985 surveillance program are listed in Table 1. These parameters were selected because of their relevance to chemical eutrophication and because of their importance as indicators of water quality. Several of the parameters (chlorophyll-a, dissolved ortho-phosphorus, dissolved reactive silicon, total nitrate + nitrite nitrogen, total ammonia nitrogen) are used directly as state variables in the nutrient based eutrophication models (DiToro and Matystik, 1980; DiToro and Connolly, 1980; Rodgers and Salisbury, 1981a) that have been developed for the Great Lakes.

Other parameters (total Kjeldahl nitrogen, total phosphorus, and total dissolved phosphorus) are used indirectly along with temperature and turbidity as calibration and verification variables in the models. Among the other parameters measured in this program, the conservative ions, chloride and sulfate, have been noted to be increasing in concentration in Lake Michigan (Rockwell et al., 1980) and in Lake Huron (Dolan et al., 1983; Moll et al., 1985). Sodium concentrations in Lake Michigan have also been increasing and may represent an emerging environmental problem. These conservative parameters are also useful for identification of homogeneous water masses. In addition to the parameters mentioned above, dissolved oxygen was measured near the bottom in Lakes Huron and Michigan and at all depths in Lake Erie. The bacteriological parameter "total plate count" was also determined in each lake as a measure of aerobic heterotroph levels.

Stations

Focusing on the relatively homogeneous open lake water mass is a key feature of this surveillance plan. Under the 1975 GLISP plan, for example, 92 stations were sampled in Lake Michigan, 67 in Lake Huron, and 82 in Lake Erie during each survey. The 1985 plan included 11 sites in Lake Michigan, 10 of 20 stations per leg in Lake Huron, and 17 stations in Lake Erie.

Table 1. Parameters measured during the 1985 surveillance program.

Parameter	STORET Code[a]	STORET Units	Surveys[b]	Depths
Air temperature	00020	degrees C	1-3	--
Wind speed	82127	knots	1-3	--
Wind direction	00040	azimuth	1-3	--
Barometric pressure	00025	mm of Hg	1-3	--
Secchi depth	00078	meters	1-3	--
Wave height	70222	WMO code	1-3	--
Wave direction	70220	WMO code	1-3	--
Water temperature	00010	degrees C	H,1-3	All
Turbidity	00076	Hach FTU	H,1-3	All
Specific conductance	00095	uS/cm	H,1-3	All
Field pH	00400	SU	H,1-3	All
Laboratory pH	00403	SU	H	All
Total alkalinity ($CaCO_3$)	00410	mg/L	H,1-3	All
Dissolved oxygen	00300	mg/L	H,1-3	Bottom[c]
Aerobic heterotrophs	31749	# per mL	1-3	All
Chlorophyll-a	32209	ug/L	H,1-3	All
Pheophytin-a	32213	ug/L	H,1-3	All
Dissolved reactive silicon	01140	ug-Si/L	H,1-3	All
Total Kjeldahl nitrogen	00625	mg-N/L	H,1-3	All
Total NO_2 + NO_3	00630	mg-N/L	H,1-3	All
Total NH_3 + NH_4	00610	mg-N/L	H,1-3	All
Total phosphorus	00665	mg-P/L	H,1-3	All
Total dissolved phosphorus	00666	mg-P/L	H,1-3	All
Dissolved ortho phosphorus[d]	00671	mg-P/L	H,1-3	All
Chloride	00940	mg/L	H,1-3	All
Sulfate	00945	mg-SO_4/L	H,1-3	All
Calcium	00916	mg/L	2	Surface, B2/B1
Potassium	00937	mg/L	2	Surface, B2/B1
Sodium	00929	mg/L	2	Surface, B2/B1
Magnesium	00927	mg/L	2	Surface, B2/B1

[a] Numerical code used for data retrieval from STORET.
[b] H = Helicopter mid-winter survey; 1 = early spring survey; 2 = summer survey; and 3 = fall survey.
[c] Dissolved oxygen was measured at all depths in Lake Erie.
[d] Often referred to as dissolved (or soluble) reactive phosphorus.

Each of the stations selected for sampling are GLISP stations deemed to be representative of the open lake (explicitly excluding nearshore areas). Because it is anticipated that many of the results of this survey will be expressed in terms of averages of the parameter values, it is important that the individual samples making up the averages come from homogeneous areas of the lakes. Therefore, the sampling stations were selected within areas identified as homogeneous by analysis of the earlier GLISP surveys (Kwiatkowski, 1980; Lesht, 1984b; Moll et al., 1985; El-Shaarawi, 1984a). The locations of the stations are mapped in Figures 1-3, and the exact locations and approximate station depths are listed in Table 2. Master stations are those located at the deepest sounding at which additional samples were taken in the upper fifty meters. Each station was sampled during each survey leg, except in Lake Huron. In Lake Huron half of the stations were sampled on each leg because of the large number and great spacing of the stations. This was accomplished by surveying the eastern or western sides of the northern and central basin and in a zig-zag fashion in the southern basin. The helicopter and ship sampling times (Julian day and Greenwich time) for the 1985 surveys are shown in Tables 3 through 6.

Sample Depths

Water samples were collected throughout the water column at each station. The criteria for choosing sampling depths were based on the thermal structure of the water column. During isothermal conditions, samples were taken in Lakes Michigan and Huron at the surface (one meter depth), mid-depth, ten meters above the bottom, and two meters above the bottom, while in Lake Erie the western and central basins were sampled at the surface (one meter) mid-depth, and one meter above the bottom. The western basins was sampled at surface (one meter depth), mid-depth, ten meters above the bottom, and one meter above the bottom. At sites where the water column was sufficiently deep, one-hundred meter and two-hundred meter samples were taken during all surveys.

When the water column was thermally stratified in Lake Michigan and Huron, samples were taken at the surface (one meter depth), within the lower epilimnion, one meter above the knee of the thermocline, at the thermocline in the upper hypolimnion, one meter below the knee of the thermocline, ten meters above the bottom, and two meters above the bottom. In Lake Erie, the sampling regime added a mid-thermocline sample and moved the bottom sample to one meter above the bottom as required by the Lake Erie GLISP.

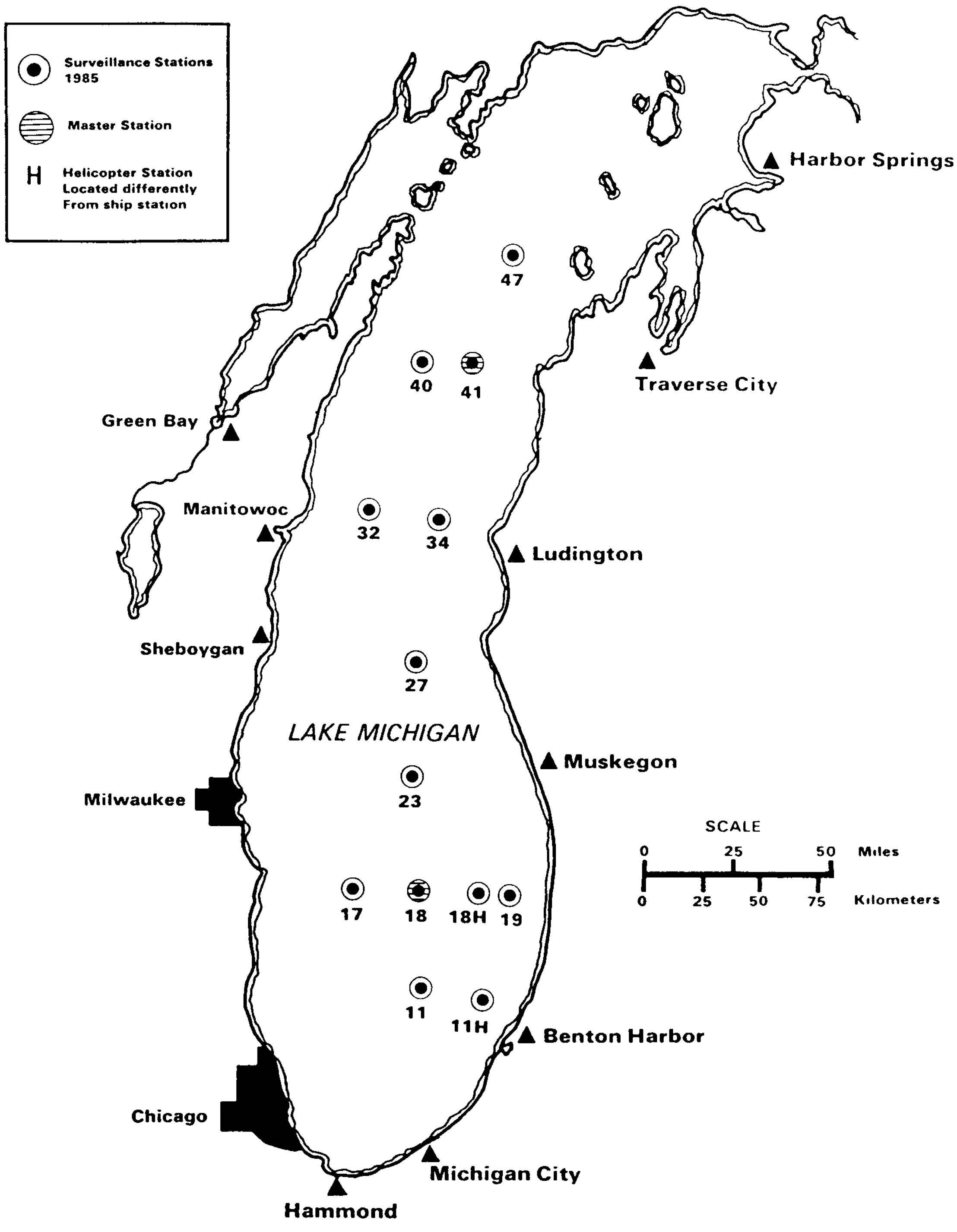

Figure 1. Location of 1985 surveillance stations in Lake Michigan.

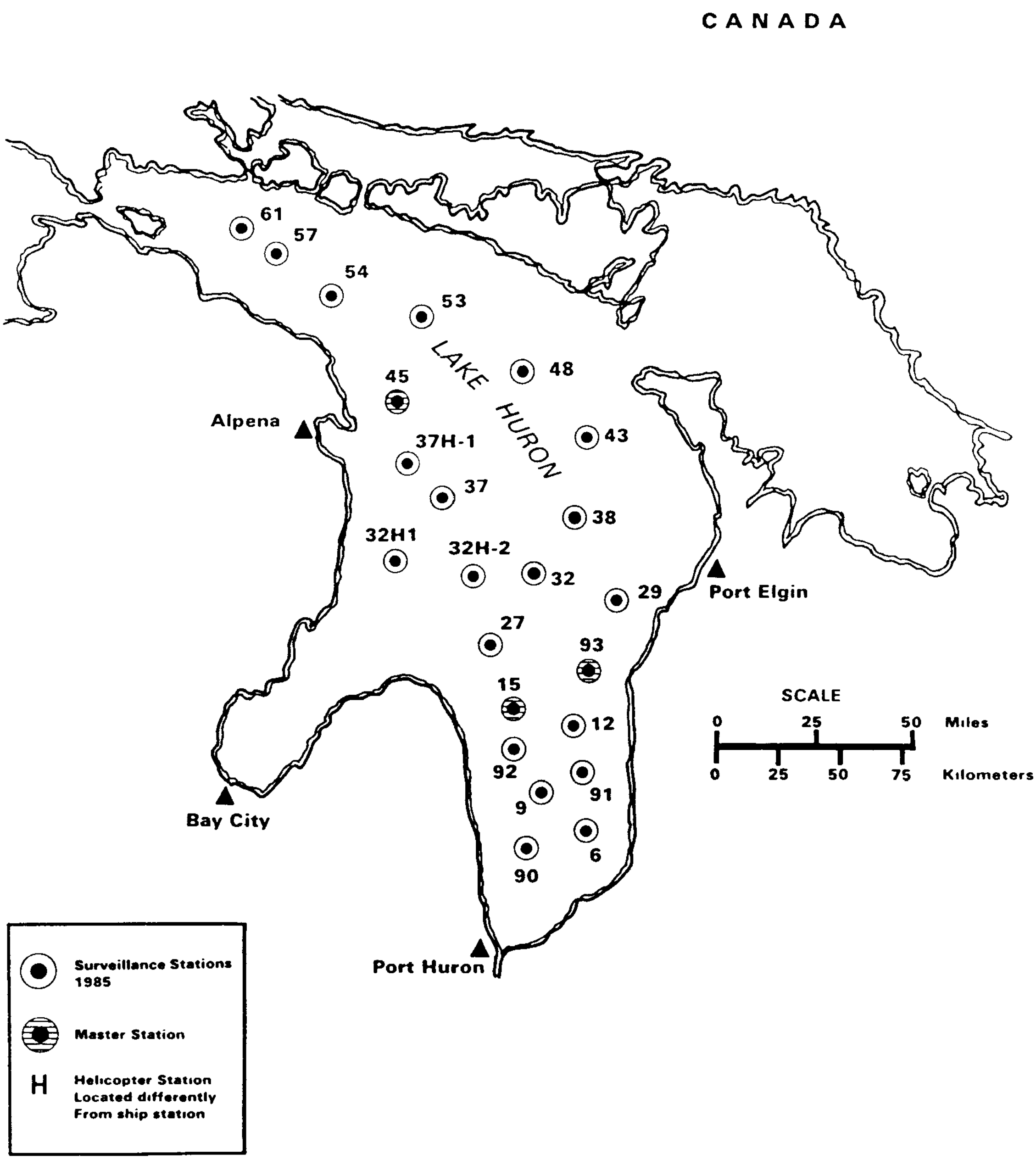

Figure 2. Location of 1985 surveillance stations in Lake Huron.

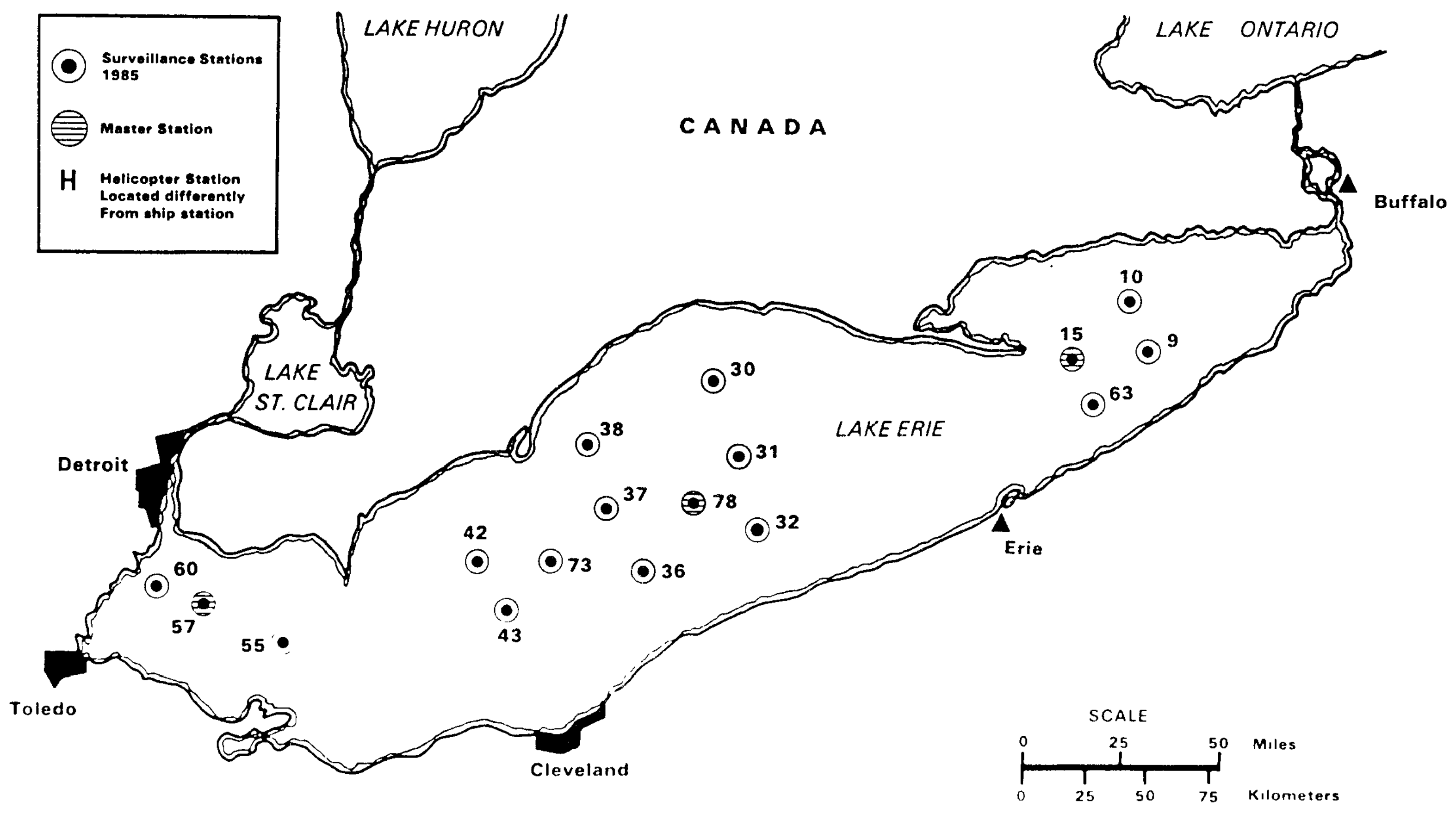

Figure 3. Locations of 1985 surveillance stations in Lake Erie.

Table 2. Station locations and depths--1985 surveillance program.

STORET Station Designation[a]	Latitude (north)	Longitude (west)	Approximate Depth (meters)
L. MICH 11	42 23 00.0	87 00 00.0	136
L. MICH 11H8502	42 23 06.0	86 38 18.0	66
L. MICH 17	42 44 00.0	87 25 00.0	107
L. MICH 18	42 44 00.0	87 00 00.0	168
L. MICH 18H8502	42 43 48.0	86 36 18.0	97
L. MICH 19	42 44 00.0	86 35 00.0	86
L. MICH 23	43 08 00.0	87 00 00.0	100
L. MICH 23H8502	43 08 12.0	87 00 24.0	89
L. MICH 27	43 36 00.0	86 55 00.0	116
L. MICH 27H8502	43 36 00.0	86 55 00.0	94
L. MICH 32	44 08 24.0	87 14 00.0	159
L. MICH 34	44 05 24.0	86 46 00.0	160
L. MICH 34H8502	44 05 00.0	86 46 00.0	160
L. MICH 40	44 45 36.0	86 58 00.0	160
L. MICH 41	44 44 12.0	86 43 18.0	251
L. MICH 41H8502	44 44 36.0	86 43 48.0	260
L. MICH 47	45 10 42.0	86 22 30.0	186
L. MICH 47H8502	45 10 46.0	86 22 20.0	190
L. HURON 06	43 28 00.0	82 00 00.0	46
L. HURON 09	43 42 00.0	02 01 00.0	59
L. HURON 09H8501	43 38 00.0	82 13 00.0	60
L. HURON 09H8502	43 37 42.0	82 12 48.0	60
L. HURON 12	43 53 24.0	82 03 24.0	86
L. HURON 15	44 00 00.0	82 21 00.0	66
L. HURON 15H8501	44 00 00.0	82 37 07.0	68
L. HURON 15H8502	44 00 06.0	82 20 55.0	68
L. HURON 27	44 11 54.0	82 30 12.0	50
L. HURON 29	44 22 00.0	81 50 00.0	137
L. HURON 32	44 27 12.0	82 20 30.0	73
L. HURON 32H8501	44 38 24.0	83 07 00.0	51
L. HURON 32H8502	44 27 02.0	82 38 50.0	51
L. HURON 37	44 45 42.0	82 47 00.0	73
L. HURON 37H8501	44 53 25.0	83 05 41.0	70
L. HURON 37H8502	44 45 43.0	82 46 59.0	70
L. HURON 38	44 44 24.0	82 03 36.0	137
L. HURON 43	45 00 48.0	82 00 30.0	219
L. HURON 45	45 08 12.0	82 59 00.0	101
L. HURON 45H8501	45 09 00.0	83 03 24.0	113
L. HURON 45H8502	45 08 14.0	82 58 59.0	113
L. HURON 48	45 16 42.0	82 27 06.0	115
L. HURON 53	45 27 00.0	82 54 54.0	90
L. HURON 54	45 31 00.0	82 25 00.0	91
L. HURON 54H8502	45 31 02.0	83 24 48.0	15
L. HURON 57	45 40 00.0	83 43 36.0	132
L. HURON 57H8502	45 39 56.0	83 44 20.0	75

Table 2. (Continued) Station locations and depths--1985 surveillance program.

STORET Station Designation[a]	Latitude (north)	Longitude (west)	Approximate Depth (meters)
L. HURON 61	45 45 00.0	83 55 00.0	120
L. HURON 61H8502	45 45 02.0	83 54 59.0	88
L. HURON 90	43 24 00.0	82 18 00.0	42
L. HURON 90H8501	43 24 00.0	82 18 00.0	37
L. HURON 90H8502	43 22 00.0	82 18 24.0	37
L. HURON 91	43 42 00.0	82 01 00.0	75
L. HURON 92	43 48 00.0	82 22 00.0	62
L. HURON 93	44 06 00.0	82 07 00.0	91
L. ERIE 09	42 32 18.0	79 37 00.0	50
L. ERIE 09H8501	42 32 11.0	79 37 00.0	42
L. ERIE 09H8502	42 32 19.0	79 37 13.0	42
L. ERIE 10	42 40 48.0	79 41 30.0	32
L. ERIE 15	42 31 00.0	79 53 36.0	64
L. ERIE 15H8501	42 31 00.0	79 53 22.0	42
L. ERIE 15H8502	42 31 04.0	79 54 14.0	42
L. ERIE 18H8501	42 25 11.0	80 04 29.0	31
L. ERIE 18H8502	42 25 01.0	80 04 43.0	31
L. ERIE 30	42 25 48.0	81 12 18.0	20
L. ERIE 31	42 15 12.0	81 06 24.0	21
L. ERIE 32	42 04 54.0	81 00 42.0	22
L. ERIE 36	41 56 06.0	81 28 42.0	22
L. ERIE 37	42 06 36.0	81 28 42.0	24
L. ERIE 38	42 16 54.0	81 40 18.0	20
L. ERIE 42	41 57 54.0	82 03 30.0	22
L. ERIE 43	41 47 18.0	81 56 42.0	22
L. ERIE 55	41 44 18.0	82 44 00.0	9
L. ERIE 55H8501	41 44 18.0	82 44 00.0	9
L. ERIE 55H8502	41 44 02.0	82 44 03.0	9
L. ERIE 57	41 49 54.0	83 01 06.0	9
L. ERIE 57H8501	41 49 54.0	83 01 06.0	9
L. ERIE 57H8502	41 49 47.0	83 01 10.0	9
L. ERIE 60	41 53 30.0	83 11 48.0	7
L. ERIE 60H8501	41 53 30.0	83 11 48.0	7
L. ERIE 60H8502	41 53 27.0	83 11 55.0	9
L. ERIE 63	42 25 00.0	79 48 00.0	42
L. ERIE 73	41 58 40.0	81 45 25.0	24
L. ERIE 73H8501	41 58 40.0	81 45 15.0	24
L. ERIE 73H8502	41 58 04.0	81 45 33.0	24
L. ERIE 78	42 07 00.0	81 15 00.0	24
L. ERIE 78H8501	42 07 00.1	81 15 00.0	24
L. ERIE 78H8502	42 07 01.1	81 15 05.0	24
L. ERIE 79H8501	42 15 00.0	80 48 00.0	20
L. ERIE 79H8502	42 14 48.0	80 48 04.0	20

[a]Stations designated H8501 were sampled by helicopter in January 1985. Stations designated H8502 were sampled by helicopter in February 1985.

Table 3. Julian day and Greenwich time of sampling in Lakes Erie, Huron, and Michigan as part of the 1985 helicopter survey related to the 1985 surveillance program.[a]

Stations	Survey 8501 Julian Day Time	Survey 8502 Julian Day Time
L. ERIE 09H	013 - 16:29	049 - 14:54
L. ERIE 15H	013 - 17:06	049 - 14:26
L. ERIE 78H	013 - 20:55	048 - 17:48
L. ERIE 73H	013 - 21:32	048 - 17:12
L. ERIE 55H	014 - 14:55	048 - 14:52
L. ERIE 60H	014 - 15:39	048 - 14:19
L. ERIE 57H	015 - 14:40	048 - 13:51
L. HURON 90H	015 - 17:44	041 - 18:02
L. HURON 09H	015 - 18:14	041 - 17:38
L. HURON 15H	015 - 19:05	041 - 17:02
L. HURON 34H	015 - 21:22	041 - 14:28
L. HURON 37H	015 - 15:06	041 - 13:55
L. HURON 45H	016 - 15:35	040 - 21:10
L. HURON 54H		040 - 20:36
L. HURON 57H		040 - 20:05
L. HURON 61H		040 - 19:42
L. MICH 11H		038 - 21:10
L. MICH 18H		038 - 21:54
L. MICH 23H		039 - 20:32
L. MICH 27H		039 - 21:10
L. MICH 34H		039 - 21:52
L. MICH 41H		040 - 15:00
L. MICH 47H		040 - 15:44

[a]L. ERIE 18H L. ERIE 79H, L. MICH 06H and L. MICH 57H were also sampled (see Lesht and Rockwell, 1987).

Discrete samples were collected for phytoplankton analysis at one, five, ten, and twenty meters, and composited to represent the upper twenty meters at each station. For the shallow western basin of Lake Erie, the sample at one meter above the bottom replaced the ten meter depth, and the twenty meter depth was not taken. For the central basin of Lake Erie, the sample at one meter above the bottom replaced the twenty meter depth. The composited sample represented four equal aliquots from available samples within the upper 20 meter layer (or three samples if less than 20 meters deep).

Table 4. Julian day and Greenwich time of sampling in Lake Michigan during the 1985 surveillance program.[a]

Station	Spring Leg 1	Spring Leg 2	Summer Leg 1	Summer Leg 2	Summer Leg 3	Fall Leg 1	Fall Leg 2
Southern Basin							
L. Michigan 11	106 13:50	122 10:55	232 18:18	233 19:40	244 13:30	318 16:00	338 07:00
L. Michigan 17	106 10:00	122 16:11	232 14:45	233 23:20	244 20:30	318 11:45	338 19:00
L. Michigan 18*	110 22:44	122 13:46	232 11:15	233 01:50	244 16:40	318 20:00	338 10:15
L. Michigan 19	111 01:39	122 07:33	232 08:30	234 04:23	244 09:00	318 23:27	338 01:30
L. Michigan 23	111 05:30	121 03:52	232 04:20	234 08:24	244 04:30	319 04:05	338 02:19
L. Michigan 27	111 09:10	122 00:30	230 20:56	234 12:29	243 23:59	319 08:30	337 22:40
Northern Basin							
L. Michigan 32	111 15:49	121 18:02	230 02:00	234 19:33	243 16:45	319 16:00	337 19:22
L. Michigan 34	111 13:00	121 20:59	230 16:25	234 16:40	243 19:35	319 13:00	334 21:23
L. Michigan 40	111 20:44	121 13:35	229 20:30	235 00:05	243 11:30	319 21:25	334 10:52
L. Michigan 41*	111 22:45	121 11:31	229 18:00	235 02:00	243 09:00	319 23:30	334 13:40
L. Michigan 47	112 03:13	121 07:44	229 13:30	235 05:54	243 04:45	320 04:20	333 02:30

[a]Stations are ordered along the survey track and grouped into basins.
*Asterisks denote master stations.

One station within each lake basin was identified as a master station. These stations were generally located at the deepest sounding within the basin. Additional samples were taken at the master stations through the first 50 meters at 5, 10, 20, 30, 40 and 50 meters to provide better vertical resolution of the sampled parameters. The master stations are identified by an asterisk in Tables 4 through 6.

Table 5. Julian day and Greenwich time of sampling in Lake Huron during the 1985 surveillance program.[a]

Station	Spring Leg 1	Spring Leg 2	Summer Leg 1	Summer Leg 2	Summer Leg 3	Fall Leg 1	Fall Leg2
Northern Basin							
L. Huron 61		120 16:30		235 20:30			332 05:01
L. Huron 57	112 18:11		228 21:50		242 05:15	322 01:00	
L. Huron 54		120 14:10		235 23:50			332 01:54
L. Huron 53	112 22:57		228 17:14		242 00:45	322 11:00	
L. Huron 48	113 01:55		228 14:00		241 21:45	322 14:15	
L. Huron 45*		120 01:03		236 03:45			331 22:06
L. Huron 43*	113 05:30		228 10:07		241 14:00	322 17:20	
L. Huron 38	113 08:50		228 05:50		241 15:10	322 20:26	
L. Huron 37		120 00:34		236 20:30			331 18:55
L. Huron 32		119 21:19		237 00:20			331 14:45
L. Huron 29	113 12:15		228 02:30		241 12:20	323 00:04	
Southern Basin							
L. Huron 27		119 19:10		237 02:50			331 11:40
L. Huron 93*	113 15:00		227 23:30		241 09:00	323 03:30	
L. Huron 15*		119 17:15		237 05:00			331 09:07
L. Huron 92	113 18:02		227 20:40		241 06:10	323 07:10	
L. Huron 12		119 15:11		237 07:30			331 05:50
L. Huron 91	113 20:19		227 18:20		241 03:00	323 09:30	
L. Huron 09		119 12:57		237 10:05			331 03:15
L. Huron 90	113 23:14		227 15:15		241 01:15	323 12:40	
L. Huron 06		119 11:16		237 12:10			331 01:17

[a]Stations are ordered along the cruise track and grouped into basins.
*Asterisks denote master stations.

Table 6. Julian day and Greenwich time of sampling in Lake Erie during the 1985 surveillance program.[a]

Station	Spring Leg 1	Spring Leg 2	Summer Leg 1	Summer Leg 2	Summer Leg 3	Fall Leg 1	Fall Leg 2
L. Erie 60	114	118	218	226	238	325	329
	20:50	16:29	05:40	10:10	07:00	03:20	05:35
L. Erie 57*	114	118	218	226	238	325	329
	22:28	15:08	07:55	08:50	08:30	04:40	04:27
L. Erie 55	115	118	218	226	238	325	329
	00:17	13:30	09:45	06:55	10:30	11:05	02:37
Central Basin							
L. Erie 42	115	118	218	226	238	325	329
	06:33	07:20	16:35	00:25	16:00	13:30	20:21
L. Erie 43	115	118	218	226	238	325	328
	04:50	08:45	14:45	02:10	15:08	11:45	21:54
L. Erie 73	115	118	218	225	238	325	328
	08:15	05:35	18:40	22:40	18:40	15:15	18:83
L. Erie 36	115	118	219	225	239	325	328
	09:50	04:05	00:45	20:55	04:40	16:45	16:40
L. Erie 37	115	118	218	225	238	325	329
	11:30	02:41	22:55	19:10	20:15	18:19	14:40
L. Erie 38	115	118	218	225		325	329
	13:33	01:18	21:03	17:35		20:05	12:20
L. Erie 78*	115	117	219	225	239	326	328
	16:00	22:49	02:45	14:45	02:35	01:50	05:30
L. Erie 32			219	225	239	326	328
			04:25	13:10	00:50	03:30	03:44
L. Erie 31	115	117	219	225	238	326	328
	17:38	21:25	06:30	11:30	23:00	00:31	07:00
L. Erie 30	115	117	219	225		325	328
	19:23	19:55	09:00	10:00		22:52	08:50
Eastern Basin							
L. Erie 15*	116	117	220	225		326	327
	03:54	11:55	04:40	01:05		21:10	19:50
L. Erie 10	116	117	220	224		326	327
	05:50	09:25	07:35	23:10		22:58	17:58
L. Erie 09	116	117	220	224		327	327
	07:25	08:00	09:30	21:25		00:28	15:15
L. Erie 63	116	117	220	225		326	327
	02:16	13:05	03:00	02:45		19:30	21:09

[a]Stations are ordered along the cruise track and grouped into basins.
*Asterisks denote master stations.

Helicopter Survey

A continuing problem in lake surveillance has been the difficulty of obtaining data during the winter. Ice conditions and bad weather generally preclude ship borne sampling. This problem was overcome as part of the 1983 survey by using a helicopter as a sampling platform. The helicopter sampling survey was expanded as part of the 1984 program to include two separate sampling periods, in January and February 1985, as well as sampling from deeper depths than in February 1984. The sampling locations for the helicopter surveys are shown in Table 2. These sampling locations differ from ship survey sites due to ice conditions or safety requirements preventing flight to offshore sites. A reduced parameter set (Table 1) was sampled by collecting water from two depths at each helicopter station and returning the samples to a land-based laboratory after each flight. The day and time of sampling (Greenwich Time) are given in Table 3. These data were also reported in Lesht and Rockwell (1987) for the 1984 station network and have been modified to report results for the 1985 station network.

METHODS

SHIP AND SAMPLING EQUIPMENT

The methods used in this surveillance program corresponded to well-established accepted protocols for water quality sampling (USEPA, 1983). All sampling was conducted from the R/V Roger R. Simons, a former Coast Guard vessel built in 1939 as a lighthouse tender. The ship is 122 ft long, has a beam of 27 ft, a draft of 7 ft at maximum displacement, and displaces 342 tons.

Loran-C and radar ranges and bearings were used to navigate and to establish the ship's position on station. As a precaution against contamination of surface samples no overboard discharge of laundry, shower, or galley waste was allowed 5 minutes before the ship reached a sampling station until after sampling was completed.

A 12-attachment Rosette sampler system (General Oceanics Model 1015-12-8)[a] was used to collect the water samples. This system consists of a steel frame with 11 sampling bottles and an electrobathythermograph (EBT, Guildline Model 8705) mounted at one collector position. The sampling array is controlled using 500 m of multi-conductor cable run through the ship's A-frame to a 5-horsepower variable-speed winch. The Rosette sampling array can accommodate any of the General Oceanics rigid PVC 1010 Niskin sampling bottles up to the 8-L size. The sampling bottles mounted on the Rosette were sequentially closed by remote control from the deck of the ship while the sampling array was submerged.

Because sampling depths were determined in relation to the thermal structure of the water column, the standard procedure was to use the EBT on the Rosette to measure the temperature profile of the water column as the sampling array was lowered to the bottom, and then collect the water samples at the appropriate depths as the Rosette was returned to the surface. The EBT was factory calibrated and checked before each survey by immersion in an ice-water bath.

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[a]Mention by U.S. Environmental Protection Agency of commercial products in this report does not connote recommendation of products to the exclusion of other products that may be suitable.

SAMPLING PROCEDURES

The protocol used for removing the water samples from the collection bottles and distributing them to the various sample-storage bottles was designed to minimize the possibility of contamination. Each Niskin bottle was emptied into the sample bottles as soon as possible after collection. This was normally done within 1 minute and never later than 10 minutes after the Rosette was brought back on deck. All the chemistry sample bottles were rinsed once with the sample before filling. New 1-gallon polyethylene containers were used to hold the sample for the onboard analysis and preparations.

To reduce possible contamination from atmospheric dust, the empty bottles were capped during preparation for sampling. The caps were replaced immediately after collection or after the addition of preservative (when preservation was required). Sample transfers from one bottle to another were avoided when possible. Smoking was not allowed in the laboratory, preparation room, wet laboratory, microbiological laboratory, or on the deck during sampling operations.

ANALYTICAL METHODS

A complete analytical wet laboratory was installed on the vessel and was operated almost continuously during the sampling surveys. The laboratory included eight Technicon Autoanalyzers (System II) configured for analysis of ammonia, nitrate + nitrite, dissolved orthophosphorus, dissolved reactive silicon, chloride, sulfate, total dissolved phosphorus, and total phosphorus. The quality control plan for onboard analysis required that all samples be analyzed for all unacidified and unstable parameters within 2 to 48 hours of collection. If the analytical time limit was violated (which occurred rarely) the sample data were discarded.

To minimize sample-degradation problems, many of the water-quality analyses were conducted onboard the ship immediately after collection of the samples. Samples for those procedures that could not be conducted onboard (e.g., those that required digestion) were preserved immediately after collection. The analytical procedures that were used in this program are summarized below; an indepth coverage of the procedures has been reported by Rockwell (1983).

- Water Temperature--The temperatures recorded using the Electro-bathythermograph were verified using a mercury thermometer readable to 0.1°C. Water temperature was read within 1 minute of sampling and recorded to the nearest 0.1°C.

- Air Temperature--Air temperature was determined with a dial scale bimetallic helix thermometer (Weston 4200) that was allowed to stabilize in the shade in an open area on deck. Air temperature was recorded to the nearest 0.5°C.

- Wind Speed and Direction--Wind speed and direction were measured with a permanently mounted Danforth Marine Wind Direction and Speed Indicator while the ship was stopped for sampling. Wind direction was recorded to the nearest 10 degrees (to the right of true north), and wind speed was measured and recorded to the nearest nautical mile per hour.

- Wave Height--Average wave height (to crest distance) was estimated to the nearest 0.5 ft by the senior crew member on the bridge at each sampling location. Wave heights were recorded to the nearest 0.1 m.

- Turbidity--Turbidity was measured with a Turner Turbidimeter within 2 hours of sample collection. Before its use, the turbidimeter was calibrated with a standard within the anticipated range. The turbidity samples were heated to 25°C to avoid condensation on the sample cuvette. Readings from 0-1 FTU were recorded to the nearest 0.01 FTU, and readings from 1-40 FTU were recorded to the nearest 0.1 FTU.

- Secchi Disc Depth--Secchi disc depths were recorded at all stations sampled during the daytime by use of a 30-cm, all-white disc. Secchi disc depths were recorded to the nearest 0.5 m.

° pH--Analyses for pH were made by electrometric measurement, typically within 15 minutes of sample collection. The pH meter (Orion Model 701) was standardized with two buffers, one of pH 7.0 and the other of pH 9.0. The Orion pH meter was equipped with an automatic temperature compensation probe and was used with a combination glass membrane silver/silver chloride internal electrode. The pH readings were recorded to the nearest 0.01 pH unit.

° Chloride--Chloride analyses were made with a Technicon Autoanalyzer System II using Technicon's industrial method 99-70W (O'Brien, 1962) adjusted to provide a working range of 0-30 mg/L. This method is based on the displacement of mercury in mercuric thiocyanate by chloride to produce un-ionized soluble mercuric chloride. The thiocyanate, released by this displacement reacts with ferric ion to produce ferric thiocyanate, which is then measured photometrically. The raw water samples were stored and refrigerated in the four-liter polyethylene sample containers and were analyzed within 1 week of collection.

° Sulfate--Samples were analyzed for sulfate with a Technicon Autoanalyzer System II using Technicon's industrial method 118-71W (Lazrus et al., 1965). The working range was 0-30 mg/L. In this procedure, the sample is passed through a cation-exchange column to remove interferring cations. The sample is then mixed with an equimolar solution of barium chloride and methyl thymol blue (MTB). The sulfate reacts with the barium, reducing the amount of barium available for reaction with the MTB. The free MTB is then measured photometrically. The raw water samples were stored, refrigerated, in the four liter polyethylene container and analyzed within 1 week of collection.

° Specific Conductance--Specific conductance or conductivity was determined within 2 hours of sample collection. Determinations were made with a Barnstead model PM70CB conductivity bridge and a conductivity cell (YSI 3401 or YSI 3403). An immersion heater connected to an electronic temperature controller was used to heat the sample in a 250-mL polypropylene beaker to 25°C. The temperature was monitored with a mercury thermometer with 0.1°C divisions. The sample was stirred during heating. The apparatus was standardized daily using a 0.15-g/L KC solution (Lind et al., 1959).

- Total Alkalinity--Total alkalinity as $CaCO_3$ was determined within 2 hours of sample collection by titration of a 100-mL aliquot to pH 4.5 with commercial 0.02 N sulfuric acid. The pH controller/meter (Cole Parmer model 5997 with combination electrode) was standardized daily with pH 4 and pH 7 buffers, each prepared from Fisher Scientific concentrates.

- Alkaline Earths and Alkali Metals--Analyses for calcium, magnesium, and sodium were conducted by inductively coupled argon plasma emission spectroscopy. The potassium determinations were done by flame atomic absorption. All the samples were preserved immediately upon collection by addition of 5 mL/L concentrated nitric acid.

- Dissolved Oxygen--Dissolved oxygen determinations were made using the azide modification of the Winkler test (U.S. Environmental Protection Agency, 1979) or with a YSI-5720 self-stirring BOD bottle probe that was calibrated daily against the modified Winkler test. The analysis of dissolved oxygen was performed immediately after sample collection when the YSI probe was used. The dissolved oxygen sample aliquot was obtained by inserting an 8 to 10-inch length of flexible plastic tubing (e.g., Tygon) into the Niskin bottle outlet plug and running directly to the bottom of a 60 mL glass BOD bottle. Flow from the outlet plug was regulated so as to minimize turbulence; two to three bottle volumes were allowed to flow through the bottle before closure and subsequent addition of reagents to fix the dissolved oxygen.

° Dissolved Nutrients--Samples for analysis of dissolved nutrients were prepared by vacuum filtration of an aliquot from the Polyethylene collection containers. The samples were filtered within at most 2 hours of collection (in most cases within 30 minutes). A 47-mm diameter, 0.45-um membrane filter (HAWP 04700) held in a polycarbonate filter holder (Millipore XX 11 04710) was used with a polypropylene filter flask prewashed with 100 to 200-mL of either demineralized or sample water. New 125-mL polyethylene sample bottles with linerless closures, rinsed once with the filtered samples, were used to hold the filtrate for subsequent analysis.

° Dissolved Reactive (ortho) Phosphorus--Filtered samples were analyzed for orthophosphate using a Technicon Autoanalyzer System II and Technicon's industrial method 155-71W (Murphy and Riley, 1962). This is the single-reagent ascorbic acid reduction method in which a phosphate-molybdenum blue complex is measured photometrically at 880 nm. Analyses for dissolved orthophosphate were conducted onboard within 2 to 24 hours of sample collection.

° Total Phosphorus and Total Dissolved Phosphorus--Samples for analysis of total phosphorus and total dissolved phosphorus were transferred to acid washed screw cap digestion tubes as soon as possible after collection. The digestion procedure that converts the various forms of phosphorus to orthophosphate is an adaptation of the acid persulfate digestion method (Gales et al., 1966). After addition of the sample, and digestion solution, the digestion tubes were heated in a forced air oven to 150°C for 30 minutes. The samples were then cooled and analyzed for orthophosphate using the Technicon Autoanalyzer System II. The orthophosphate method used for the digested total phosphorus and total dissolved phosphorus analyses was similar to that described above for analysis of dissolved orthophosphate, except that the sulfuric acid concentration in the color reagent was reduced to 500 mL to compensate for the acid in the digestion tubes. These analyses were also conducted onboard within 24 to 48 hours of sampling.

° <u>Dissolved Reactive Silicon</u>--The Technicon Autoanalyzer System II was used with Technicon's industrial method 186-72W/Tentative to analyze the filtered samples for reactive silicon. This method is based on the reduction of a silicomolybdate in acid solution to molybdenum blue by ascorbic acid. Oxalic acid is added to the sample to eliminate interference from phosphorus. These analyses were also conducted onboard within 2 to 24 hours of sampling.

° <u>Nitrate + Nitrite Nitrogen</u>--Filtered samples were analyzed for nitrate + nitrite nitrogen with the Technicon Autoanalyzer System II and Technicon's industrial method 158-71W (Armstrong et al., 1967). In this procedure, nitrate is reduced to nitrite in a copper cadmium column, which is then reacted with sulfanilamide and N-1-napthylethylenediamine dihydrochloride to form a reddish purple azo dye. Analyses for nitrate + nitrite were performed onboard within 2 to 24 hours of sample collection.

° <u>Ammonia Nitrogen</u>--Unfiltered samples were analyzed for ammonia using a modification of Technicon's industrial method 154-71W/Tentative. The sample pump tube rate for this method is 0.80 mL/min, complexing agent tube 0.42 mL/min, alkaline phenol tube 0.23 mL/min, hypochlorite 0.16 mL/min, nitroprusside 0.23 mL/min, and flow cell 1.00 mL/min. The ammonia determinations were performed onboard as soon as possible after sample collection, usually within 2 hours and no longer than 24 hours.

° <u>Total Kjeldahl Nitrogen</u>--The water samples collected for analysis of total Kjeldahl nitrogen were preserved by addition of 0.40 mL of sulfuric acid (300 mL/L) to each 125 mL. The preservative was added within 30 minutes of sample collection. The analyses were made using an "ultramicro semi-automated" method (Jirka et al., 1976), in which a 10-mL sample is digested with a solution of potassium sulfate and mercuric oxide in a thermostated 370°C block digester. After cooling and dilution with water the sample is neutralized and a determination for ammonia is made using the Technicon Autoanalyzer System II. The analyses for total Kjeldahl nitrogen were made within 180 days of sample collection at the U.S. EPA Central Regional Laboratory.

° Chlorophyll-a and Pheophytin--Samples used for chlorophyll-a and pheophytin determinations were filtered at <7 psi vacuum along with 1 to 2 mL of magnesium carbonate suspension (10 gL), usually within 1 hour of sample collection. The filter (Gelman type AE) was retained at -10°C in a capped glass tube containing 10 mL of 90 percent spectrograde acetone. Before analysis, the tubes were placed in an ultrasonic bath for at least 20 minutes and allowed to steep for at least 24 hours while refrigerated at less than 4°C. The fluorometric analyses were performed using an Aminco dual monochromator spectrofluorometer (Strickland and Parsons, 1965).

1985 HELICOPTER SURVEYS

During January and February 1985, the three lakes were sampled using a helicopter as the sampling platform. Water was collected with an 8-L Niskin bottle from two depths at each helicopter station. Aliquots were distributed among prelabeled bottles immediately after collection and were filtered and preserved (when appropriate) upon landing after the collection flight. The time between collection and filtration was less than 3 hours (usually less than 2 hours).

After filtration and preservation, the samples were shipped in ice via air freight to the USEPA's Region V Central Regional Laboratory in Chicago. All analyses were completed within 48 hours of sample collection. The raw results of these analyses are included in Appendix B.

QUALITY ASSURANCE

The analyses conducted onboard the research vessel and those done at EPA's Central Regional Laboratory were subject to quality control procedures that consisted of (1) analysis of stable check standards, (2) analysis of reagent and sample blanks, (3) analysis of duplicate unknowns, and (4) analysis of spiked samples. These procedures were performed both to monitor the precision and accuracy associated with each analytical method and to ensure that both the onboard and central laboratories were in a state of statistical control at all times.

The quality control procedures were conducted as part of the regular analysis. One depth at each regular (i.e., not master) station was randomly designated as a quality control depth. The sample taken at this depth was split both at collection and again in the laboratory. The regular array of analyses were run on all four subsamples. At master stations one sample was randomly chosen for a laboratory split; analyses were run in duplicate on these samples.

Estimates of the analytical variance associated with each procedure were used to establish control limits for the check standards, reagent blanks, and duplicate ranges. If any determination or sequence of determinations indicated a probability of less than one in one hundred that the procedure is in control (i.e., violated the control limits for the procedure), the processing of samples was stopped until the method was brought back under control. Samples that were in the analysis stream when the control limits were violated were reanalyzed.

The estimates of procedure variance obtained from the analysis of the reagent blanks were also used to establish a criterion of detection for each parameter. For this study, "criterion of detection" is defined as the minimum concentration that must be obtained in an analysis for the analyst to state, with some prespecified degree of confidence, that the concentration of the material of interest in the sample is different from zero. Criterion of detection is calculated here as the mean of the reagent blanks plus two standard deviations. This corresponds to a confidence interval of approximately 95 percent.

The results of the quality control analyses for several parameters for each survey are shown in Tables 7 through 10. The values of both the

Table 7. Summary of quality control analyses, winter helicopter surveys, 1985 surveillance program.

Parameter	Check[a] Standard 1	Check[a] Standard 2	Field[b,e] Blank	Duplicate[c] Audit	Laboratory[d] Blank
Total phosphorus (ug/L)	5.6 ± 0.4 (5.6) N = 14	30.0 ± 1.2 (28) N = 14	2.9 ± 4.0 (<1) N = 14	0.39 ± 0.45 (<6) N = 14	0.13 ± 0.30 N = 14
Total dissolved phosphorus (ug/L)	5.9 ± 0.4 (5.6) N = 11	29.8 ± 1.0 (28) N = 11	5.2 ± 5.2 (<1) N = 11	0.33 ± 0.32 (<6) N = 11	0.03 ± 0.12 N = 11
Dissolved reactive phosphorus (ug/L)	3.6 ± 0.3 (4.2) N = 15	18.6 ± 1.1 (21) N = 15	1.2 ± 1.3 (<1) N = 15	0.57 ± 0.69 (<2) N = 8	0.13 ± 0.28 N = 15
Dissolved reactive silicon (ug/L)	113 ± 25 (93) N = 14	486 ± 31 (473) N = 14	13 ± 47 (<4) N = 15	5 ± 5 (<30) N = 9	12.3 ± 24.5 N = 15
Total ammonia nitrogen (ug/L)	6.9 ± 2.6 (4.4) N = 15	46.9 ± 3.8 (44) N = 15	-0.15 ± 2.3 (<3) N = 13	1.9 ± 1.5 (<5) N = 8	0.46 ± 1.63 N = 15
Total nitrate + nitrite nitrogen (ug/L)	71.4 ± 12.3 (72) N = 15	703 ± 75 (720) N = 15	4 ± 8 (<7) N = 15	6.7 ± 14.1 (<20) N = 9	0.13 ± 0.50 N = 15
Chloride (mg/L)	1.88 ± 0.25 (2.0) N = 15	7.99 ± 0.19 (8.0) N = 15	0.41 ± 0.61 (<0.4) N = 15	0.14 ± 0.13 (<0.53) N = 8	0.05 ± 0.12 N = 15
Sulfate (mg/L)	2.87 ± 0.51 (3.0) N = 15	15.2 ± 0.22 (15.0) N = 15	0.79 ± 1.09 (<0.2) N = 14	0.36 ± 0.35 (≤0.7) N = 8	0.25 ± 0.20 N = 15
Alkalinity (mg/L)	50.3 ± 0.5 (50) N = 13	100.4 ± 0.7 (100) N = 13	2.5 ± 3.2 (<0.5) N = 14	0.29 ± 0.25 (≤1.5) N = 14	0.39 ± 0.34 N = 14
Specific conductance (uS/cm)	198.3 ± 2.1 (197) N = 14	295.1 ± 1.9 (293) N = 14	7.0 ± 8.7 (<2.23) N = 14	0.5 ± 0.5 (≤3) N = 14	1.98 ± 1.40 N = 13
pH	6.85 ± 0.04 (6.86) N = 14	9.26 ± 0.03 (9.18) N = 14	4.60 ± 0.95 (<5) N = 14	0.04 ± 0.03 (<0.16) N = 14	4.08 ± 0.56 N = 13

[a]Check standards are stable solutions of known concentrations, target values in parentheses.
[b]Acceptable level of reagent blanks in parentheses.
[c]Average difference between duplicates - laboratory split.
[d]Acceptable level of reagent blanks in parentheses as in field blanks.
[e]Contaminated reagent water taken on survey.

Table 8. Summary of quality control analyses, spring surveys, 1985 surveillance program.

Parameter	Check[a] Standard 1	Check[a] Standard 2	Field[b] Blank	Duplicate[c] Audit	Laboratory[d] Blank
Total phosphorus (ug/L)	4.6 ± 0.4 (5.6) N = 74	25.5 ± 0.9 (28) N = 74	−0.16 ± 0.33 (<1) N = 73	0.9 ± 1.5 (<6) N = 74	−0.04 ± 0.38 N = 73
Total dissolved phosphorus (ug/L)	4.6 ± 0.4 (5.6) N = 74	25.0 ± 0.8 (28) N = 74	0.06 ± 0.52 (<1) N = 73	0.4 ± 0.4 (<6) N = 74	−0.05 ± 0.60 N = 73
Dissolved reactive phosphorus (ug/L)	3.8 ± 0.5 (4.2) N = 74	19.4 ± 0.7 (21) N = 74	0.34 ± 0.31 (<1) N = 73	0.3 ± 0.3 (<2) N = 74	−0.03 ± 0.18 N = 74
Dissolved reactive silicon (ug/L)	89 ± 5 (93) N = 74	468 ± 13 (467) N = 74	1.3 ± 8.6 (<4) N = 72	3 ± 3 (<30) N = 73	0.15 ± 1.83 N = 74
Total ammonia nitrogen (ug/L)	7 ± 2 (4.4) N = 72	45 ± 3 (44) N = 72	1.8 ± 1.6 (<3) N = 73	1 ± 2 (<5) N = 72	0.9 ± 0.6 N = 72
Total nitrate + nitrite nitrogen (ug/L)	66 ± 8 (70) N = 74	705 ± 51 (720) N = 74	0.7 ± 2.8 (<7) N = 71	5 ± 5 (<20) N = 73	0.58 ± 2.5 N = 74
Chloride (mg/L)	5.5 ± 0.2 (5.6) N = 74	17.5 ± 0.3(17.3) N = 74	0.19 ± 0.11 (<0.4) N = 71	0.07 ± 0.08 N = 73 (<0.53)	0.19 ± 0.11 N = 74
Sulfate (mg/L)	2.5 ± 0.2 (2.4) N = 74	19.9 ± 0.5(20.5) N = 74	0.02 ± 0.06 (<0.2) N = 73	0.2 ± 0.2 (≤0.7) N = 74	0.01 ± 0.06 N = 74
Turbidity (FTU)	0.35 ± 0.03 (0.4) N = 29	7.87 ± 1.1 (10) N = 29	0.05 ± 0.05(<0.22) N = 64	0.11 ± 0.20 (≤0.4) N = 71	No data
Alkalinity (mg/L)	79.7 ± 0.9 (80) N = 30	99.0 ± 1.2 (100) N = 30	0.41 ± 0.32 (<0.5) N = 64	0.6 ± 0.9 (<1.5) N = 73	No data
Specific conductance (uS/cm)	196.6 ± 0.6 (196.5) N = 28	292.5 ± 1.1 (293) N = 28	1.40 ± 0.43(<2.23) N = 64	0.5 ± 0.8 (≤3) N = 73	No data
pH	6.84 ± 0.05 (6.86) N = 29	9.27 ± 0.07 (9.18) N = 29	(<5)	0.06 ± 0.06 (<0.16) N = 65	No data
Dissolved oxygen (mg/L)				(≤0.28)	No data

[a]Check standards are stable solutions of know concentrations, target values in parentheses.
[b]Acceptable level of reagent blanks in parentheses.
[c]Average difference between duplicates - laboratory split.
[d]Acceptable level of reagent blanks in parentheses as in field blanks.

Table 9. Summary of quality control analyses, summer surveys, 1985 surveillance program.

Parameter	Check[a] Standard 1	Check[a] Standard 2	Field[b] Blank	Duplicate[c] Audit	Laboratory[d] Blank
Total phosphorus (ug/L)	5.3 ± 2.1 (5.6) N = 118	27.5 ± 2.7 (28) N = 118	-0.04 ± 0.87 (<1.2) N = 92	2.0 ± 4.1 (<6) N = 114	0.11 ± 0.87 N = 118
Total dissolved phosphorus (ug/L)	4.9 ± 1.4 (5.6) N = 118	27.7 ± 3.3 (28) N = 118	0.24 ± 1.67 (<1.6) N = 93	1.3 ± 2.2 (<6) N = 116	0.31 ± 1.20 N = 118
Dissolved reactive phosphorus (ug/L)	4.7 ± 0.7 (4.2) N = 116	23.8 ± 2.0 (21) N = 116	0.44 ± 0.70 (<1) N = 93	1.0 ± 1.9 (<2) N = 115	0.43 ± 0.97 N = 117
Dissolved reactive silicon (ug/L)	94 ± 3 (93) N = 116	471 ± 8 (467) N = 116	5 ± 19 (<4) N = 93	24 ± 94 (<30) N = 116	0.5 ± 1.8 N = 118
Total ammonia nitrogen (ug/L)	8 ± 3 (4.4) N = 118	46 ± 5 (44) N = 118	0.6 ± 1.3 (<3) N = 93	2 ± 9 (<5) N = 118	0.8 ± 1.2 N = 118
Total nitrate + nitrite nitrogen (ug/L)	65 ± 6 (70) N = 116	729 ± 25 (720) N = 116	0.3 ± 1.1 (<7) N = 93	6 ± 27 (<20) N = 116	0 ± 0.88 N = 118
Chloride (mg/L)	5.4 ± 0.2 (5.6) N = 118	17.4 ± 0.3 (17.3) N = 118	0.23 ± 0.19 (<0.4) N = 93	0.1 ± 0.1(<0.53) N = 118	0.22 ± 0.16 N = 118
Sulfate (mg/L)	2.4 ± 0.2 (2.4) N = 118	20.4 ± 0.5 (20.5) N = 118	0.06 ± 0.20 (<0.2) N = 93	0.2 ± 0.4 (≤0.7) N = 118	0.06 ± 0.19 N = 118
Turbidity (FTU)	0.31 ± 0.08 (0.4) N = 33	8.24 ± 1.67 (10) N = 36	0.07 ± 0.02 (<0.22) N = 90	0.07 ± 0.13 (≤0.4) N = 108	No data
Alkalinity (mg/L)	78.9 ± 0.8 (80) N = 38	98.6 ± 0.9 (100) N = 38	0.60 ± 0.40 (<0.5) N = 87	0.3 ± 0.4 (<1.5) N = 109	No data
Specific conductance (uS/cm)	197.2 ± 0.8(196.5) N = 40	292.9 ± 0.7 (293) N = 40	1.14 ± 0.37 (<2.23) N = 91	0.4 ± 0.9 (≤3) N = 109	No data
pH	6.88 ± 0.03(6.86) N = 41	9.21 ± 0.04 (9.18) N = 41	5.54 ± 0.25 (<5.0) N = 91	0.02 ± 0.02 (<0.16) N = 109	No data
Dissolved oxygen (mg/L)	_____	_____	_____	0.4 ± 0.5 (≤0.28) N = 100	No data

[a]Check standards are stable solutions of known concentration.
[b]Acceptable level of reagent blanks in parentheses.
[c]Average difference between duplicates - laboratory split.
[d]Acceptable level of reagent blanks in parentheses as in field blanks.

Table 10. Summary of quality control analyses, fall surveys, 1985 surveillance program.

Parameter	Check[a] Standard 1	Check[a] Standard 2	Field[b] Blank	Duplicate[c] Audit	Laboratory[d] Blank
Total phosphorus (ug/L)	5.8 ± 0.8 (5.6) N = 75	27.3 ± 1.4 (28) N = 75	0.1 ± 0.4 (<1) N = 60	7 ± 0.9(<6) N = 76	0.1 ± 0.4 N = 75
Total dissolved phosphorus (ug/L)	5.4 ± 1.1 (5.6) N = 75	26.9 ± 2.0 (28) N = 75	0.2 ± 0.5 (<1) N = 60	0.4 ± 0.5 (<6) N = 76	0.1 ± 0.4 N = 75
Dissolved reactive phosphorus (ug/L)	3.8 ± 0.8 (4.2) N = 76	19.8 ± 2.2 (21) N = 76	-0.1 ± 0.6 (<1) N = 60	0.4 ± 0.5 (<2) N = 76	0.0 ± 0.4 N = 76
Dissolved reactive silicon (ug/L)	99 ± 9 (93) N = 76	470 ± 17 (467) N = 76	45 ± 86 (<4) N = 60	6 ± 6 (<30) N = 76	0 ± 2 N = 76
Total ammonia nitrogen (ug/L)	6 ± 2 (4.4) N = 76	42 ± 2 (44) N = 74	0.3 ± 0.8 (<3) N = 60	2 ± 11 (<5) N = 11	0 ± 0.4 N = 75
Total nitrate + nitrite nitrogen (ug/L)	68 ± 4 (70) N = 76	713 ± 21 (720) N = 76	0.1 ± 0.6 (<7) N = 60	10 ± 19 (<20) N = 76	0 ± 0 N = 76
Chloride (mg/L)	5.4 ± 0.2 (5.6) N = 76	17.5 ± 0.4 (17.3) N = 76	0.15 ± 0.15 (<0.4) N = 60	0.1 ± 0.1(<0.53) N = 76	0.1 ± 0.2 N = 76
Sulfate (mg/L)	2.2 ± 0.2 (2.4) N = 76	19.6 ± 1.0 (20.5) N = 76	0.06 ± 0.13 (<0.2) N = 60	0.3 ± 0.3 (≤0.7) N = 76	0.0 ± 0.1 N = 76
Turbidity (FTU)	0.40 ± 0.07 (0.4) N = 26	9.96 ± 0.14 (10) N = 26	0.05 ± 0.03 (<0.22) N = 58	0.16 ± 0.52 (≤0.4) N = 75	No data
Alkalinity (mg/L)	79.1 ± 0.7 (80) N = 27	98.7 ± 1.1 (100) N = 27	0.05 ± 0.47 (<0.5) N = 59	0.3 ± 0.4 (<1.5) N = 75	No data
Specific conductance (uS/cm)	197.2 ± 0.6 (196.5) N = 25	293.3 ± 0.7 N = 26 (293)	1.34 ± 0.28 (<2.23) N = 58	0.6 ± 1.0 (≤3) N = 75	No data
pH	6.87 ± 0.06 (6.86) N = 27	9.21 ± 0.04 (9.18) N = 27	5.3 ± 0.37 (<5) N = 57	0.01 ± 001 (<0.16) N = 74	No data
Dissolved oxygen (mg/L)	———	———	———	0.7 ± 0.5 (≤0.28) N = 74	No data

[a]Check standards are stable solutions of known concentration.
[b]Acceptable level of reagent blanks in parentheses.
[c]Average difference between duplicates - laboratory spilt.
[d]Acceptable level of reagent blanks in parentheses as in field blank.

check standards and the procedure variances changed from survey to survey, and as a result, the criteria of detection also varied. The calculated criteria of detection are listed in Table 11. The data were entered into the U.S. EPA STORET Water Quality Database, with values below the criterion of detection recorded as real values flagged with the code letter "T" as suggested by Clark (1980). All data in this report are reported as quantitated by analytical instrumentation. Values reported below the criteria of detection have not been flagged in this report. Concentrations below the criteria of detection (Table 11) may not be accurate or precise.

Table 11. Criteria of detection established by analysis of reagent blanks - 1985 surveillance program.[a]

Parameter	Winter	Spring	Summer	Fall
Total phosphorus (ug/L)	2.3	0.8	1.5	1.0
Total dissolved phosphorus (ug/L)	2.0	1.0	3.6	1.1
Dissolved reactive phosphorus (ug/L)	1.3	1.0	1.8	1.3
Dissolved reactive silicon (ug/L)	11	21	10	220[b]
Total ammonia (ug/L)	13	5	3	2
Total nitrate + nitrite nitrogen (ug/L)	12	7	3	1
Chloride (mg/L)	0.3	0.4	0.6	0.5
Sulfate (mg/L)	0.6	0.1	0.5	0.3
Turbidity (FTU)	0.14	0.17	0.11	0.10
Alkalinity (mg/L)	0.9	1.1	1.3	1.4
Specific conductance (uS/cm)	1.9	2.3	1.9	1.9

[a]All data in this report are reported as quantitated by analytical instrumentation. Values reported below the criteria of detection have not been flagged in this report. The reader is cautioned that concentrations below the criteria of detection listed above may not be accurate or precise.

[b]The deionized water cartridge on the ship failed. Laboratory blanks using distilled water were found to have a criteria of detection level of 14 ug/L.

RESULTS

SCOPE

The analysis of the data collected during the 1985 surveillance program follows closely the analysis done on the 1983 and 1984 surveillance data (Lesht and Rockwell, 1985 and 1987). The data collected during 1983 through 1985 were intended to answer fairly specific and limited questions concerning the water quality of Lakes Erie, Huron, and Michigan. Because the design of the surveillance program was based on the assumption of horizontal uniformity of constituent concentrations within major lake basins, issues related to the spatial distribution of the measured parameters within a basin were not addressed. Similarly, the three surveillance surveys were not timed so as to provide the data required to resolve the temporal structure of the annual nutrient cycles within these lakes. Thus, the results presented here often are not (and were not intended to be) as encompassing as those presented in the several reports that have been published about the GLISP surveys (Rockwell et al., 1980; Herdendorf, 1984; Moll et al., 1985).

From the inception of this survey program, the investigators anticipated that most of the results would be reported as basin averages. This accounts for the emphasis placed on sampling of water masses expected to be relatively homogeneous. Such sampling helps ensure that the sample variance associated with the calculated averages is dominated by random sampling error rather than by the more systematic error that results from spatial effects inherent in sampling an unknown (necessarily) spatial distribution in a Great Lake. This dominance of random sampling error is required for the application of many of the statistical tests often applied to limnological data.

Although the sampling program was designed to reduce statistical artifacts due to horizontal variations, the investigators recognized that temporal and vertical variations might also bias statistical calculations based on simple, unsubsetted populations. Experience with the 1983 and 1984 surveillance data suggested that temporal variation within surveys would be small and that horizontal variation between adjacent lake basins would be most evident in Lake Erie. However, the actual periods of sampling conducted in spring 1984 were found to be sufficiently different to warrant separation of the two runs of the spring survey. Therefore, the first step taken in the analysis of the 1985 data was to search for the occurrence of natural subsets that could be used to classify the samples. The initial subsets chosen were based on locations (lake basin), time (survey and leg), and position within the water column relative to the thermal structure.

TEMPORAL VARIATION WITHIN SURVEYS

The Student's t-test was used to evaluate the difference in basin means calculated for adjacent legs within each survey. The lake basins were defined in a manner similar to 1983 and 1984 and the two-tailed t-test was conducted under the assumption that the variances associated with the sample populations were unknown and not necessarily equal. The stations associated with each basin are found in Tables 4-6. In some basins, the sampling of adjacent legs was completed within 24 hours, a period that must be considered synoptic by limnological standards. In other cases, however, adjacent legs were sampled two weeks apart. Because we anticipated pooling all the data for each survey for analysis, the t-tests were used to evaluate the magnitude of any error or bias that might result.

The question of pooling data separated in time and space is more complicated than is usually appreciated. It is impossible to do truly synoptic water sampling on the Great Lakes (remote sensing excepted); therefore, samples separated in space are also separated in time. Furthermore, samples taken at the same location over time (i.e., Eulerian) may be considered as spatially separated, since the water itself will have moved between samplings. The proper approach is, therefore, to design the sampling scheme in such a manner that it provides data that can be used to answer the questions being posed by the monitoring program. In this case, we are interested in parameter estimates representative of the major lake basins during particular periods of the year. Because these values are dependent on both space and time, the best that can be done is to calculate sample averages.

The results given in Tables 12 through 14 show that except for the two legs of the fall survey in Lake Michigan and Lake Huron, the differences between adjacent survey legs are insignificant (alpha = 0.05) and that the data may be pooled by survey. The two legs of the fall survey in Lake Michigan and Lake Huron, however, had too many significant differences, related to the occurrence of the fall overturn between the surveys, to justify pooling the data for many analyses. Thus, in the remainder of this report many of the analyses are presented with these data as subsets in which these legs are referred to as surveys Fall-1 and Fall-2.

SPATIAL SEGMENTATION

We also used the Student's t-test to examine the differences between parameter means calculated for subsets of the surveillance data based on station location within the major lake basins. As before, the t-test was conducted under the assumption that the variances associated with the sample populations were unknown and not necessarily equal. The purpose of this analysis was to determine the degree to which the open lake regions differed from one another and whether these differences were consistent throughout the year. Since we restricted the comparisons to data collected within the epilimnion and compared the basin subsets on a survey-by-survey (season-by-season) basis, the fundamental criterion required for strict application of the t-test (i.e., that the data be random samples from independent, normally distributed populations) was satisfied. This would not have been the case if the comparisons had been based on data known to be distributed non-normally (e.g., data from all surveys combined). Since we were interested in spatial gradations within the data, the comparisons were done in a pairwise manner using adjacent basins only. The results of these analysis for several water quality parameters are shown in Tables 15-18.

In 1983 only Lake Erie showed consistent differences between basins; in 1984 all three lakes had several parameters that were significantly different between basins. In Lake Michigan, for example, during 1983 only temperature and conductivity were consistently different between basins. In 1984 the northern and southern basins of Lake Michigan were

Table 12. Comparison of survey legs - Lake Michigan southern basin epilimnion.[a]

Parameter		Spring[b]			Summer					Fall		
		Leg 1		Leg 2	Leg 1		Leg 2		Leg 3	Leg 1		Leg 2
	x	2.3		2.8	20.8		20.6		20.6	8.3		5.4
Temperature	t		-8.29			0.90		-0.03			12.35	
(°C)	result		<			=		=			>	
	x	0.31		0.49	0.40		0.44		0.60	0.25		0.45
Turbidity	t		-6.32			-0.63		-3.15			-4.76	
(FTU)	result		<			=		<			<	
Specific	x	280.4		279.5	277.7		278.4		277.0	282.0		279.6
Conductance	t		5.10			-0.89		2.27			7.89	
(uS/cm)	result		>			=		>			>	
	x	4.6		5.3	2.7		2.6		2.2	4.0		5.5
Total phosphorus	t		-3.10			0.05		1.29			-5.34	
(ug/L)	result		<			=		=			<	
Total dissolved	x	2.3		2.4	1.6		1.7		1.0	2.4		2.8
phosphorus	t		-0.69			-0.24		2.65			-1.63	
(ug/L)	result		=			=		>			=	
Dissolved	x	569		564	101		88		103	389		610
reactive	t		1.03			2.21		-2.64			-12.60	
silicon	result		=			>		<			<	
(ug/L)												
Nitrate + nitrite	x	299		286	167		160		149	249		290
nitrogen	t		0.80			1.20		1.94			- 7.80	
(ug/L)	result		=			=		=			<	
	x	0.33		1.57	0.94		1.18		1.24	0.56		0.32
Chlorophyll-a	t		-13.0			-3.68		-0.94			5.68	
(ug/L)	result		<			>		=			>	

[a]Comparisons are based on two-tailed t-test with alpha = 0.05. x is the sample average, t is the Student's t value, symbols < > denote statistically significant differences, symbol = denotes no statistical difference.
[b]Spring epilimnion denotes entire water column.

Table 13. Comparison of survey legs — Lake Huron northern basin epilimnion.[a]

Parameter		Spring[b] Leg 1		Spring[b] Leg 2	Summer Leg 1		Summer Leg 2		Summer Leg 3	Fall Leg 1		Fall Leg 2
Temperature (°C)	x	1.4		1.5	17.7		17.6		17.7	7.9		6.2
	t		-1.43			0.53		0.47			12.49	
	result		<			=		=			>	
Turbidity (FTU)	x	0.34		0.89	0.22		0.20		0.20	0.21		0.43
	t		-1.24			0.76		-0.25			-6.26	
	result		=			=		=			<	
Specific conductance (uS/cm)	x	202.9		202.3	200.3		196.8		199.4	205.0		201.9
	t		2.14			1.24		-0.94			3.62	
	result		>			=		=			>	
Total phosphorus (ug/L)	x	3.4		5.6	4.7[c]		2.2		1.6	2.9		3.8
	t		-0.88			0.66		2.00			-3.07	
	result		=			=		=			<	
Total dissolved phosphorus (ug/L)	x	1.3		1.2	3.7[d]		1.1		0.8	1.1		0.9
	t		0.85			0.44		1.18			1.01	
	result		=			=		=			=	
Dissolved reactive silicon (ug/L)	x	782		760	491		355		414	632		747
	t		5.19			4.64		-1.80			-6.13	
	result		>			>		=			<	
Nitrate + nitrite nitrogen (ug/L)	x	323		274	286		240		271	308		301
	t		15.4			5.72		-3.95			1.77	
	result		>			>		<			>	
Chlorophyll-a (ug/L)	x	0.30		1.42	1.06		1.02		0.92	0.58		0.30
	t		-21.3			0.15		0.88			5.87	
	result		<			=		=			>	

[a]Comparisons are based on two-tailed t-test with alpha=0.05. x is the sample average, t is Student's t value, symbols < > denote statistically significant differences, symbol = denotes no statistical difference.
[b]Spring epilimnion denotes entire water column.
[c]Includes two values (17.7 and 18.2), which are an order of magnitude greater than remaining values. Without these values x=2.1.
[d]Includes two values (15.3 and 16.9), which are an order of magnitude greater than remaining values. Without these values x=1.3.

Table 14. Comparison of survey legs — Lake Erie central basin epilimnion.[a]

Parameter		Spring[b] Leg 1		Spring[b] Leg 2	Summer Leg 1		Summer Leg 2		Summer Leg 3	Fall Leg 1		Fall Leg 2
Temperature (°C)	x	5.0		5.1	22.0		22.4		22.2	10.9		10.3
	t		-0.52			-9.15		4.82			8.71	
	result		=			<		>			>	
Turbidity (FTU)	x	1.73		1.80	0.44		0.40		0.41	2.48		2.26
	t		-0.34			1.77		-0.50			1.65	
	result		=			>		=			=	
Specific conductance (uS/cm)	x	276.2		276.7	276.2		275.9		273.8	278.6		278.4
	t		-0.77			0.45		3.21			0.15	
	result		=			=		>			=	
Total phosphorus (ug/L)	x	12.4		13.1	8.0		8.6		10.0	21.5		21.2
	t		-1.10			-0.70		-1.32			0.30	
	result		=			=		=			=	
Total dissolved phosphorus (ug/L)	x	4.0		3.6	3.1		3.4		5.0	9.9		9.8
	t		1.88			-0.63		-2.44			0.15	
	result		=			=		<			=	
Dissolved reactive silicon (ug/L)	x	8.7		10.4	108		143		177	76.6		81.2
	t		-1.11			-2.26		-1.66			-0.55	
	result		=			<		=			=	
Nitrate + nitrite nitrogen (ug/L)	x	207		203	193		201		180	120		137
	t		0.67			-1.22		2.92			-3.35	
	result		=			=		>			<	
Chlorophyll-a (ug/L)	x	1.60		3.64	3.10		3.07		3.34	2.84		2.39
	t		-10.7			0.08		-0.98			2.31	
	result		<			=		=			>	

[a]Comparisons are based on two-tailed t-test with alpha =0.05. x is the sample average, t is Studénts's value, symbols < > denote statistically significant differences, symbol = denotes no statistical difference.

[b]Spring epilimnion means entire water column.

Table 15. Comparison of Lake Michigan northern and southern basin epilimnia.[a]

Parameter		Winter 2[b] North	Winter 2[b] South	Spring[b] North	Spring[b] South	Summer North	Summer South	Fall 1 North	Fall 1 South	Fall 2 North	Fall 2 South
Temperature (°C)	x	1.5	2.0 3	2.5	2.6	18.5	20.7	8.1	8.3	6.5	5.4
	t	-0.74		-0.53		-9.79		-0.51		8.13	
	result	=		=		<		=		>	
Turbidity (FTU)	x	0.34	0.40	0.36	0.48	0.23	0.25	0.26	0.45	0.26	0.45
	t	No Data		-1.52		-3.18		-0.65		-5.11	
	result			=		<		=		<	
Specific conductance (uS/cm)	x	283.5	281.6	279.8	279.9	276.6	277.7	281.1	282.0	278.7	279.6
	t	1.56		-0.96		-3.05		-2.79		-1.91	
	result	=		=		<		<		=	
Total phosphorus (ug/L)	x	5.6	5.8	5.2	4.9	4.5	2.5	3.2	4.0	4.3	5.5
	t	-0.31		0.95		3.10		-2.67		-5.05	
	result	=		=		>		<		<	
Total dissolved phosphorus (ug/L)	x	4.1	4.7	2.8	2.4	1.2	1.4	2.1	2.4	3.0	2.8
	t	-2.12		2.70		-1.31		-1.00		1.46	
	result	=		>		=		=		=	
Dissolved reactive reactive silicon (ug/L)	x	545	574	563	566	93	97	338	389	410	610
	t	-1.65		-0.47		-0.95		3.36		-8.15	
	result	=		=		=		=		<	
Nitrate + nitrite nitrogen (ug/L)	x	290	293	286	293	156	159	232	249	246	290
	t	-0.23		-0.79		-0.92		-2.94		-4.85	
	result	=		=		=		<		<	
Chlorophyll-a (ug/L)	x	0.89	0.79	0.75	0.95	1.00	1.12	0.78	0.56	0.32	0.32
	t	0.57		-1.32		-2.10		3.14		0.04	
	result	=		=		<		>		=	

[a]Parameter values are means of samples taken within the epilimnia. Comparisons are based on two-tailed t-test with alpha= 0.05.
[b]Epilimnia in the winter and spring surveys denote the entire water column.

Table 16. Comparison of Lake Huron northern and southern basin epilimnia.[a]

Parameter		Winter 1[b] North	Winter 1[b] South	Winter 2[b] North	Winter 2[b] South	Spring[b] North	Spring[b] South	Summer North	Summer South	Fall 1 North	Fall 1 South	Fall 2 North	Fall 2 South
Temperature (°C)	x	1.8	2.0	0.8	0.2	1.5	1.8	17.7	19.7	7.9	8.3	6.2	6.9
	t	- 0.75		2.27		-4.33		-14.10		-4.54		-5.36	
	result	=		>		<		<		<		<	
Turbidity (FTU)	x					0.39	0.53	0.21	0.25	0.21	0.31	0.43	0.42
	t	No Data		No Data		-2.68		-1.99		-5.52		0.39	
	result					<		<		<		=	
Specific conductance (uS/cm)	x	206.5	206.0	202.6	205.2	202.7	203.4	198.9	206.5	205.0	207.0	201.9	204.4
	t	0.62		-2.44		-3.05		-4.54		-3.46		-5.29	
	result	=		<		<		<		<		<	
Total phosphorus (ug/L)	x	3.0	4.8	3.7	5.0	3.3	3.6	2.8	2.3	2.9	3.0	3.8	3.7
	t	-3.06		-0.70		-0.76		0.80		-0.64		0.43	
	result	<		=		=		=		=		=	
Total dissolved phosphorus (ug/L)	x	2.1	3.0	2.3	2.0	1.3	1.3	1.9	1.3	1.1	0.8	0.9	2.1
	t	-1.47		1.66		-0.31		1.03		2.68		-4.79	
	result	=		=		=		=		>		<	
Dissolved reactive silicon (ug/L)	x	769	713	801	799	773	782	422	338	632	716	747	741
	t	16.3		0.31		-2.91		4.23		-4.22		0.33	
	result	>		=		<		>		<		=	
Nitrate + nitrite nitrogen (ug/L)	x	335	331	304	329	302	301	267	276	308	328	301	297
	t	1.56		-1.77		0.24		-1.75		-2.02		0.73	
	result	=		=		=				=		=	
Chlorophyll-a (ug/L)	x	0.89	0.85	0.80	1.30	0.78	1.09	1.00	1.36	0.58	0.60	0.30	0.40
	t	0.50		-3.75		-2.79		-2.71		-0.32		-2.46	
	result	=		<		<		<		=		<	

[a]Parameter values are means of samples taken within the epilimnia. Comparisons are based on two-tailed t-test with alpha=0.05.
[b]Epilimnia in the winter and spring surveys denotes the entire water column.

Table 17. Comparison of Lake Erie western and cental basin epilimnia.[a]

Parameter		Winter 1[b]		Winter 2[b]		Spring		Summer		Fall 1	
		West	Central	West	Central	West	Central	West	Central	West	Central
Temperature (°C)	x	0.0	2.0	0.0	0.0	12.0	5.1	22.5	22.2	7.0	10.6
	t					21.46		1.75		-14.39	
	result	<		=		>		=		>	
Turbidity (FTU)	x	No Data		No Data		6.39	1.77	4.17	0.42	12.02	2.37
	t					11.61		13.36		5.82	
	result					>		>		>	
Specific conductance (uS/cm)	x	260.2	290.8	263.8	283.8	256.1	276.5	234.0	275.4	244.6	278.5
	t					-5.02		-18.62		-6.25	
	result	<				<		<		<	
Total phosphorus (ug/L)	x	16.8	42.9	8.2	9.5	20.7	12.8	17.9	8.8	32.6	21.4
	t					7.32		4.39		4.06	
	result	<				>		>		>	
Total dissolved phosphorus (ug/L)	x	4.0	7.5	No Data	No Data	3.9	3.8	4.2	3.7	6.9	9.9
	t					0.29		1.08		-2.98	
	result	<				=		=		<	
Dissolved reactive silicon (ug/L)	x	710	75	638	36	633	10	329	140	743	79
	t					13.98		5.10		11.67	
	result	>				>		>		>	
Nitrate + nitrite nitrogen (ug/L)	x	511	217	457	221	699	204	181	192	433	128
	t					11.27		-0.44		10.91	
	result	>		>		>		=		>	
Chlorophyll-a (ug/L)	x	3.49	4.57	2.14	2.47	5.85	2.75	10.84	3.16	1.72	2.62
	t					3.39		5.34		-3.61	
	result	=		=		>		>		<	

[a]Parameter values are means of samples taken within the epilimnia. Comparisons are based on two-tailed t-test with alpha= 0.05.
[b]Epilimnia in the winter and spring surveys denotes the entire water column.

Table 18. Comparison of Lake Erie central and eastern basin epilimnia.[a]

Parameter		Winter 1[b] Central	Winter 1[b] East	Winter 2[b] Central	Winter 2[b] East	Spring[b] Central	Spring[b] East	Summer Central	Summer East	Fall 1 Central	Fall 1 East
Temperature (°C)	x	2.0	3.5	0.0	0.0	5.1	2.1	22.2	21.8	10.6	10.4
	t					19.54		4.96		2.51	
	result					>		>		>	
Turbidity (FTU)	x	No Data		No Data		1.77	2.63	0.42	0.48	2.37	4.10
	t					-5.56		-0.62		-2.57	
	result					<		=		<	
Specific conductance (uS/cm)	x	290.8	290	283.8	289	276.5	278.2	275.4	280.2	278.5	283.5
	t					-3.75		-12.19		-9.14	
	result					<		<		<	
Total phosphorus (ug/L)	x	42.9	16.4	9.5	11.6	12.8	12.8	8.8	5.7	21.4	15.3
	t					-0.19		6.28		+4.55	
	result					=		>		>	
Total dissolved phosphorus (ug/L)	x	7.5	8.4	No Data	No Data	3.8	6.2	3.7	2.3	9.9	6.6
	t					-18.20		4.15		11.26	
	result					<		>		>	
Dissolved reactive silicon (ug/L)	x	75	62	36	68	10	72	140	75	79	90
	t					-32.69		6.60		-1.49	
	result					<		>		<	
Nitrate + nitrite nitrogen (ug/L)	x	217	263	221	274	204	287	192	185	128	205
	t					-19.75		1.09		-16.89	
	result					<		=		<	
Chlorophyll-a (ug/L)	x	4.57	1.92	2.47	1.06	2.75	0.49	3.16	1.39	2.62	0.82
	t					13.80		11.88		15.34	
	result					>		>		>	

[a]Parameter valuesd are means of samples taken within the epilimnia. Comparisons are based on two-tailed t-test with alpha= 0.05.
[b]Epilimnia in the winter and spring surveys denotes the entire water column.

significantly different in nitrate + nitrite nitrogen (all surveys), dissolved reactive silicon, chlorophyll-a, and turbidity (spring-2 and summer surveys). Both dissolved reactive silicon and nitrate + nitrite nitrogen were significantly different in the northern and southern basins of Lake Huron during all of the 1984 surveys. Lake Erie continued to exhibit the most pronounced differences between basins although the contrast between the western and central basins in 1984 was less than in 1983.

In 1985, fewer consistently statistically significant differences (alpha = 0.05) were observed in Lakes Michigan and Huron than in 1984. Lake Erie exhibited many significant differences between the western and central basins in all surveys for the eight parameters tracked (Table 17). Similarly the central and eastern basins were different with the exception of the spring survey when only total phosphorus (out of the eight parameters) was different (Table 18). Lake Michigan basins were not different during the winter for these reported parameters, but total dissolved phosphorus showed a marked decrease in the spring as well as significant basin differences. Lake Huron also showed a marked decrease in total dissolved phosphorus between the winter and spring surveys. A corresponding increase in biological activity can be noted in higher chlorophyll levels in southern Lake Huron.

Following the procedures used in analysis of the 1983 and 1984 surveillance data, most of the analyses were conducted basin-by-basin rather than for all basins combined. This was done to facilitate historical comparisons, and in recognition of the fact that t-test results represent only the sample data that are used for calculation and not the populations that the samples are intended to represent. Although we assume that our sample was representative of the population, a t-test result indicating that the difference between sample means is not significantly different from zero (i.e., accept the null hypothesis) does not necessarily imply that the underlying population means are the same, only that we have insufficient evidence to conclude that they are different. Given the uncertainty associated with limnological observations, the t-tests used here can only suggest that basin means are different, not that they are equal.

WATER COLUMN STRUCTURE

Temperature

One goal of the surveillance program was to sample the three lakes at three distinct times during the annual thermal cycle. The desired times were (1) spring after ice out and before stratification, (2) summer, at maximum stratification, and (3) fall, after turnover.

Figures 4 through 8 (ISSCO, 1984) depict the average basin surface water temperature measured during each survey leg along with the time series of daily average surface temperature measured by the National Data Buoy Office buoys (Hamilton, 1980) deployed in Lakes Erie, Huron, and Michigan. These figures show how the surveillance sampling periods related to the annual thermal cycle in these lakes. In Lake Michigan and Lake Huron, the spring survey was completed on May 2. This survey occurred well before the lakes began warming above 4°C, which occurred in late May to mid-June. During June, rapid warming was observed in each lake basin resulting in epilimnetic water temperatures near maximum by July. Peak surface temperatures occurred in each basin during August or September. As a result, the 1985 summer survey occurred later in the stratified period than in 1983 and 1984. As in 1984, surface temperatures began to decline in September and all lakes had cooled substantially by the fall survey. Lake Erie was completely turned over while Lakes Michigan and Huron had cooled to 9°C or lower temperatures.

The vertical distribution of temperature in each lake basin is plotted in Figures 9 through 13. The data for these plots were taken from the basin master stations listed in Table 2. These figures show that the first survey (16 April to 2 May) was conducted while the deeper basins of the middle Great Lakes were still stably unstratified, with slightly warmer water near the bottom. All sites visited in Lake Erie's western basin were stratified during the first sampling of the spring survey (April 24-25) and had 'turned over' to a nearly isothermal temperature structure by April 28th. The central basin had begun to stratify, with

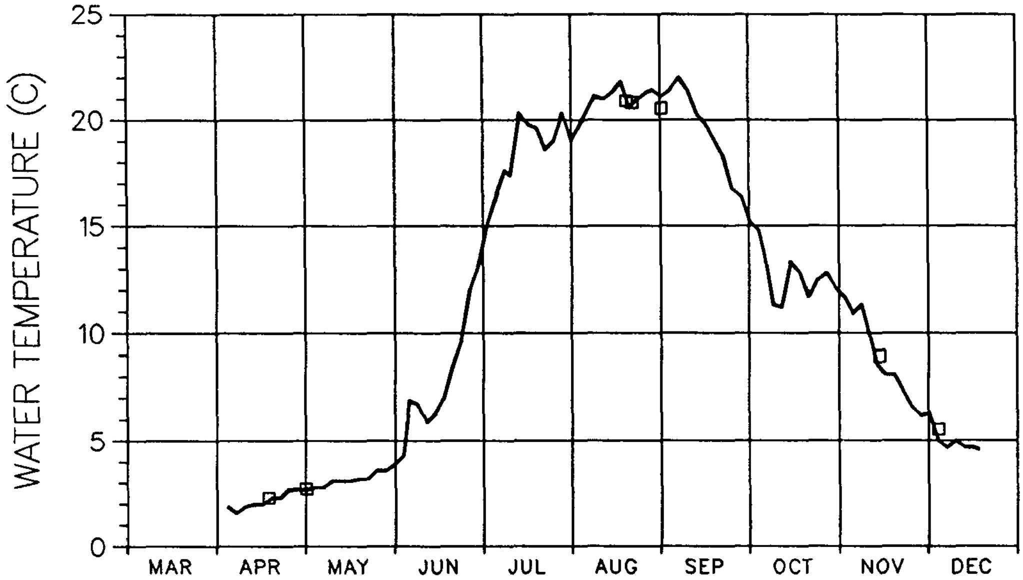


Figure 4. Surface water temperature in southern Lake Michigan - 1985. Survey basin means (squares) are compared to NDBO buoy 45007 data (line) showing the relationship between surveillance periods and the annual thermal cycle.

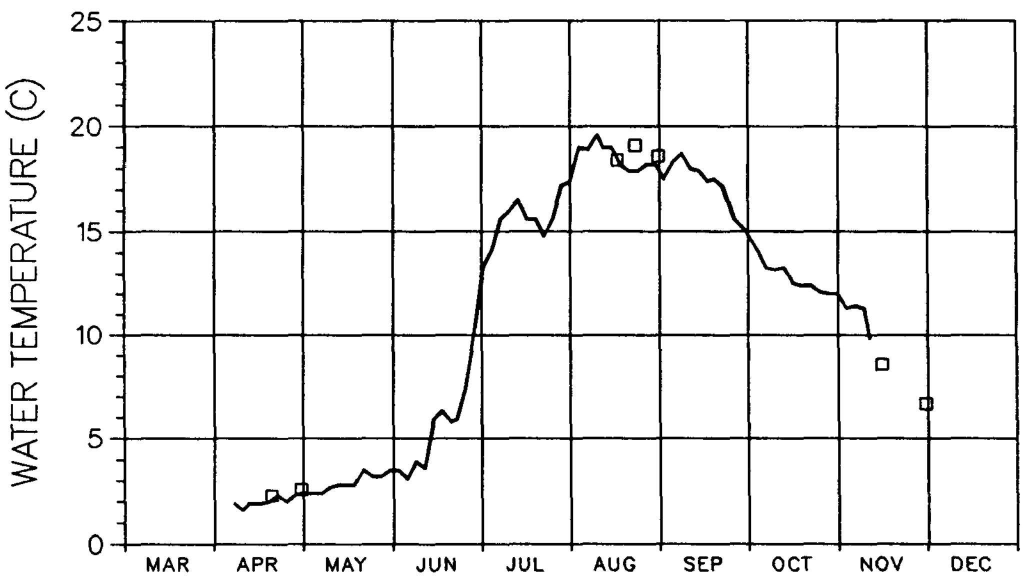


Figure 5. Surface water temperature in northern Lake Michigan - 1985. Survey basin means (squares) are compared to NDBO buoy 45002 data (line) showing the relationship between surveillance periods and the annual thermal cycle.

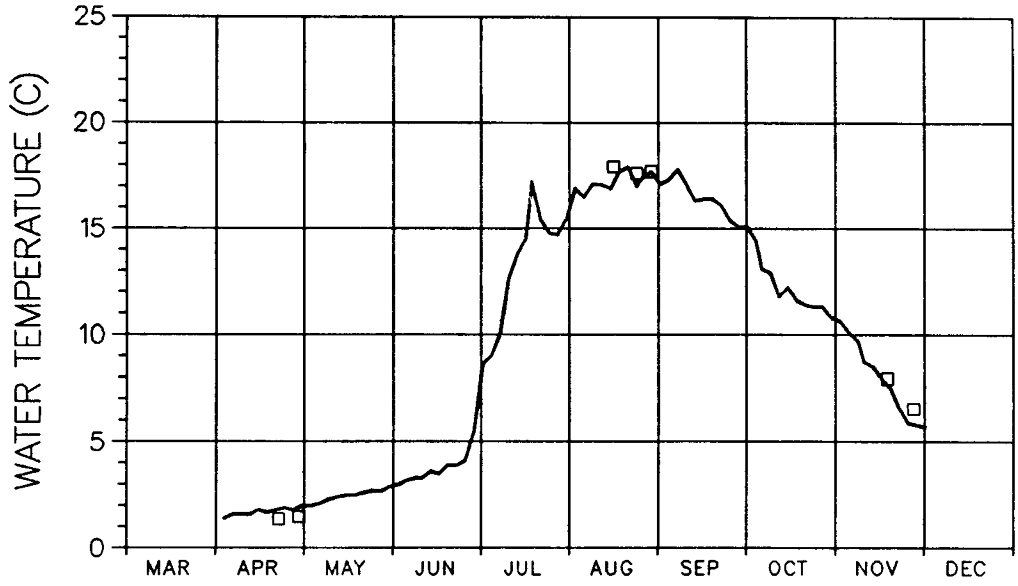


Figure 6. Surface water temperature in northern Lake Huron - 1985. Survey basin means (squares) are compared to NDBO buoy 45003 data (line) showing the relationship between surveillance periods and the annual thermal cycle.

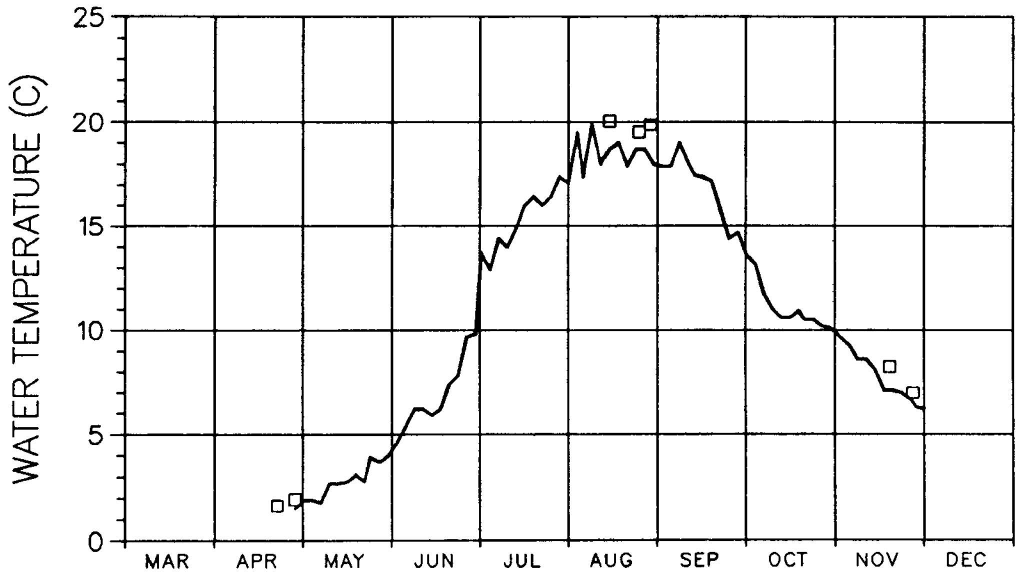


Figure 7. Surface water temperature in southern Lake Huron - 1985. Survey basin means (squares) are compared to NDBO buoy 45008 data (line) showing the relationship between surveillance periods and the annual thermal cycle.

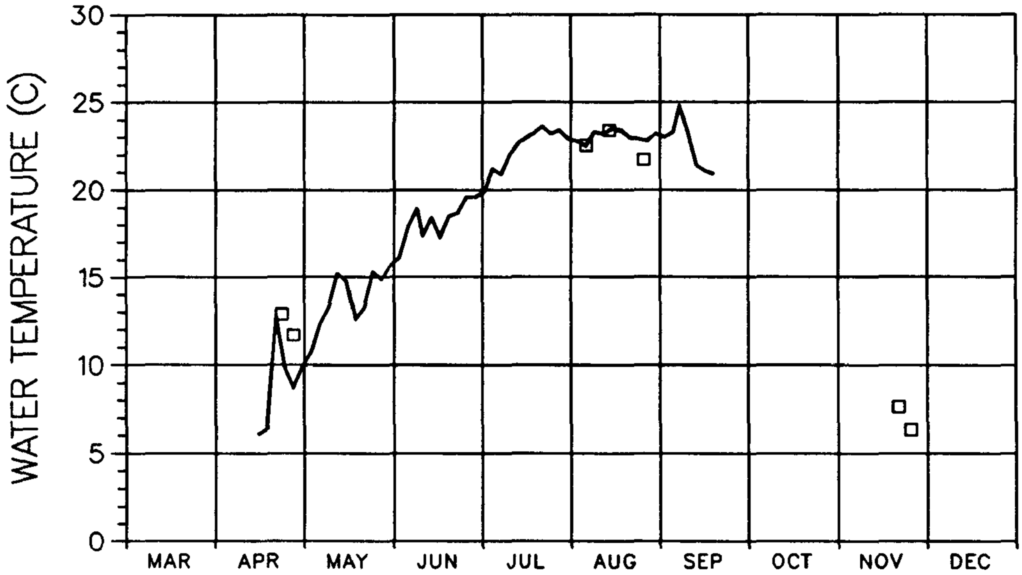


Figure 8. Surface water temperature in western Lake Erie - 1985. Survey basin means (squares) are compared to NDBO buoy 45005 data (line) showing the relationship between surveillance periods and the annual thermal cycle.

several of the western most sites being stratified, while the remainder of the basin was isothermal. The water temperatures in all basins did not change appreciably during the spring survey in Lake Michigan and Huron. The maximum basin temperature increase observed was 0.4°C (about 0.07°C/day) in the southern basin of Lake Huron during the 6-day interval between sampling visits. This rate of increase was almost twice as fast as the 1984 rate where a 0.04°C/day increase was observed between the spring sampling periods.

As designed, the summer survey was completed during the stable stratified period (August 6 - September 1). Summer epilimnion temperatures were cooler and thermocline depths (Table 19) were deeper when compared to 1983 (Lesht and Rockwell, 1985) with epilimnion temperatures 5 to 10% lower and thermocline depths 10 to 30% greater.

In 1985, Lake Erie's central basin hypolimnion (1.6m) was about 1/3 as thick as in 1983 and 1984 (Table 20). This thin layer and a larger than usual oxygen depletion rate (Fay and Rathke, 1987) resulted in an

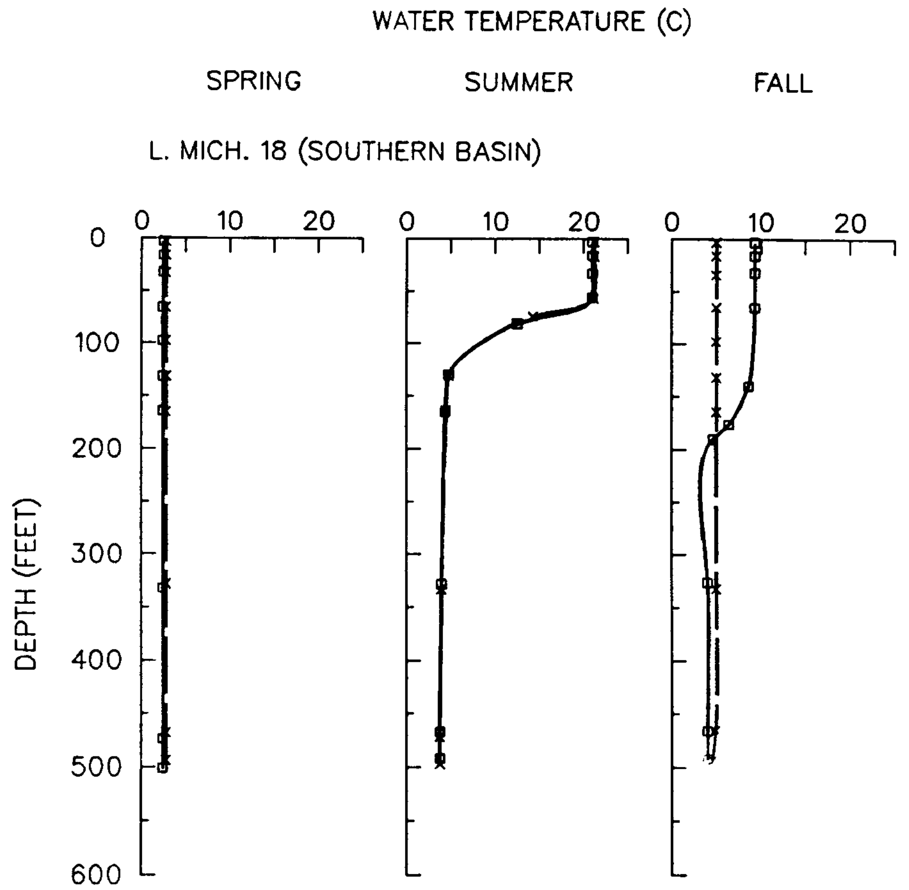


Figure 9. Vertical profiles of water temperature in southern Lake Michigan, station 18, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

anoxic hypolimnion. The release of nutrients from the sediments can be seen in a dramatic increase in phosphorus concentration. In 1985, average phosphorus concentrations were six times greater for total phosphorus and twenty seven times greater for ortho phosphorus in the hypolimnion and nepheloid layer when compared to epilimnion concentrations.

The 1985 fall survey (November 14 - December 4) was conducted two weeks earlier than the 1984 fall survey and two weeks later than the 1983 fall survey. During this survey, the southern basin of Lake Michigan

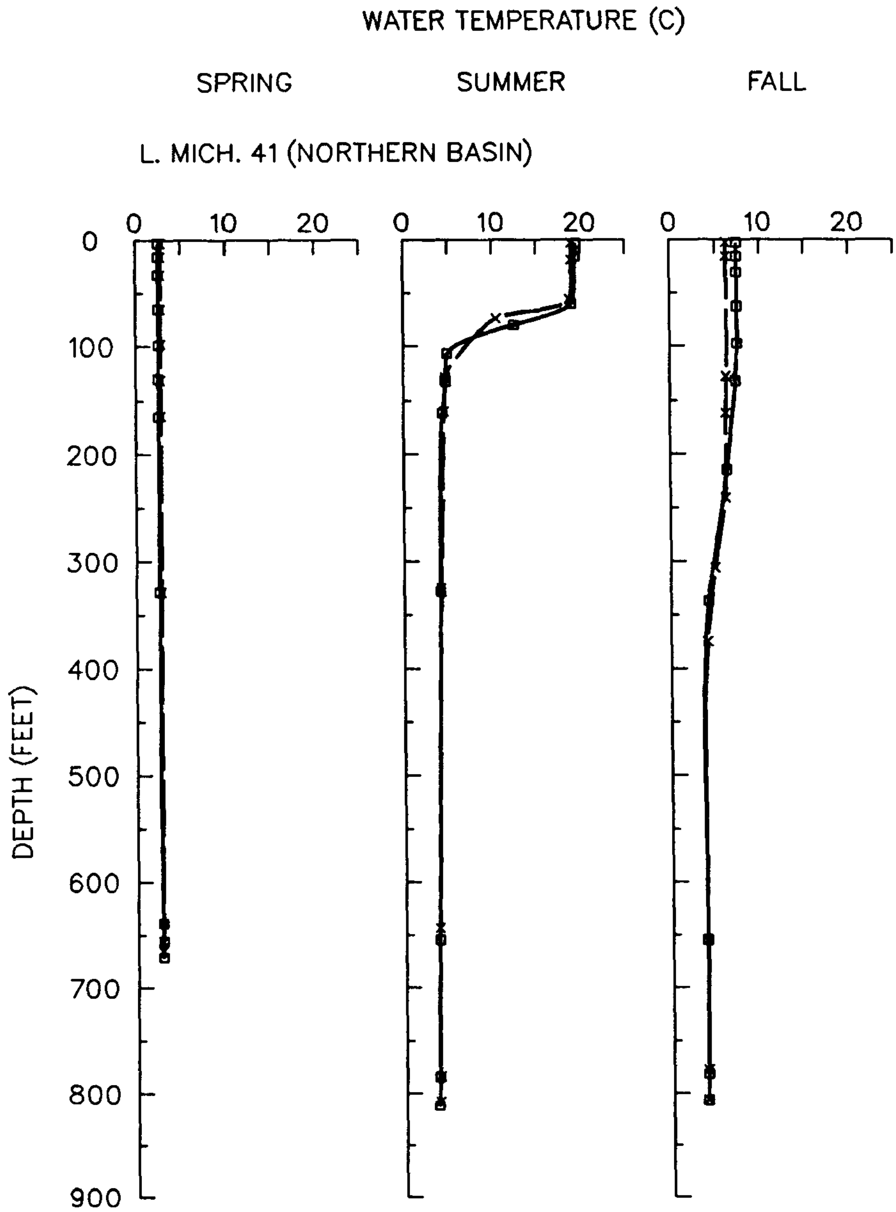


Figure 10. Vertical profiles of water temperature in northern Lake Michigan, station 41, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

turned over between sampling runs providing a quantitative picture of chemical concentrations before and after turnover. Lake Michigan's northern basin remained stratified. The stratification in northern Lake

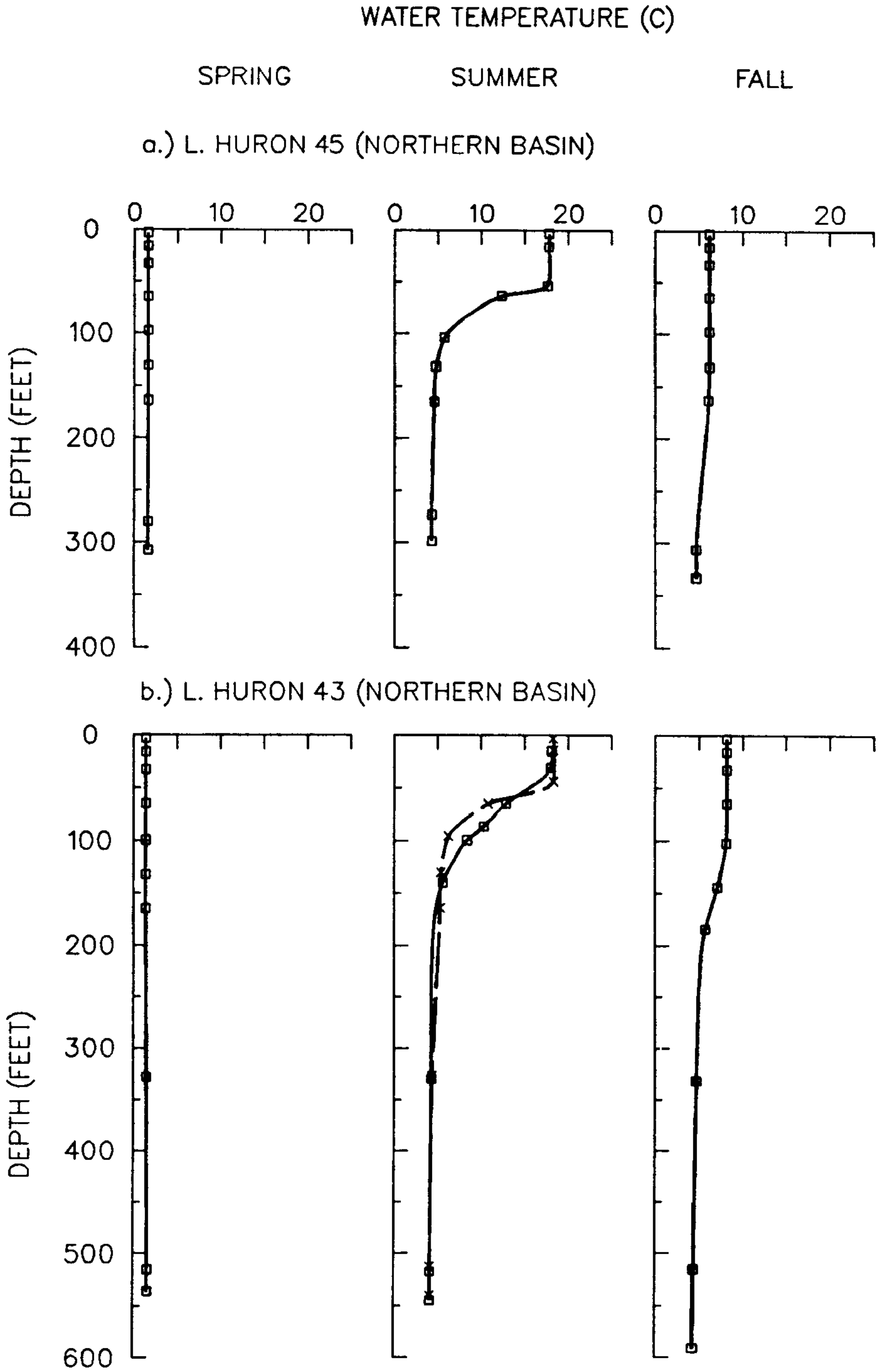


Figure 11. Vertical profiles of water temperature in northern Lake Huron, stations 45 and 43, during the spring, summer and fall surveys. See Figure 12 for a detailed explanation.

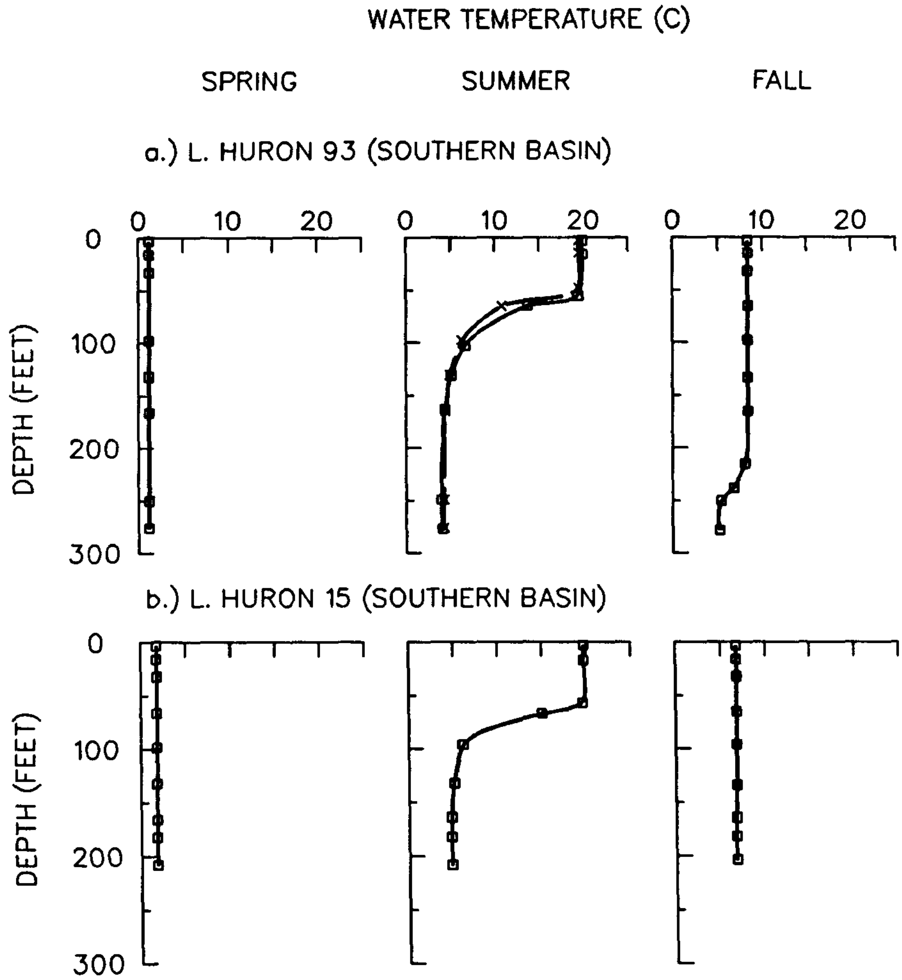


Figure 12. Vertical profiles of water temperature in southern Lake Huron, stations 93 and 15, during the spring, summer and fall surveys. In a). the observed data of the second runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. In b). the observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. Also in b)., the observed data of the third run of the summer survey are shown as xs with a dashed smoothing curve.

Michigan during the Fall-2 was much weaker than in Fall-1 and much deeper with surface to bottom temperature differentials at the master station being reduced from 3.7°C to 2.5°C.

<u>Turbidity</u>

Turbidity profiles observed at the master stations during each

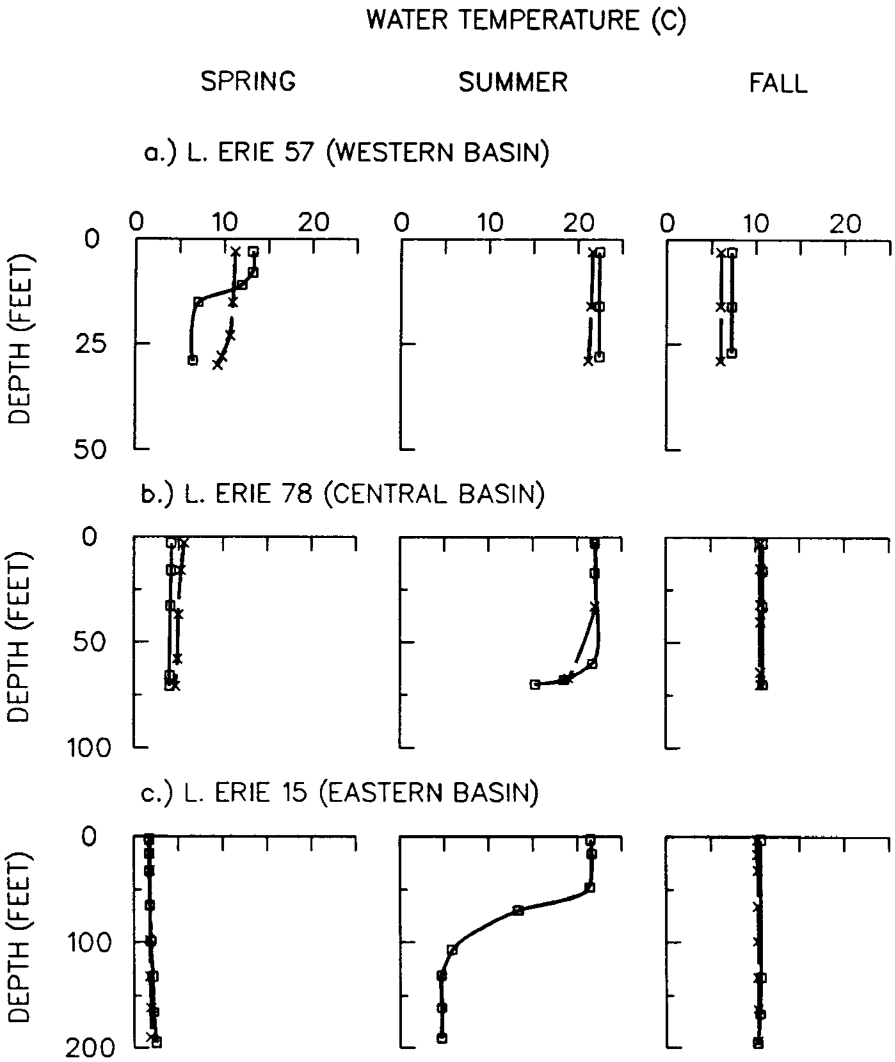


Figure 13. Vertical profiles of water temperature in western, station 57; central, station 78; and eastern, station 15, Lake Erie, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

survey are plotted in Figures 14 through 18. These profiles suggest the presence of a benthic nepheloid layer (Bell et al., 1980) in the deeper basins of each lake after thermal stratification. Data from the spring survey suggest that similar high turbidity layers may exist in all deep basins near the bottom during the winter, too, when the lake is again

Table 19. Average epilimnion temperature and thermocline depth[a] by survey and basin, 1985.

Surveys	Epilimnion temperature (°C)						Thermocline depth (meter)		
	Winter 1 January	Winter 2 February	Spring	Summer	Fall 1	Fall 2	Summer	Fall 1	Fall 2
Basins									
Lake Michigan									
South	–[b]	2.0	2.5	20.7	8.3	5.4	20.5 ± 3.0 (18)	51.6 ± 5.7 (5)	*[c]
North	–	1.5	2.5	18.5	8.1	6.5	20.8 ± 3.7 (15)	60.1 ± 11.4 (5)	91.2 ± 20 (5)
Lake Huron									
North	1.7	0.8	1.5	17.6	7.9	6.2	17.1 ± 2.6 (17)	56.4 ± 10.7 (6)	*
South	2.0	0.2	1.8	19.7	8.2	6.9	19.6 ± 1.8 (13)	59.0 ± 11.8 (3)	68.9 (1)
Lake Erie					Fall 1 & 2			Fall 1 & 2	
West	0.0	0.0	12.0	22.5	7.0		–	*	
Central	2.0	0.0	5.1	22.2	10.6		19.7 + 1.5 (27)	*	
East	3.2	0.0	2.1	21.8	10.4		20.2 + 0.9 (8)	*	

[a]Thermocline depth ± one standard deviation with number of stations in parentheses.
[b]"–" indicates no data.
[c]"*" indicates isothermal conditions.

Table 20. Summer survey estimated layer thickness (meters) and the percentage of total average basin depth in the central and eastern basins of Lake Erie, 1983, 1984 and 1985.

	1983		1984		1985[b]*	
Central Basin	Thickness meters	(%)	Thickness meters	(%)	Thickness meters	(%)
Epilimnion Thickness	12.6	(57)	14.7	(66)	18.8	(86)
Mesolimnion Thickness	4.2	(19)	3.5	(15)	1.5	(07)
Hypolimnion Thickness	5.4	(24)	4.3	(19)	1.6	(07)
Total Depth	22.2		22.5		21.9	
Eastern Basin	Thickness meters	(%)	Thickness meters	(%)[a]	Thickness meters	(%)
Epilimnion Thickness	14.4	(31)	15.2	(32)	17.8	(41)
Mesolimnion Thickness	10.5	(22)	8.2	(17)	6.3	(14)
Hypolimnion Thickness	22.2	(47)	23.9	(50)	19.7	(45)
Total Depth[a]	47.0		47.3		43.8	

[a]Totals and % may not add up due to rounding.
[b]Station network expanded to IJC 1986 Lake Erie GLISP recommended locations.

thermally stable. Nepheloid layers in the Great Lakes have been a subject of interest (Sandilands and Mudroch, 1983; Eadie et al., 1984) because of the high concentrations of many chemical species associated with the particulate matter forming that layer. Table 21 shows the contrasts between parameter concentration within the benthic nepheloid layer (here defined as the B10 and B2 samples in Lakes Michigan and Huron and B10 and B1 in Lake Erie) and the hypolimnion in Lakes Michigan, Huron, and Erie.

Nutrients

Vertical profiles of major nutrient concentrations measured at 1985 master stations are plotted in Figures 19 to 28. These profiles show epilimnetic depletion of dissolved silicon and nitrate + nitrite nitrogen during the summer survey, along with hypolimnetic and nepheloid enrichment. These nutrients are reintroduced after "fall overturn" into the eplimnetric waters resulting in a generally isoclinic concentration.

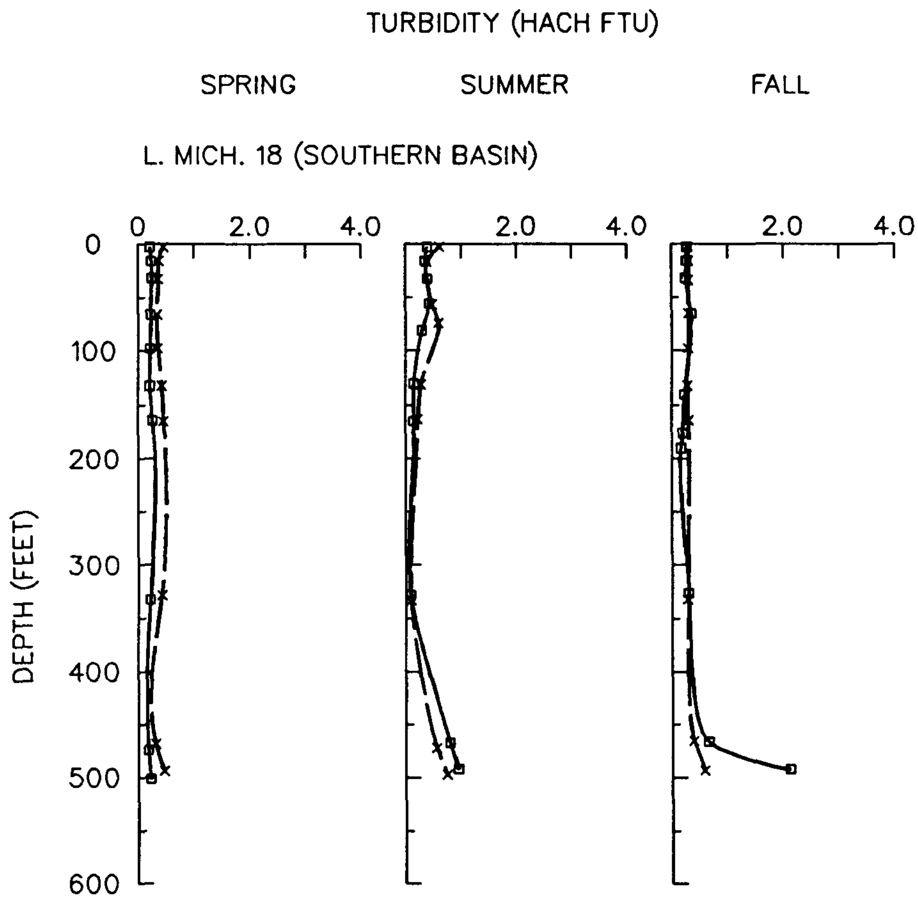


Figure 14. Vertical profiles of turbidity in southern Lake Michigan, station 18, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

Stations LM18, LH43, and LH93 sampled on Fall-1 before the fall overturn and stations LM18, LH45, and LM15 sampled on Fall-2 after overturn clearly demonstrate the breakdown of the deep thermocline and effect of the "fall overturn." The Fall-2 profiles are similar to corresponding spring profiles while Fall-1 profiles are similar to summer profiles. Fall-2 overturn concentrations are generally equal to or lower than the corresponding spring concentrations for nitrate + nitrite nitrogen, while Fall-2 dissolved silicon concentrations are generally equal to or higher than corresponding spring concentrations. These patterns are also

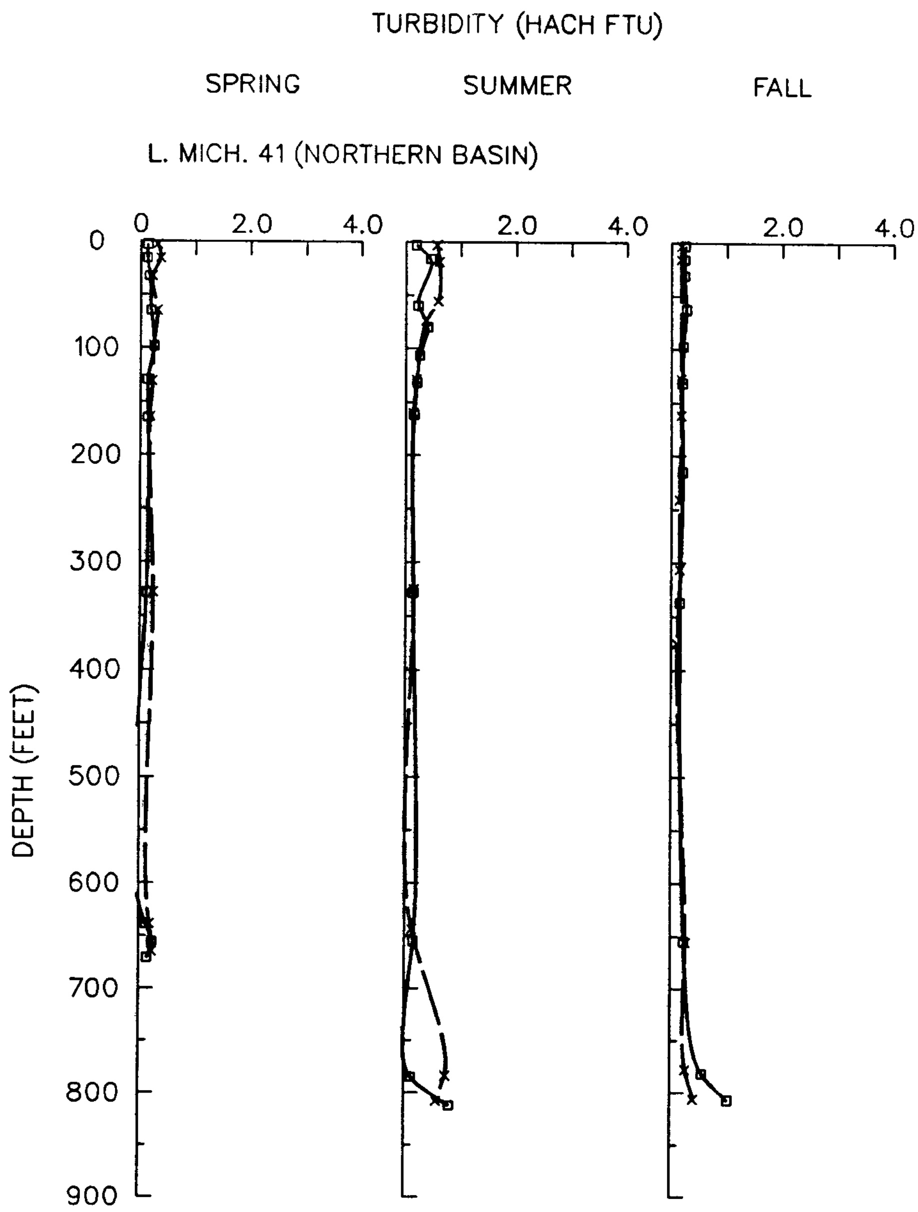


Figure 15. Vertical profiles of turbidity in northern Lake Michigan, station 41, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

observed in eastern Lake Erie and western Lake Erie. Central Lake Erie differs in that epilimnetic nutrient enrichment occurred during the August survey (when compared to spring nutrient levels) due to reintroduction of

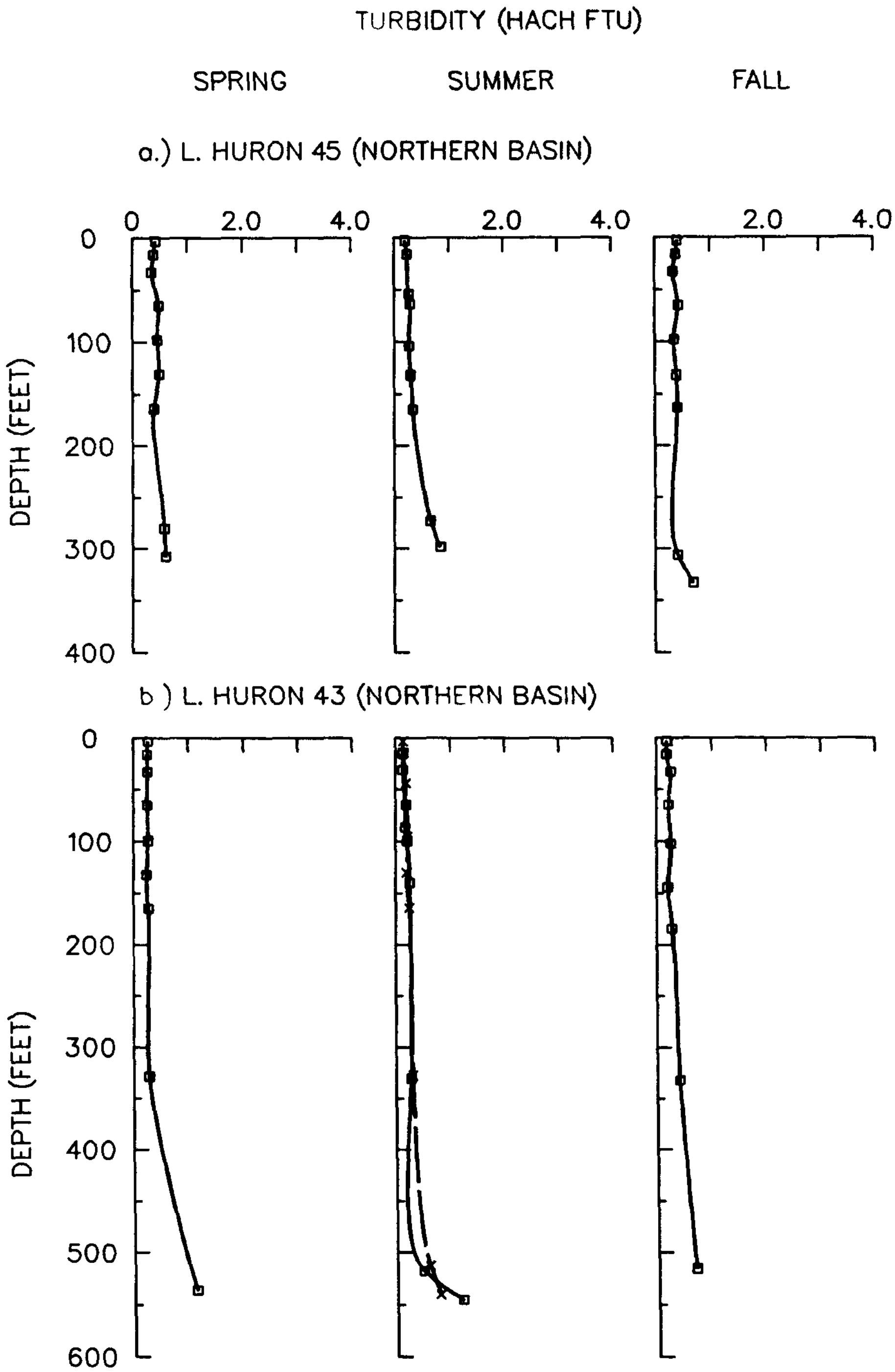


Figure 16. Vertical profiles of turbidity in northern Lake Huron, stations 45 and 43, during the spring, summer and fall surveys. See Figure 17 for a detailed explanation.

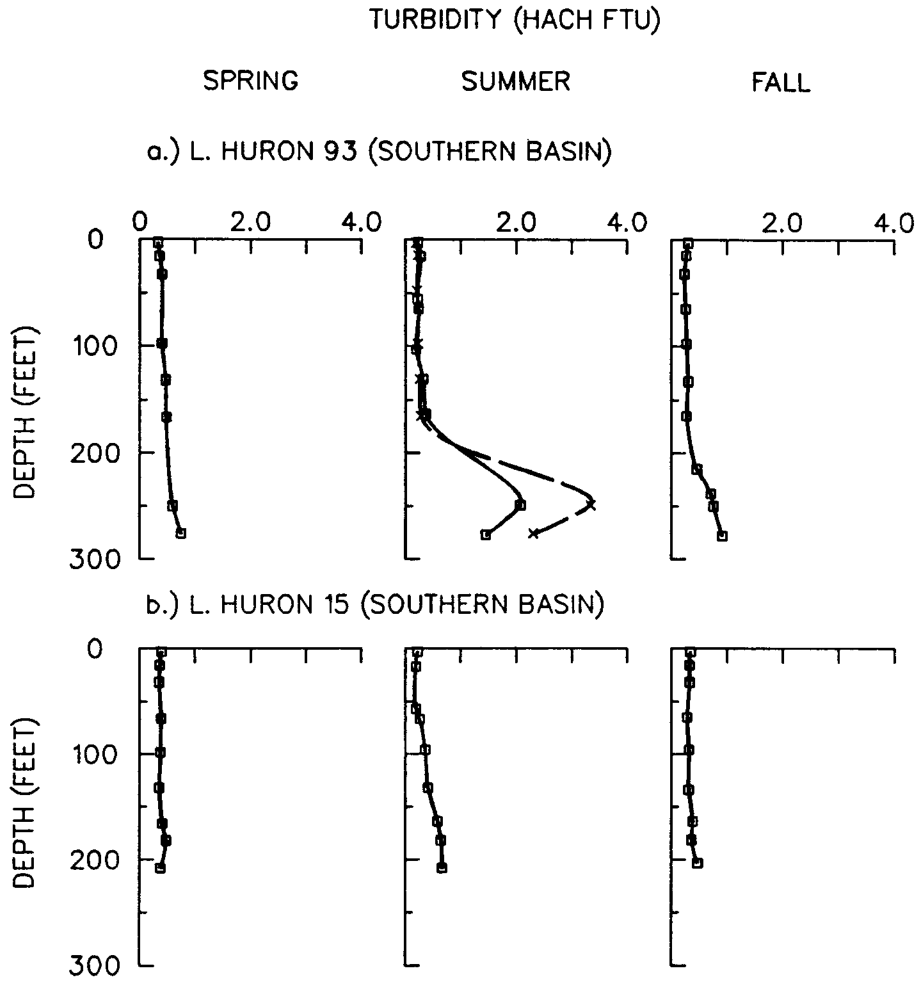


Figure 17. Vertical profiles of turbidity in southern Lake Huron, stations 93 and 15, during the spring, summer and fall surveys. In a). the observed data of the second runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. In b). the observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. Also in b)., the observed data of the third run of the summer survey are shown as xs with a dashed smoothing curve.

soluble nutients from the anoxic hypolimnion.

Because the nepheloid layers were so distinct after stratification, samples taken within them are included as a separate subset in the statistical summaries that follow. These subsets differ from 1983 and 1984 analyses (Lesht and Rockwell, 1985 and 1987) in that only B1, B2

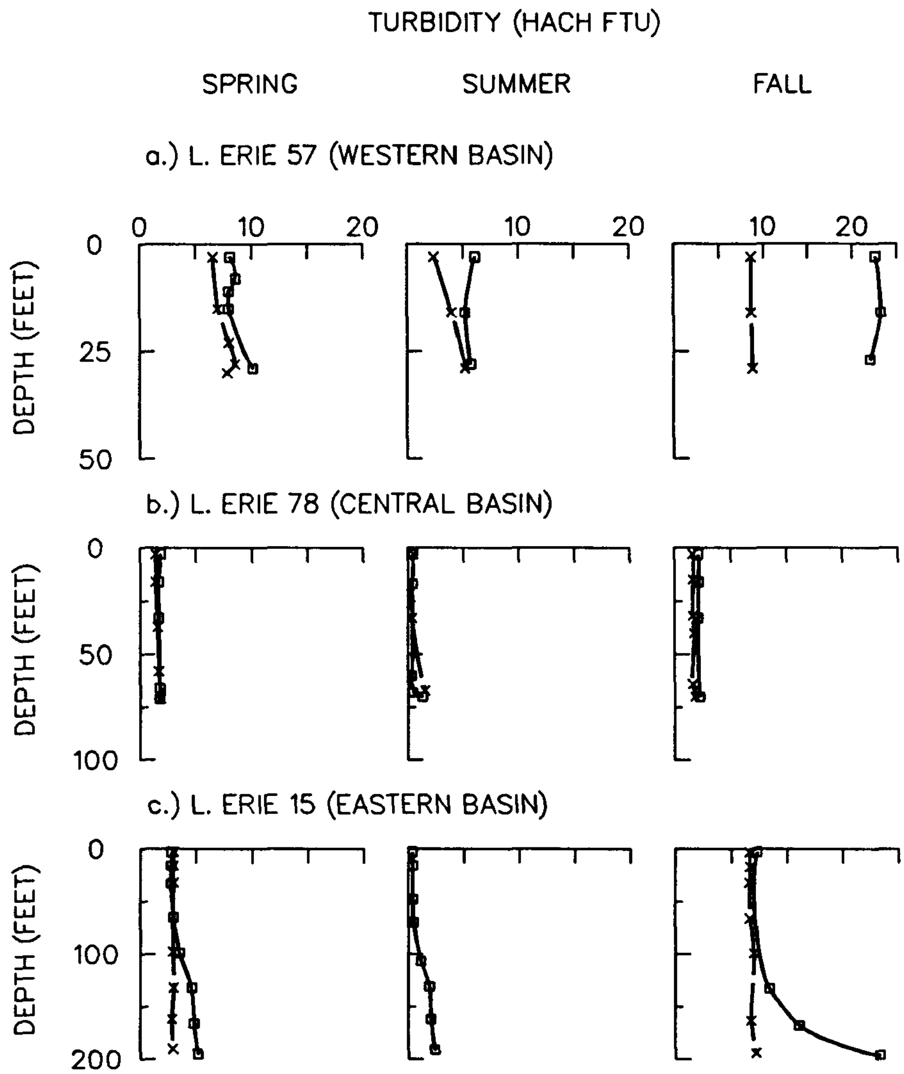


Figure 18. Vertical profiles of turbidity in western, station 57; central, station 78; and eastern, station 15, Lake Erie, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

and/or B10 depths are included in the nepheloid layer if the depths were below the thermocline. If the theromocline was deeper than B10 or if the water column was isothermal, these depths were not included in the nepheloid layer.

Table 21. Comparison of summer survey basin mean values of turbidity, nutrients, conductivity, and temperature in the hypolimnia and nepheloid layers of Lakes Michigan, Huron and Erie, 1985. [a,b]

Parameter	Southern Lake Michigan Hypolimnion	Southern Lake Michigan Nepheloid	t[c]	Northern Lake Michigan Hypolimnion	Northern Lake Michigan Nepheloid	t
Turbidity (FTU)	0.32 ± 0.18 (34)	0.88 ± 0.45 (35)	-6.82*	0.20 ± 0.10 (37)	0.75 ± 0.27(30)	-10.76*
Dissolved reactive silicon	431 ± 204 (34)	906 ± 298 (36)	-7.80*	420 ± 97 (37)	1004 ± 199 (30)	-14.72*
Nitrate + nitrite nitrogen	274 ± 23 (34)	316 ± 18 (36)	-8.48*	283 ± 15 (37)	314 ± 15 (30)	- 8.36*
Total phosphorus	3.5 ± 1.4 (34)	6.0 ± 3.2 (35)	-4.33*	3.4 ± 1.6 (36)	8.0 ± 2.3 (30)	- 9.71*
Total dissolved phosphorus	1.6 ± 1.1 (34)	3.7 ± 2.7 (36)	-4.21*	1.6 ± 1.0 (36)	5.7 ± 2.3 (30)	- 9.08*
Dissolved ortho phosphorus	0.6 ± 0.7 (22)	2.6 ± 2.2 (23)	-5.22*	0.9 ± 0.7 (37)	4.0 ± 2.6 (30)	- 6.36*
Conductivity (uS/cm)	281.1 ± 0.81 (34)	283.1 ± 0.96 (36)	-8.31*	281.4 ± 0.79 (37)	283.1 ± 1.11 (30)	- 7.08*
Temperature (°C)	4.9 ± 0.7 (34)	4.1 ± 0.3 (36)	5.74*	4.5 ± 0.6 (37)	3.8 ± 0.1 (30)	+ 6.87*

Parameter	Southern Lake Huron Hypolimnion	Southern Lake Huron Nepheloid	t	Northern Lake Huron Hypolimnion	Northern Lake Huron Nepheloid	t
Turbidity (FTU)	0.34 ± 0.13 (19)	1.14 ± 0.67 (25)	-5.84*	0.29 ± 0.09 (29)	0.92 ± 0.55 (34)	- 6.61*
Dissolved reactive silicon	767 ± 133 (19)	1061 ± 161 (25)	-6.49*	685 ± 90 (29)	977 ± 127 (34)	-10.37*
Nitrate + nitrite nitrogen	334 ± 21 (19)	363 ± 19 (25)	-4.85*	323 ± 21 (29)	354 ± 14 (34)	- 6.73*
Total phosphorus	2.9 ± 0.8 (19)	4.1 ± 1.4 (25)	-3.47*	2.8 ± 1.1 (29)	3.3 ± 1.6 (34)	- 1.34*
Total dissolved phosphorus	1.2 ± 0.5 (19)	1.1 ± 0.3 (25)	+0.76*	1.5 ± 0.8 (29)	1.3 ± 0.5 (34)	+ 0.84*
Dissolved ortho phosphorus	0.5 ± 0.3 (19)	0.7 ± 0.3 (25)	-2.01*	0.4 ± 0.4 (29)	0.6 ± 0.5 (34)	- 1.67*
Conductivity (uS/cm)	205.9 ± 1.84 (19)	206.8 ± 1.65 (25)	-1.53	204.4 ± 1.21 (29)	204.8 ± 0.92 (34)	+ 1.62*
Temperature (°C)	5.7 ± 0.8 (19)	4.8 ± 0.6 (25)	4.45*	5.1 ± 0.8 (29)	4.1 ± 0.2 (34)	+ 6.18*

Parameter	Eastern Lake Erie Hypolimnion	Eastern Lake Erie Nepheloid	t
Turbidity (FTU)	1.59 ± 0.40 (10)	1.92 ± 0.33 (16)	-2.29*
Dissolved reactive silicon	303 ± 83 (10)	341 ± 59 (16)	-1.34*
Nitrate + nitrite nitrogen	346 ± 35 (10)	349 ± 28 (16)	-0.25*
Total phosphorus	7.1 ± 2.4 (10)	7.5 ± 2.6 (16)	-0.36
Total dissolved phosphorus	2.5 ± 0.8 (10)	3.4 ± 2.1 (16)	-1.49
Dissolved ortho phosphorus	2.5 ± 0.9 (10)	2.8 ± 0.6 (15)	-1.17
Conductivity (uS/cm)	286.6 ± 1.4 (10)	287.0 ± 1.3 (16)	-0.81
Temperature (°C)	5.8 ± 1.1 (10)	5.7 ± 1.2 (16)	+0.33

[a]Values given are means ± one standard deviation with the number of samples in parentheses.
[b]All nutrient concentrations are in ug/L.
[c]t value significant to reject null hypothesis that hypolimnion and nepheloid values are equal, alpha= 0.05.

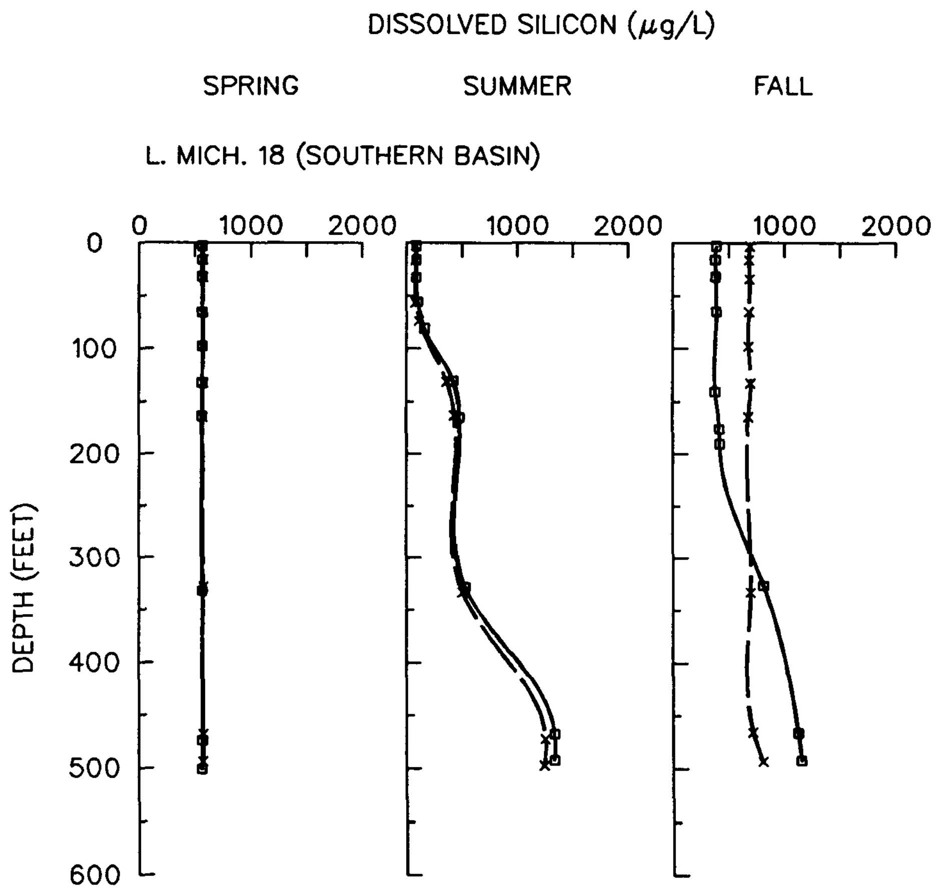


Figure 19. Vertical profiles of dissolved silicon in southern Lake Michigan, station 18, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

Vertical profiles of some of the other nutrient concentrations measured at selected master stations during 1985 are plotted in Figures 29 to 32. These profiles show (1) the deep thermocline maxima of ammonia nitrogen which occurs in the summer; (2) the general low concentration of total and total dissolved phosphorus throughout the water column with summer and fall elevated concentrations in the hypolimnion and nepheloid layers; and (3) the dramatic increase in phosphorus concentrations in the central basin of Lake Erie during the stratified period when anoxic conditions occur.

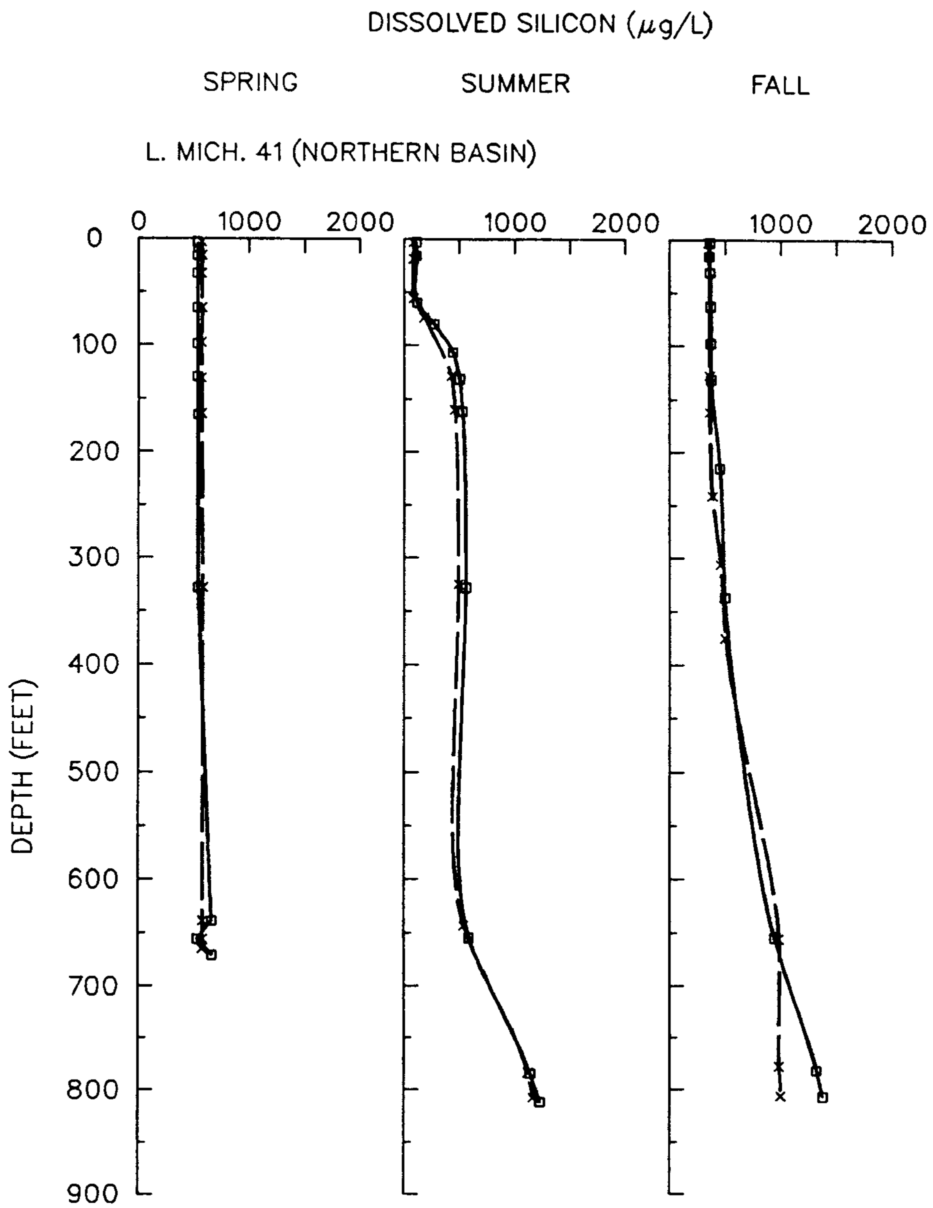


Figure 20. Vertical profiles of dissolved silicon in northern Lake Michigan, station 41, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

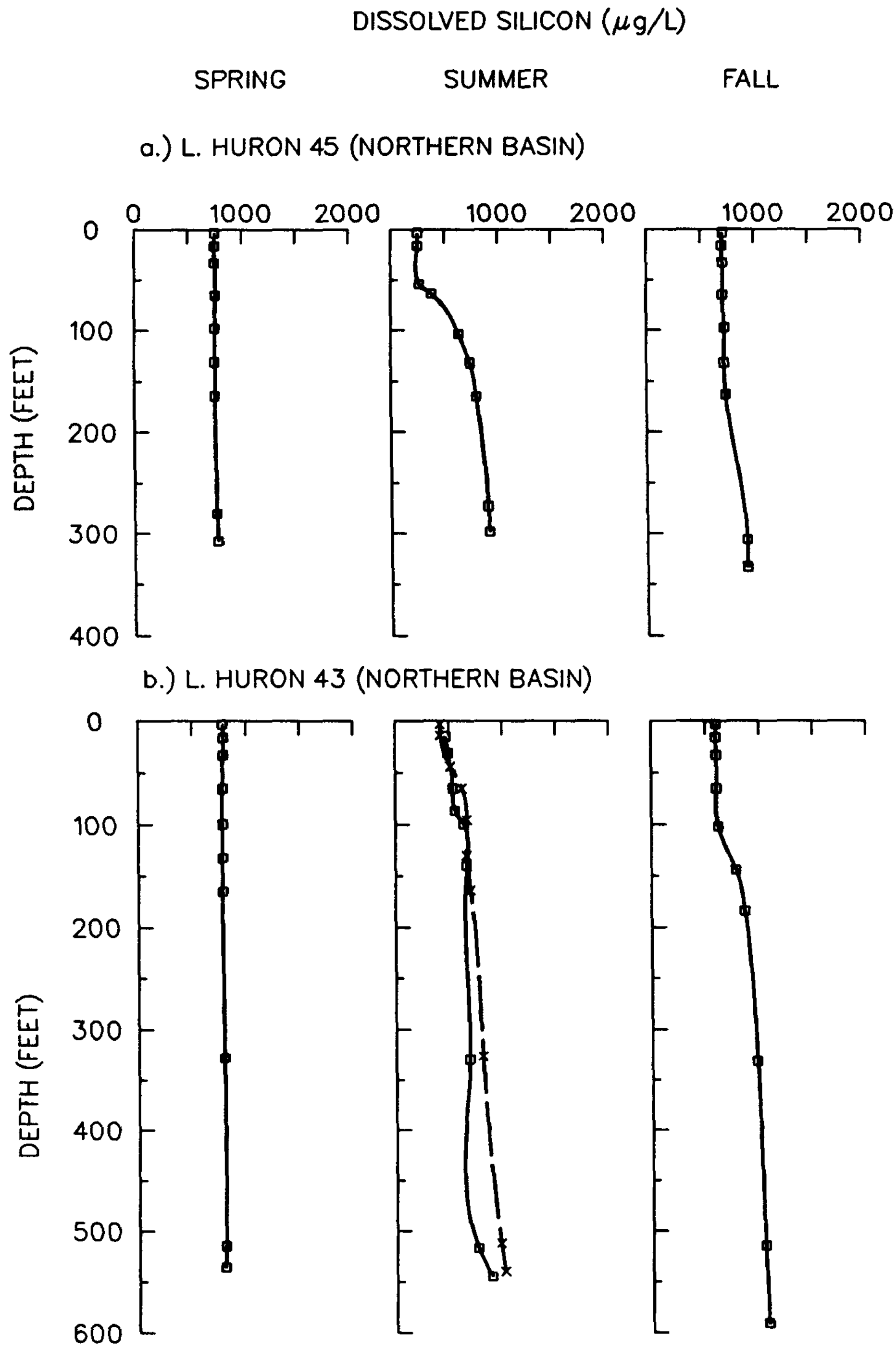


Figure 21. Vertical profiles of dissolved silicon in northern Lake Huron, stations 45 and 43, during the spring, summer and fall surveys. See Figure 22 for a detailed explanation.

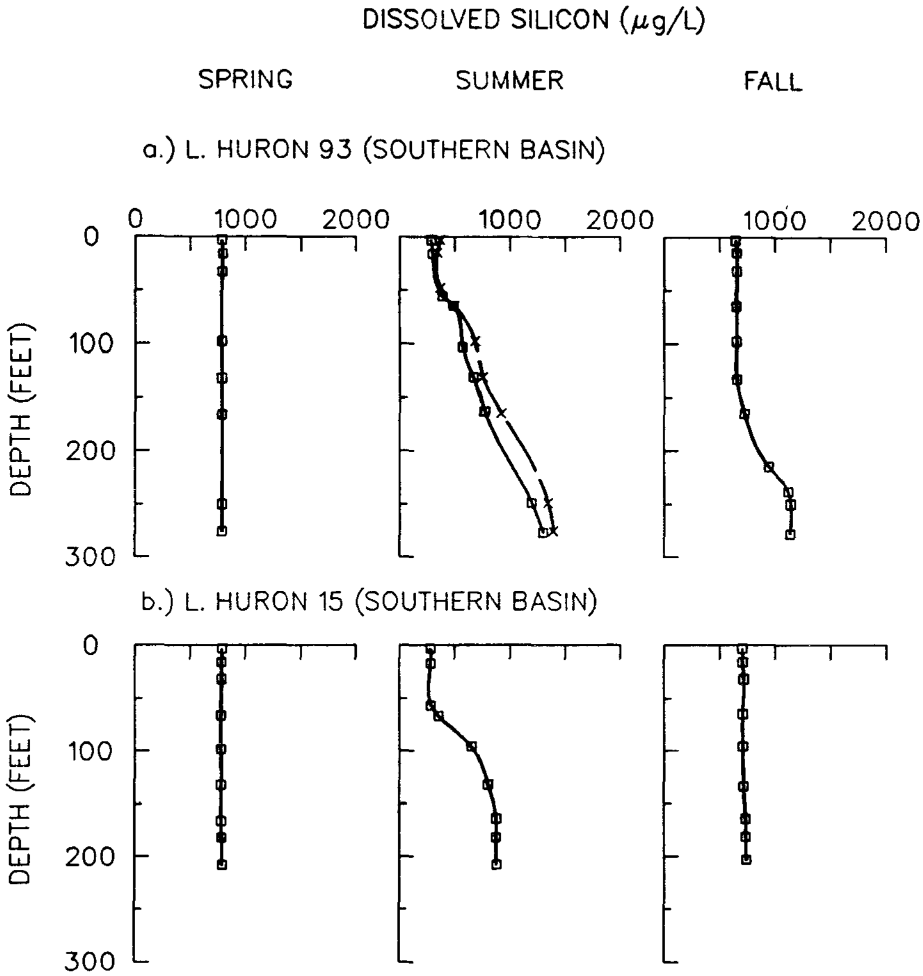


Figure 22. Vertical profiles of dissolved silicon in southern Lake Huron, stations 93 and 15, during the spring, summer and fall surveys. In a). the observed data of the second runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. In b). the observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. Also in b)., the observed data of the third run of the summer survey are shown as xs with a dashed smoothing curve.

PARAMETER MEAN VALUES BY BASIN, SURVEY, AND LAYER

The surveillance data were edited before final statistical analyses were performed. The editing procedure consisted primarily of correcting data entry errors that occurred when the raw data were entered into the STORET Water Quality Database and of eliminating a few data outliers.

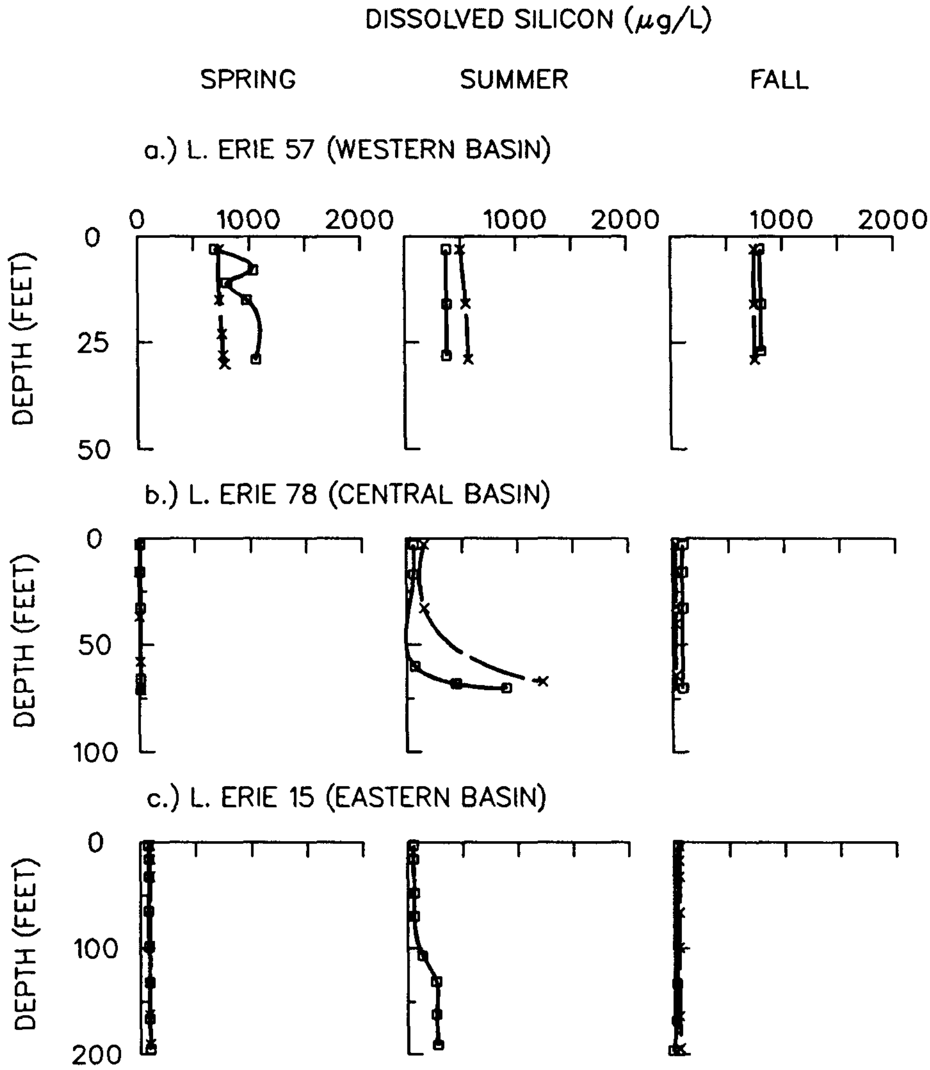


Figure 23. Vertical profiles of dissolved silicon in western, station 57; central, station 78; and eastern, station 15, Lake Erie, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

Outliers were identified in the course of the initial statistical processing. Extreme values were checked against the original survey and analysis logs and kept unless there was evidence of either contamination or analytical error. Since data values determined to be below the criterion of detection for a particular parameter were entered into the

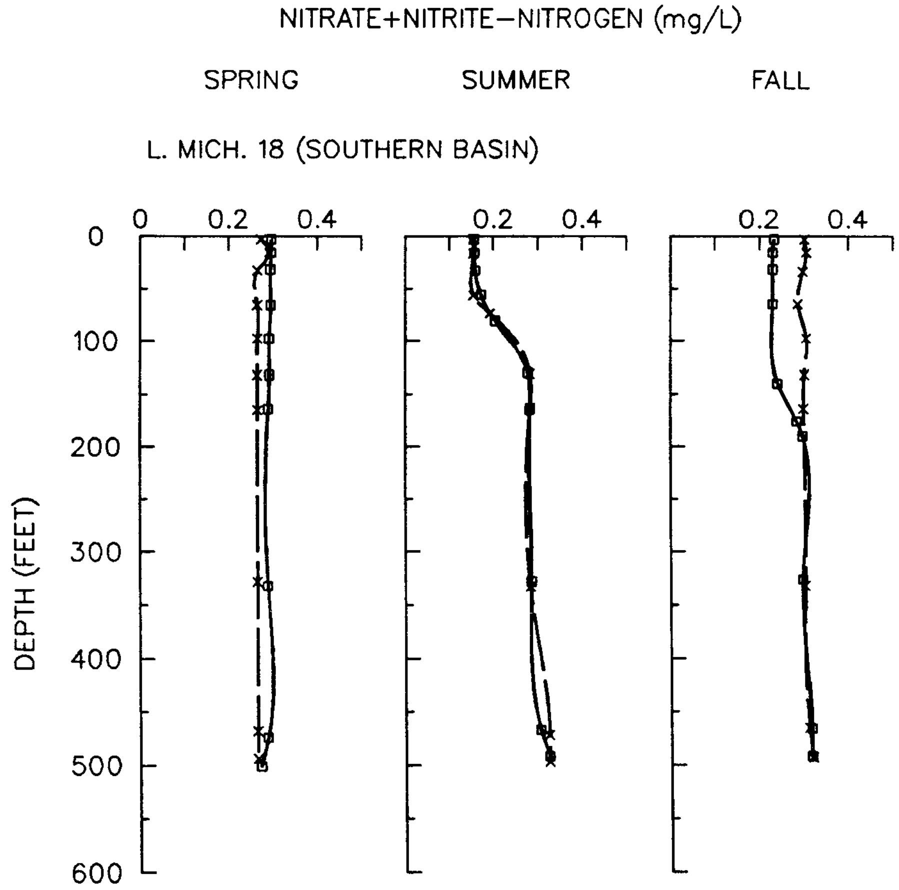


Figure 24. Vertical profiles of dissolved nitrate+nitrite nitrogen in southern Lake Michigan, station 18, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

database as real values rather than "less than" values, these values were included in the statistical summary. This is in accordance with the recommendations of the International Joint Commission's Data Quality Work Group (Clark, 1980).

Tables 22 through 24 present mean parameter values for each basin, survey, and layer, when applicable. During spring isothermal periods prior to stratification all samples are called "epilimnion" (STORET profile codes 50, 450.5, and 505). During stratified periods the

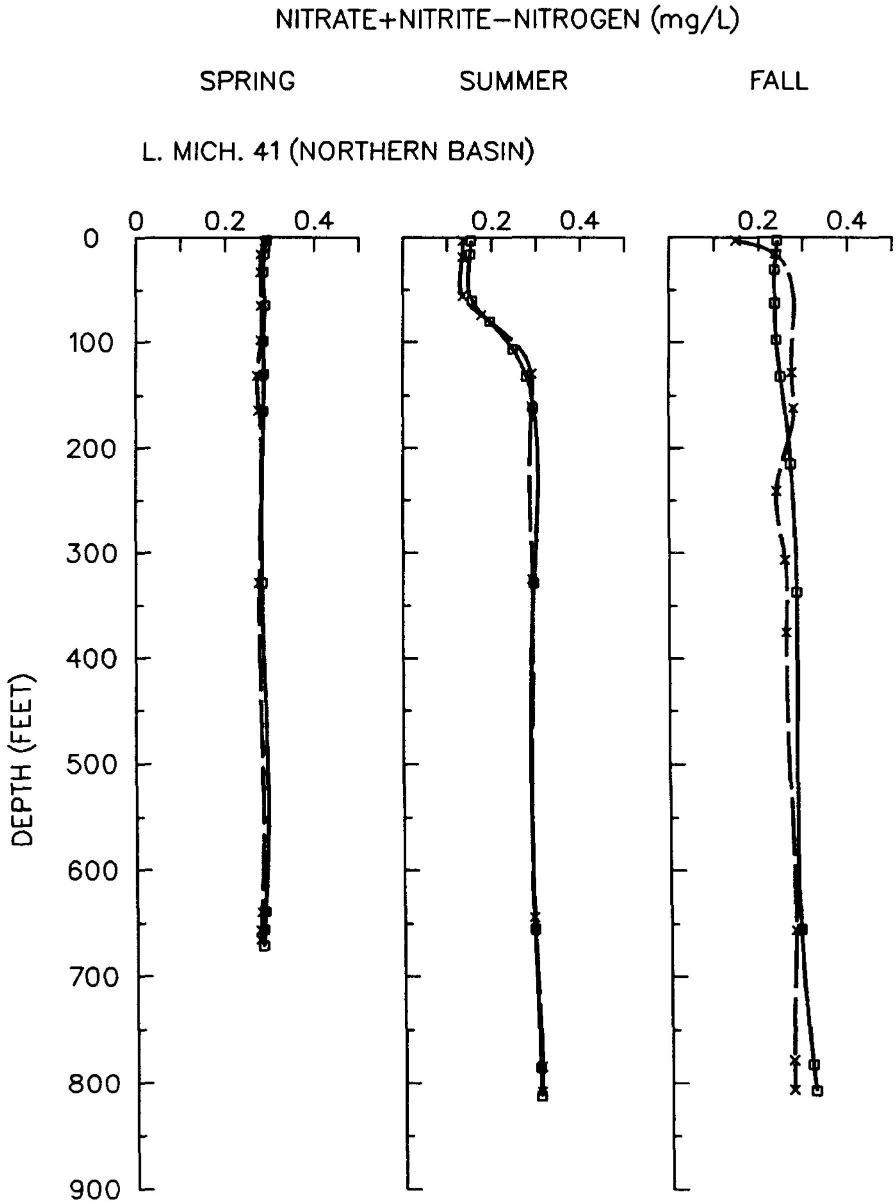


Figure 25. Vertical profiles of dissolved nitrate+nitrite nitrogen in northern Lake Michigan, station 41, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

epilimnion includes samples taken from the surface and including the sample at the upper knee of the thermocline (STORET profile codes 100-200), and the mesolimnion includes samples taken at the thermocline

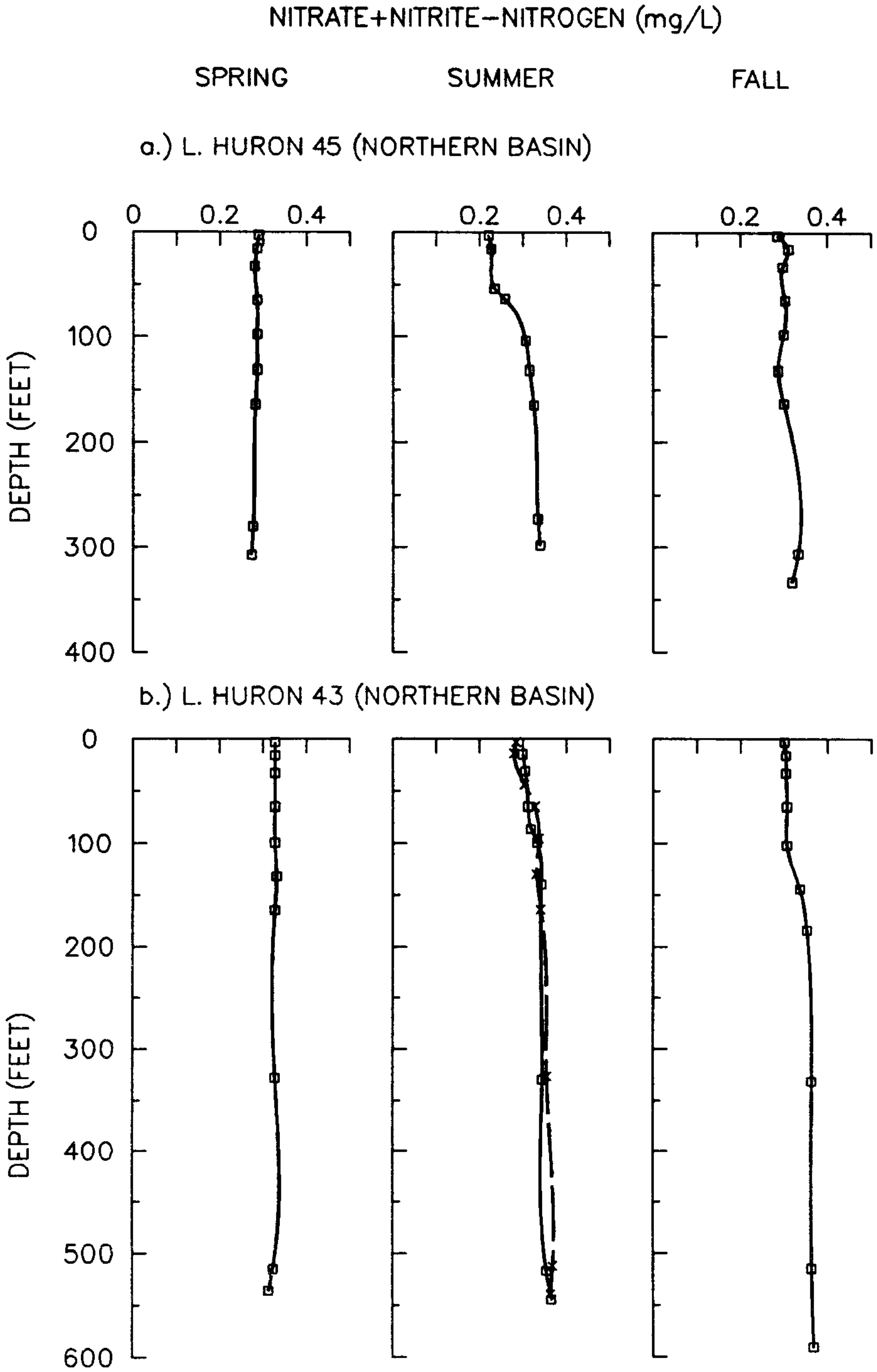


Figure 26. Vertical profiles of dissolved nitrate+nitrite nitrogen in northern Lake Huron, stations 45 and 43, during the spring, summer and fall surveys. See Figure 27 for a detailed explanation.

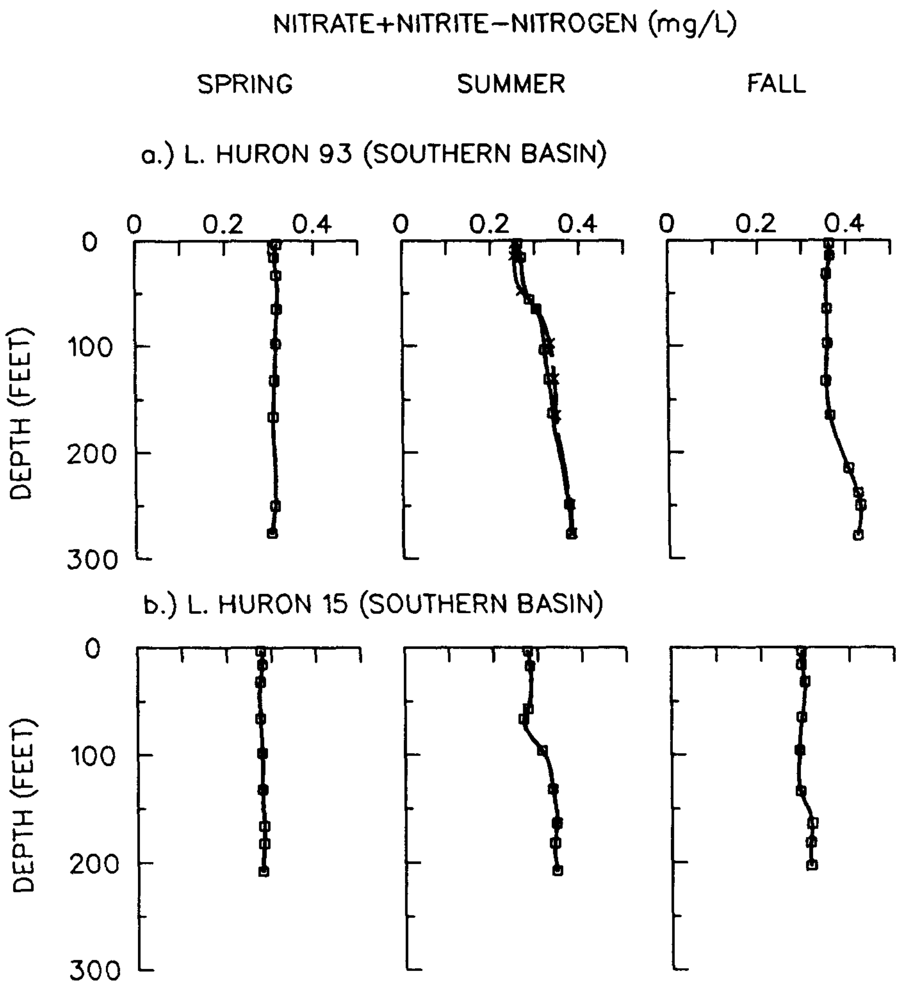


Figure 27. Vertical profiles of dissolved nitrate+nitrite nitrogen in southern Lake Huron, stations 93 and 15, during the spring, summer and fall surveys. In a). the observed data of the second runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. In b). the observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. Also in b)., the observed data of the third run of the summer survey are shown as xs with a dashed smoothing curve.

(STORET profile code 300). The hypolimnion includes all samples taken at and below the lower knee of the thermocline which are not in the nepheloid layer (profile code 350-400), and the nepheloid layer is defined as including samples taken within 10 m of the bottom (profile codes 450-500) and below the thermocline. Samples taken within 10 m of the bottom but not in the nepheloid layer are placed in appropriate layers. STORET

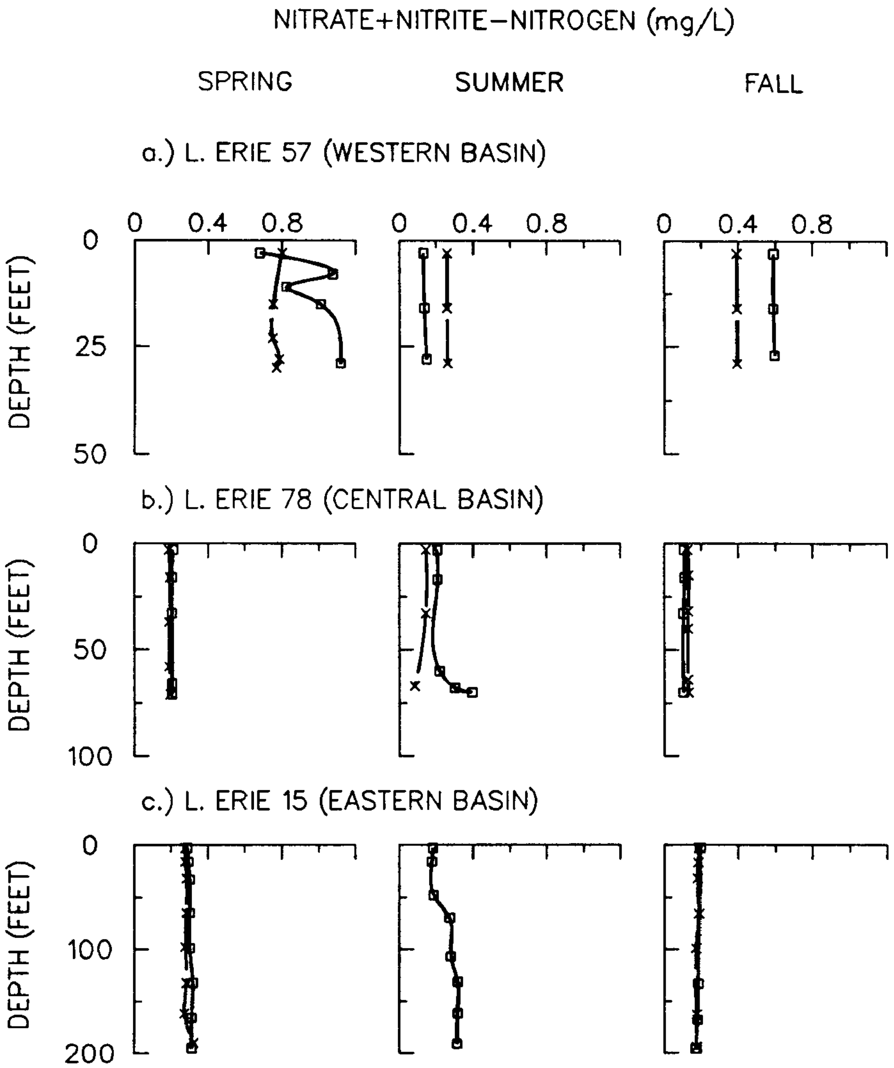


Figure 28. Vertical profiles of dissolved nitrate+nitrite nitrogen in western, station 57; central, station 78; and eastern, station 15, Lake Erie, during the spring, summer and fall surveys. The observed data of the first runs of the spring, summer and fall surveys are shown as open squares with a solid smoothing curve. The observed data of the second runs of the spring and fall surveys as well as the third run of the summer survey are shown as xs with a dashed smoothing curve.

profile codes 451.5, 452, and 520 are epilimnion samples. STORET profile codes 453, 530 are mesolimnion samples. STORET profile codes 453.5 and 535 are hypolimnion samples. These codes are used primarily in Lake Erie where the thermocline is generally located within 10 meters of the Lake

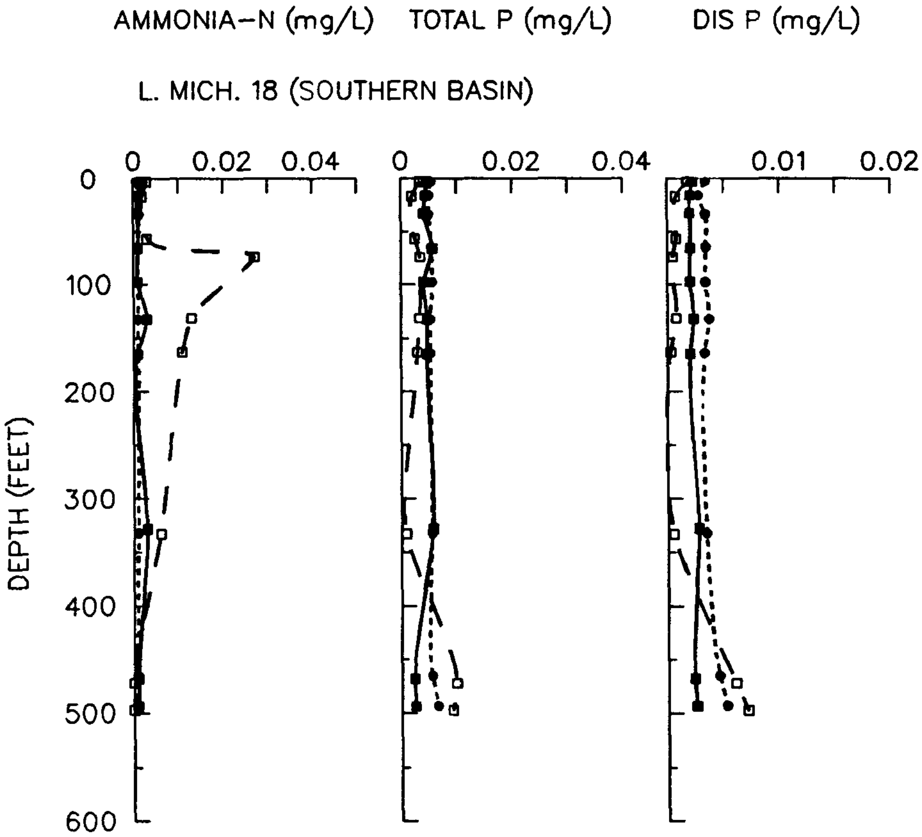


Figure 29. Vertical profiles of dissolved ammonia nitrogen, total phosphorus and total dissolved phosphorus in southern Lake Michigan, station 18, during the spring, summer and fall surveys. The observed data of the second run of the spring survey are shown as solid squares with a solid smoothing curve. The observed data of the third run of the summer survey are shown as open squares with a dashed smoothing curve. The observed data of the second run of the fall survey are shown as solid dots with a short-dashed smoothing curve.

bottom during August. A complete statistical summary is included in Appendix A.

COMPOSITED UPPER 20-METER SAMPLES

In addition to the water samples taken at discrete depths, one composite sample composed of equal volumes of water taken from several depths in the upper twenty meters of the water column (i.e., at 1, 5, 10, and 20 meters) was obtained at each station where the water column

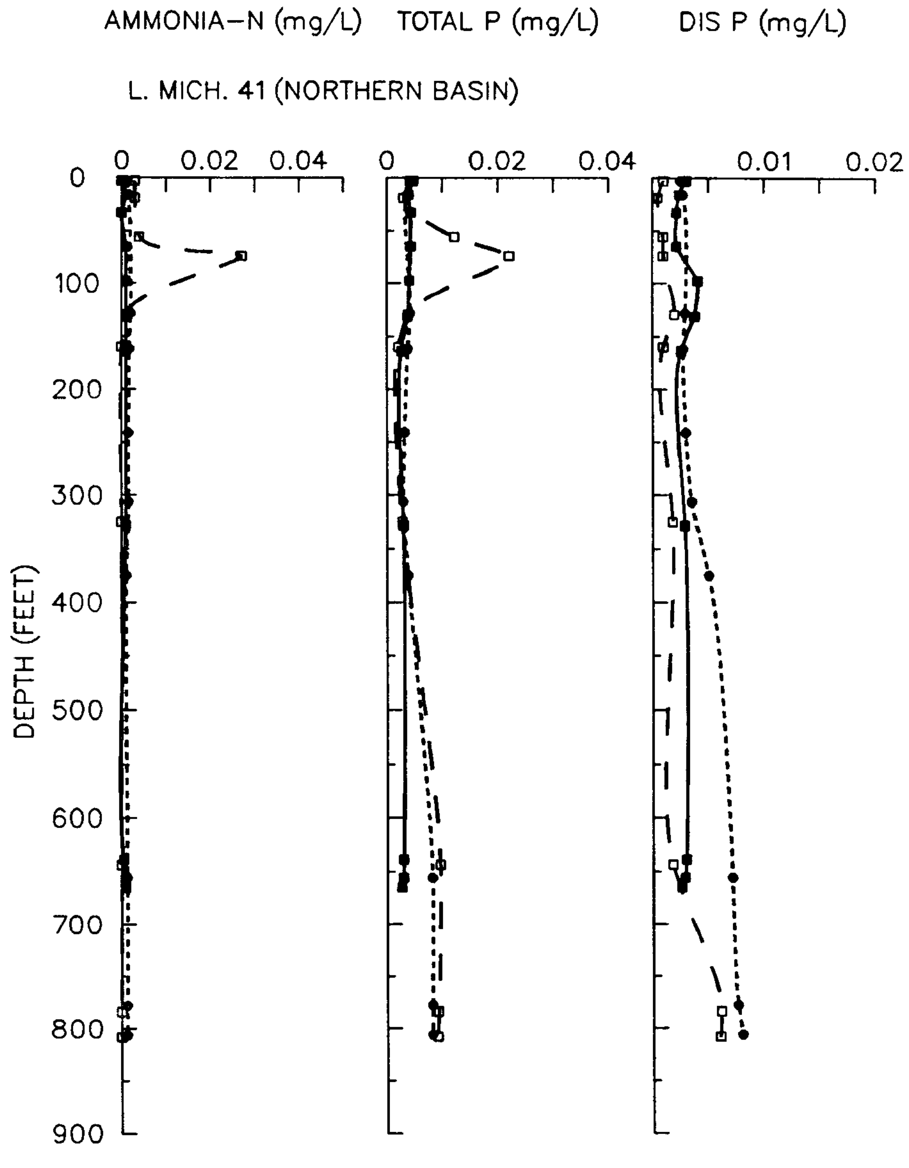


Figure 30. Vertical profiles of dissolved ammonia nitrogen, total phosphorus and total dissolved phosphorus in northern Lake Michigan, station 41, during the spring, summer and fall surveys. The observed data of the second run of the spring survey are shown as solid squares with a solid smoothing curve. The observed data of the third run of the summer survey are shown as open squares with a dashed smoothing curve. The observed data of the second run of the fall survey are shown as solid dots with a short-dashed smoothing curve.

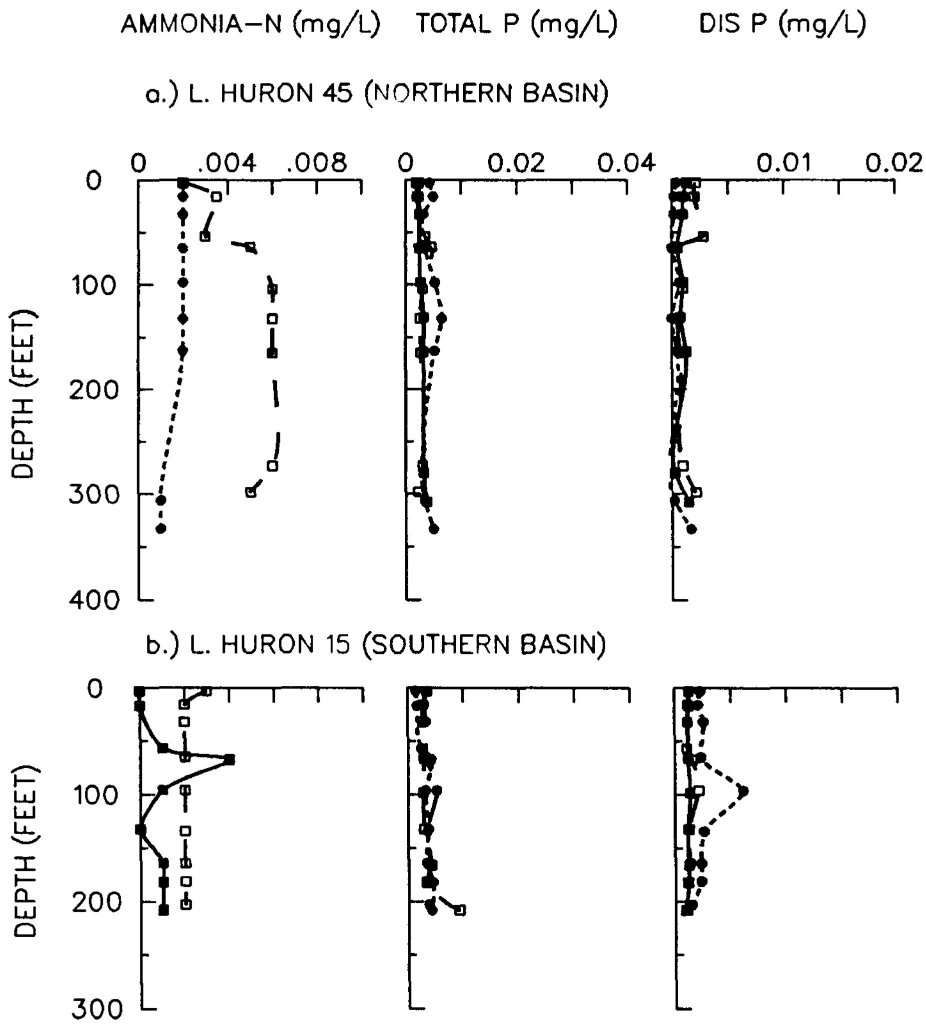


Figure 31. Vertical profiles of dissolved ammonia nitrogen, total phosphorus and total dissolved phosphorus in northern, station 45; and southern, station 15, Lake Huron, during the spring, summer and fall surveys. The observed data of the second run of the spring survey are shown as solid squares with a solid smoothing curve. The observed data of the second run of the summer survey are shown as open squares with a dashed smoothing curve. The observed data of the second run of the fall survey are shown as solid dots with a short-dashed smoothing curve.

equaled or exceeded twenty meters. Equal aliquots were taken from the prescribed samples depths for stations with less than twenty meters of water in Lake Erie's western basin. This sample, intended primarily for

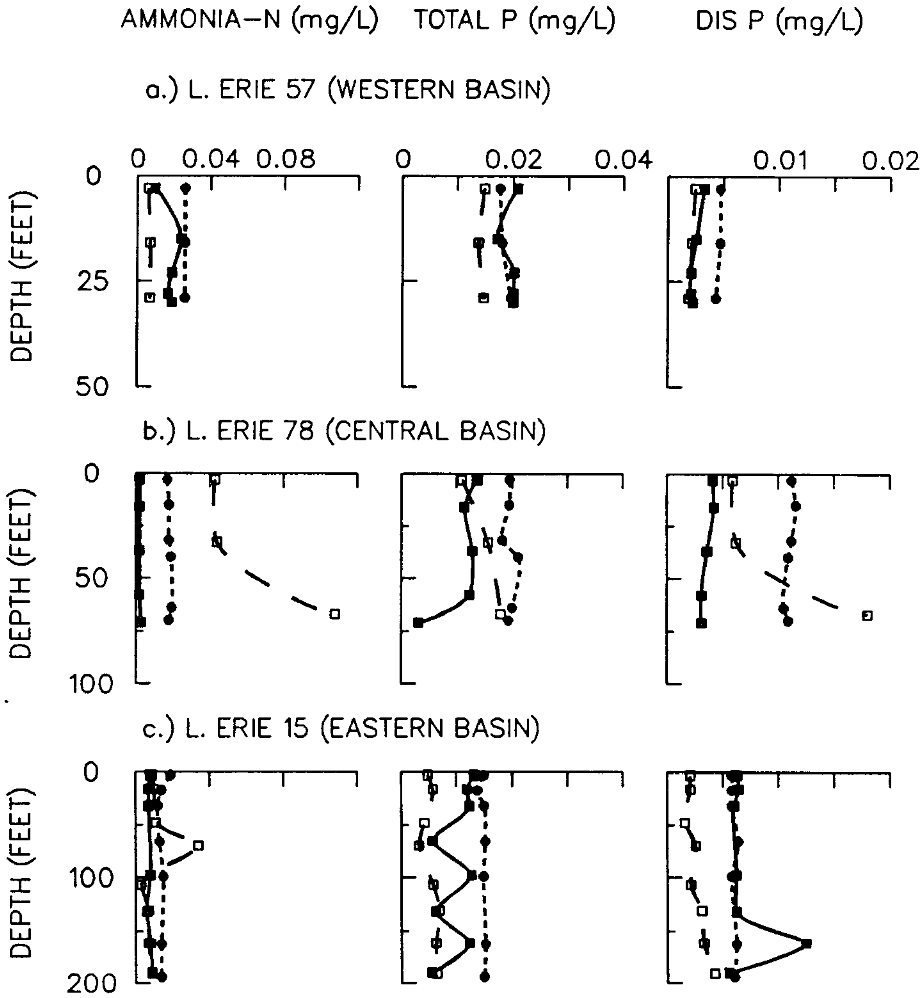


Figure 32. Vertical profiles of dissolved ammonia nitrogen, total phosphorus and total dissolved phosphorus in western, station 57; central, station 78; and eastern, station 15, Lake Erie, during the spring, summer and fall surveys. The observed data of the second run of the spring survey are shown as solid squares with a solid smoothing curve. The observed data of the first (c) or third (a and b) run of the summer survey are shown as open squares with a dashed smoothing curve. The observed data of the second run of the fall survey are shown as solid dots with a short-dashed smoothing curve.

the analysis of plankton, was also analyzed for chlorophyll-a, nutrients, chloride, and sulfate. The mean values of these constituents averaged over the survey and basin are shown in Table 25.

Table 22. Parameter means by basin, survey, and layer — Lake Michigan, 1985.

Survey/layer	Temperature (°C)	Turbidity (FTU)	Chloro-phyll-a (ug/L)	Pheophytin (ug/L)	Total Phosphorus (ug/L)	Total dissolved Phosphorus (ug/L)	Ortho Phosphorus (ug/L)	$NO_2 + NO_3$ Nitrogen (ug/L)	NH_3 Nitrogen (ug/L)	Total Kjeldahl Nitrogen (ug/L)
					Northern Basin					
Winter-2										
Epilimnion	1.5	–[a]	0.89	−0.12	5.6	4.1	1.8	290.5	4.4	200.0
Spring										
Epilimnion	2.5	0.34	0.75	−0.01	5.2	2.8	0.9	286.3	1.6	80.5
Summer										
Epilimnion	18.5	0.36	1.00	0.12	4.5	1.2	0.4	155.6	3.6	183.7
Mesolimnion	12.3	0.28	1.32	0.30	5.6	1.3	0.6	195.8	9.9	177.3
Hypolimnion	4.5	0.20	0.74	0.24	3.4	1.6	0.9	282.7	3.5	127.4
Nepheloid	3.8	0.75	0.44	0.28	8.0	5.8	4.0	313.7	1.0	132.2
Fall-1										
Epilimnion	8.1	0.23	0.78	0.23	3.2	2.1	−0.3	232.1	1.4	102.5
Mesolimnion	6.6	0.19	0.14	0.12	2.2	1.8	−0.3	279.0	0.8	112.0
Hypolimnion	4.3	0.20	0.05	0.10	3.3	3.2	1.4	293.1	0.6	73.8
Neptheloid	3.9	0.84	0.08	0.27	9.0	6.9	4.2	310.9	1.0	107.0
Fall-2										
Epilimnion	6.5	0.26	0.32	0.11	4.3	3.0	0.4	246.4	1.5	46.7
Mesolimnion	5.2	0.32	0.13	0.09	4.4	4.0	1.0	276.3	1.5	73.0
Hypolimnion	4.2	0.34	0.04	0.06	6.4	5.6	2.6	288.6	1.2	46.1
Nepheloid	4.2	0.74	0.06	0.10	8.3	6.9	3.5	294.8	1.4	26.2
					Southern Basin					
Winter-2										
Epilimnion	2.0	–	0.79	−0.07	5.8	4.7	2.6	293.0	4.5	96.2
Spring										
Epilimnion	2.6	0.40	0.95	0.05	4.9	2.4	0.9	292.5	3.0	118.9
Summer										
Epilimnion	20.7	0.48	1.12	0.19	2.5	1.4	0.4	159.1	2.3	213.4
Mesolimnion	13.9	0.45	1.23	0.28	3.5	1.7	0.4	193.6	14.0	205.7
Hypolimnion	4.9	0.32	1.07	0.37	3.5	1.6	0.6	274.2	5.6	170.6
Nepheloid	4.1	0.88	0.71	0.39	6.0	3.7	2.6	316.0	0.5	160.0
Fall-1										
Epilimnion	8.3	0.25	0.56	0.16	4.0	2.4	0.2	248.9	2.4	168.0
Mesolimnion	6.7	0.32	0.22	0.10	2.7	1.5	0.6	289.4	1.4	186.0
Hypolimnion	4.7	0.30	0.13	0.06	3.4	2.1	0.8	310.0	3.3	207.1
Nepheloid	4.3	0.80	0.09	0.13	4.9	3.3	2.6	331.4	1.0	223.0
Fall-2										
Epilimnion	5.4	0.45	0.32	0.10	5.5	2.8	0.0	289.7	1.2	67.2

[a]"–" indicates no data.

Table 22. (Continued) Parameter means — Lake Michigan, 1985.

Survey/layer	Dissolved reactive silicon (ug/L)	pH	Alkalinity (mg/L)	Specific Conductance (uS/cm)	Dissolved Oxygen (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ mg/L	K^+ mg/L	Aerobic Heterotroph (Count/mL)
					Northern Basin							
Winter-1												
Epilimnion	545.2	8.03	109.5	283.5	12.8	9.0	22.4	–	–	–	–	–
Spring												
Epilimnion	562.8	8.17	107.9	279.8	12.7	8.8	22.3	–	–	–	–	1.4
Summer												
Epilimnion	92.9	8.54	108.0	276.6	9.9	8.6	21.6	35.2	11.0	5.4	1.2	101.5
Mesolimnion	144.9	8.45	108.4	279.0	12.3	8.5	21.8	–	–	–	–	–
Hypolimnion	420.2	8.18	108.3	281.4	12.6	8.5	22.0	–	–	–	–	129.4
Nepheloid	1003.6	8.08	109.0	283.1	11.9	8.5	22.0	35.9	11.0	5.4	1.2	99.8
Fall-1												
Epilimnion	337.6	8.36	107.2	281.1	10.8	8.6	21.7	–	–	–	–	16.9
Mesolimnion	409.2	8.20	107.4	282.8	11.0	8.6	21.8	–	–	–	–	–
Hypolimnion	588.5	8.18	107.8	283.1	11.4	8.6	22.0	–	–	–	–	20.0
Nepheloid	162.5	8.10	108.5	285.0	10.8	8.6	21.7	–	–	–	–	16.4
Fall-2												
Epilimnion	410.4	8.19	107.1	278.7	12.0	8.9	21.8	–	–	–	–	–
Mesolimnion	623.8	8.16	107.0	279.6	12.2	8.9	21.9	–	–	–	–	–
Hypolimnion	765.9	8.16	107.7	281.3	12.2	8.9	21.9	–	–	–	–	–
Nepheloid	922.7	8.04	107.6	281.6	12.1	8.9	22.0	–	–	–	–	–
					Southern Basin							
Winter-2												
Epilimnion	574.4	8.05	109.4	281.6	12.8	10.1	20.1	–	–	–	–	–
Spring												
Epilimnion	566.0	8.12	108.5	279.9	12.4	8.7	22.0	–	–	–	–	2.0
Summer												
Epilimnion	97.1	8.58	108.1	277.7	9.5	8.8	21.7	36.0	11.2	5.5	1.2	37.1
Mesolimnion	110.2	8.48	108.6	279.4	11.8	8.7	21.8	–	–	–	–	190.0
Hypolimnion	431.5	8.16	108.4	281.4	12.3	8.6	21.6	–	–	–	–	94.8
Nepheloid	906.1	8.07	108.9	283.1	11.9	8.6	21.7	36.4	11.1	5.3	1.2	95.0
Fall-1												
Epilimnion	389.0	8.34	107.0	282.0	9.9	9.0	22.0	–	–	–	–	27.9
Mesolimnion	509.2	8.19	107.0	283.0	10.1	8.9	21.6	–	–	–	–	–
Hypolimnion	669.3	8.14	107.8	283.3	10.4	9.0	21.8	–	–	–	–	47.2
Nepheloid	935.3	8.09	108.3	284.8	10.0	9.1	21.9	–	–	–	–	76.8
Fall-2												
Epilimnion	609.6	8.12	107.7	279.6	11.4	8.7	23.2	–	–	–	–	–

Table 23. Parameter means by basin, survey, and layer — Lake Huron, 1985.

Survey/layer	Temperature (°C)	Turbidity (FTU)	Chlorophyll-a (ug/L)	Pheophytin (ug/L)	Total Phosphorus (ug/L)	Total dissolved Phosphorus (ug/L)	Ortho Phosphorus (ug/L)	$NO_2 + NO_3$ Nitrogen (ug/L)	NH_3 Nitrogen (ug/L)	Total Kjeldahl Nitrogen (ug/L)
					Northern Basin					
Winter-1										
Epilimnion	1.8	–[a]	0.89	–0.02	3.0	2.1	0.8	335.5	0.8	213.3
Winter-2										
Epilimnion	0.8	–	0.80	–0.10	3.7	2.4	0.8	303.8	3.2	148.3
Spring										
Epilimnion	1.5	0.39	0.78	0.02	3.3	1.3	0.3	302.1	2.2	76.3
Summer										
Epilimnion	17.7	0.21	1.00	0.17	2.8	1.9	0.3	266.8	1.8	159.0
Mesolimnion	12.1	0.24	1.61	0.21	2.9	1.1	0.3	284.0	2.3	188.8
Hypolimnion	5.1	0.29	1.47	0.36	2.8	1.5	0.4	323.2	3.3	129.1
Nepheloid	4.1	0.92	0.66	0.42	3.3	1.3	0.6	353.8	2.2	124.2
Fall-1										
Epilimnion	7.9	0.21	0.58	0.09	2.9	1.1	0.0	308.0	2.5	88.3
Mesolimnion	6.3	0.24	0.23	0.13	2.3	1.1	0.3	338.0	2.0	56.7
Hypolimnion	4.6	0.36	0.14	0.04	2.2	1.4	0.3	355.6	1.4	62.0
Nepheloid	4.3	0.57	0.07	0.11	3.1	1.4	0.7	362.8	1.9	64.6
Fall-2										
Epilimnion	6.2	0.43	0.30	0.08	3.8	0.9	0.0	300.7	2.0	119.9
					Southern Basin					
Winter-1										
Epilimnion	2.0	–	0.85	0.02	4.8	3.0	1.9	331.3	1.5	116.7
Winter-2										
Epilimnion	0.2	–	1.30	–0.21	5.0	2.0	0.9	329.3	6.7	138.3
Spring										
Epilimnion	1.8	0.53	1.09	–0.04	3.6	1.3	0.5	300.9	2.6	112.4
Summer										
Epilimnion	19.7	0.25	1.36	0.13	2.3	1.2	0.5	276.4	1.4	198.4
Mesolimnion	13.8	0.28	2.77	0.25	3.0	1.2	0.6	297.2	3.6	195.8
Hypolimnion	5.8	0.34	0.94	0.29	2.9	1.2	0.5	334.2	2.1	171.6
Nepheloid	4.8	1.14	0.88	0.30	4.1	1.1	0.7	362.1	1.0	181.7
Fall-1										
Epilimnion	8.3	0.31	0.60	0.15	3.0	0.8	0.5	327.5	3.1	98.1
Mesolimnion	6.9	0.45	0.27	0.13	2.5	0.6	0.3	339.3	1.7	80.0
Hypolimnion	5.6	0.57	0.20	0.17	3.2	1.8	0.6	348.3	1.3	46.7
Nepheloid	5.3	0.71	0.15	0.17	3.9	1.5	0.5	353.2	1.5	87.5
Fall-2										
Epilimnion	6.9	0.42	0.40	0.05	3.7	2.1	–0.5	296.9	2.5	132.4
Mesolimnion	6.5	0.42	0.20	0.00	3.0	2.1	–0.9	341.0	1.0	130.0
Hypolumnion	5.2	0.63	0.00	0.20	3.3	1.7	–0.3	360.0	1.0	240.0
Nepheloid	5.1	0.72	0.10	0.05	3.7	3.3	0.0	361.0	1.0	80.0

[a]"–" indicates no data.

Table 23. (Continued) Parameter means — Lake Huron, 1985.

Survey/layer	Dissolved reactive silicon (ug/L)	pH	Alkalinity (mg/L)	Specific Conductance (uS/cm)	Dissolved Oxygen (mg/L)	Cl^- (mg/L)	$SO4^{2-}$ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Aerobic Heterotroph (count/mL)
				Northern Basin								
Winter-1												
Epilimnion	768.8	8.03	78.6	206.5	13.2	5.3	16.0	–	–	–	–	–
Winter-2												
Epilimnion	801.3	7.96	77.2	202.6	13.3	5.6	16.1	–	–	–	–	–
Spring												
Epilimnion	772.8	8.00	76.5	202.7	13.4	5.4	15.9	–	–	–	–	1.4
Summer												
Epilimnion	421.7	8.42	75.1	198.9	9.8	5.2	15.7	26.2	7.1	3.3	0.87	12.6
Mesolimnion	495.9	8.42	75.6	201.0	12.3	5.2	15.9	–	–	–	–	–
Hypolimnion	684.7	8.13	76.2	204.4	12.6	5.3	16.0	–	–	–	–	9.8
Nepheloid	976.6	7.98	76.6	204.8	11.9	5.4	16.1	26.9	7.3	3.4	0.89	8.2
Fall-1												
Epilimnion	631.7	8.09	76.1	205.0	11.3	5.2	15.8	–	–	–	–	5.2
Mesolimnion	800.3	7.96	76.3	205.8	11.7	5.2	15.8	–	–	–	–	–
Hypolimnion	958.1	7.90	76.1	205.8	11.9	5.2	15.8	–	–	–	–	25.4
Nepheloid	1032.0	7.85	76.2	205.5	12.0	5.2	15.7	–	–	–	–	9.7
Fall-2												
Epilimnion	747.0	7.95	76.4	201.9	12.5	5.4	16.7	–	–	–	–	–
				Southern Basin								
Winter-1												
Epilimnion	712.8	8.08	78.6	206.0	12.4	5.3	15.9	–	–	–	–	–
Winter-2												
Epilimnion	798.7	7.91	78.4	205.2	13.6	5.7	16.5	–	–	–	–	–
Spring												
Epilimnion	782.4	8.03	77.6	203.4	13.5	5.4	15.7	–	–	–	–	3.1
Summer												
Epilimnion	338.2	8.44	77.6	206.5	9.4	5.6	16.1	27.8	7.4	3.6	0.90	29.5
Mesolimnion	479.4	8.30	77.2	207.0	11.4	5.6	16.0	–	–	–	–	–
Hypolimnion	766.7	8.01	76.6	205.9	11.8	5.5	15.8	–	–	–	–	27.5
Nepheloid	1061.9	7.85	76.6	206.8	10.9	5.5	16.0	27.4	7.4	3.5	0.90	27.0
Fall-1												
Epilimnion	716.2	8.07	76.5	207.0	11.2	5.4	16.3	–	–	–	–	9.8
Mesolimnion	971.7	7.83	76.5	207.0	11.0	5.3	16.1	–	–	–	–	–
Hypolimnion	1074.0	7.77	76.0	207.3	10.9	5.3	16.1	–	–	–	–	4.5
Nepheloid	1110.0	7.76	76.2	207.6	11.0	5.2	15.8	–	–	–	–	7.7
Fall-2												
Epilimnion	740.7	8.01	77.3	204.4	10.8	5.4	16.6	–	–	–	–	–
Mesolimnion	944.0	7.89	78.0	200.0	10.2	5.5	15.6	–	–	–	–	–
Hypolimnion	1104.0	7.75	78.8	206.5	11.0	5.4	15.9	–	–	–	–	–
Nepheloid	1138.0	7.74	78.0	205.3	9.8	5.5	15.6	–	–	–	–	–

a"–" indicates no data.

Table 24. Parameter means by basin, survey, and layer — Lake Erie, 1985.

Survey/layer	Temperature (°C)	Turbidity (FTU)	Chlorophyll-a (ug/L)	Pheophytin (ug/L)	Total Phosphorus (ug/L)	Total dissolved Phosphorus (ug/L)	Ortho Phosphorus (ug/L)	$NO_2 + NO_3$ Nitrogen (ug/L)	NH_3 Nitrogen (ug/L)	Total Kjeldahl Nitrogen (ug/L)
					Western Basin					
Winter-1										
Epilimnion	0.0	–[a]	3.49	0.81	16.8	4.0	2.0	511.5	64.5	71.7
Winter -2										
Epilimnion	0.0	–	2.14	0.12	8.2	–	1.6	457.5	14.5	203.3
Spring										
Epilimnion	12.0	6.39	5.85	0.31	20.7	3.9	1.0	698.7	20.5	183.6
Mesolimnion	11.0	6.81	2.95	0.25	19.8	3.4	1.0	708.0	22.5	142.5
Hypolimnion	8.4	6.51	4.26	0.35	19.4	3.9	1.5	767.1	54.3	214.0
Nepheloid	7.2	6.92	1.73	0.07	22.3	5.1	2.1	766.7	43.7	150.0
Summer										
Epilimnion	22.5	4.17	10.84	2.95	17.9	4.2	1.6	181.4	27.4	350.1
Fall										
Epilimnion	7.0	12.02	1.72	0.84	32.6	6.9	3.7	432.7	37.9	253.9
					Central Basin					
Winter-1										
Epilimnion	2.0	–	4.57	2.56	42.9	7.5	5.6	217.2	5.8	150.0
Winter-2										
Epilimnion	0.0	–	2.47	0.08	9.5	–	1.4	221.2	1.0	147.5
Spring										
Epilimnion[b]	4.6	1.85	2.82	0.04	13.0	3.8	0.9	206.4	3.2	143.6
Epilimnion[c]	6.6	1.46	2.52	0.02	11.8	3.7	0.9	197.7	3.5	115.4
Mesolimnion	5.8	1.54	2.92	0.15	15.0	3.8	2.0	220.5	2.8	100.0
Hypolimnion	4.2	1.55	1.32	0.06	13.2	3.0	0.8	230.0	5.0	135.0
Nepheloid	4.0	2.44	2.96	0.34	17.0	3.4	1.2	222.5	7.3	135.0
Summer										
Epilimnion	22.2	0.42	3.16	0.93	8.8	3.7	1.1	192.3	14.0	299.7
Mesolimnion	18.7	0.72	3.56	1.15	15.7	6.7	3.8	208.0	30.9	313.7
Hypolimnion	15.3	1.77	2.70	1.02	42.2	21.5	23.7	203.1	46.7	344.6
Nepheloid	14.1	1.58	0.50	0.50	55.1	33.0	29.5	97.0	107.0	320.0
Fall										
Epilimnion	10.6	2.37	2.62	0.57	21.4	9.9	4.9	128.2	17.9	230.2
					Eastern Basin					
Winter-1										
Epilimnion	3.5	–	1.92	0.47	16.4	8.4	3.6	262.7	6.0	156.7
Winter-2										
Epilimnion	0.0	–	1.06	0.12	11.6	–	2.6	274.5	0.5	127.5
Spring										
Epilimnion	2.1	2.63	0.40	0.07	12.8	6.1	2.7	287.6	6.9	121.7
Summer										
Epilimnion	21.8	0.48	1.39	0.61	5.7	2.3	1.1	185.2	6.6	278.6
Mesolimnion	13.8	0.61	1.22	0.60	5.3	2.1	1.4	300.7	8.2	169.7
Hypolimnion	5.8	1.59	0.37	0.47	7.1	2.5	2.5	346.1	11.2	214.0
Nepheloid	5.7	1.92	0.30	0.49	7.5	3.4	2.8	349.2	14.5	240.3
Fall										
Epilimnion	10.4	4.10	0.82	0.35	15.3	6.6	3.1	204.5	11.5	178.8

[a] "–" indicates no data.
[b] Isothermal sites
[c] Stratified sites

Table 24. (Continued) Parameter means — Lake Erie 1985.

Survey/layer	Dissolved reactive silicon (ug/L)	pH	Alkalinity (mg/L)	Specific Conductance (uS/cm)	Dissolved Oxygen (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Aerobic Heterotroph (count/mL)
				Western Basin								
Winter-1												
Epilimnion	710.3	7.95	87.0	260.2	13.6	14.0	21.0	–	–[a]	–	–	–
Winter-2												
Epilimnion	637.7	8.21	85.8	263.8	14.3	11.3	19.0	–	–	–	–	–
Spring												
Epilmnion	633.1	8.30	86.4	256.1	11.7	13.1	20.4	–	–	–	–	366.6
Mesolimnion	679.2	8.19	85.5	250.9	11.6	12.0	19.5	–	–	–	–	699.5
Hypolimnion	688.2	8.13	85.4	254.2	11.4	13.1	19.7	–	–	–	–	–
Nepheloid	744.0	8.10	86.3	258.2	11.7	13.4	19.8	–	–	–	–	613.3
Summer												
Epilimnion	329.4	8.54	82.8	234.0	8.0	9.5	18.9	29.9	8.1	6.0	1.2	453.3
Fall												
Epilimnion	743.4	8.09	83.6	244.6	10.9	10.8	18.5	–	–	–	–	10148
				Central Basin								
Winter-1												
Epilimnion	75.2	8.15	97.0	290.8	12.8	17.5	25.4	–	–	–	–	
Winter-2												
Epilimnion	36.0	–	96.6	283.8	14.0	13.4	23.7	–	–	–	–	
Spring	9.0	8.21	93.4	276.2	13.2	14.6	23.6	–	–	–	–	9.1
Epilimnion	12.0	8.31	93.1	277.5	12.7	14.8	22.7	–	–	–	–	7.5
Mesolimnion	12.5	8.20	93.1	277.6	12.3	14.9	22.7	–	–	–	–	19.0
Hypolimnion	9.6	8.15	92.6	276.9	12.0	14.6	22.5	–	–	–	–	13.5
Nepheloid	30.5	8.05	93.0	278.3	12.0	14.9	22.8	–	–	–	–	13.7
Summer												
Epilimnion	139.8	8.55	92.2	275.4	8.3	14.7	22.7	35.0	8.4	8.6	1.3	105.8
Mesolimnion	601.2	8.11	93.2	279.2	5.3	14.6	22.6	34.0	8.4	8.6	1.3	–
Hypolimnion	1572.1	7.62	96.4	284.6	1.4	14.5	22.5	35.8	8.4	8.5	1.4	119.6
Nepheloid	1360.0	7.53	100.0	290.0	0.2	14.6	23.7	37.0	8.4	8.5	1.4	–
Fall												
Epilimnion	78.8	8.19	92.1	278.5	9.9	14.7	23.1	–	–	–	–	91.7
				Eastern Basin								
Winter-1												
Epilimnion	62.3	8.19	99.5	290.0	13.3	16.5	25.8	–	–	–	–	–
Winter-2												
Epilimnion	67.8	7.97	98.2	289.0	13.4	15.2	23.8	–	–	–	–	–
Spring												
Epilimnion	71.5	7.93	92.4	278.2	12.9	14.9	23.2	–	–	–	–	62.8
Summer												
Epilimnion	75.5	8.55	92.5	280.2	8.9	15.0	23.0	35.5	8.3	8.9	1.3	173.9
Mesolimnion	145.5	7.96	93.4	284.9	7.9	14.9	22.7	–	–	–	–	–
Hypolimnion	303.3	7.91	94.2	286.6	10.1	14.8	23.3	–	–	–	–	140.0
Nepheloid	340.6	7.91	94.6	287.0	9.7	14.9	22.9	36.9	8.3	8.8	1.4	337.5
Fall												
Epilimnion	90.4	8.10	94.2	283.5	9.4	14.6	23.2	–	–	–	–	89.2

[a]"–" indicates no data.

Table 25. Parameter means determined from composited upper 20-meter samples, averaged by survey and basin- Lakes Michigan, Huron and Erie, 1985.

Survey/basin	Chloro-phyll-a (ug/L)	Pheophytin (ug/L)	Total Phosphorus (ug/L)	Total Dissolved Phosphorus (ug/L)	Dissolved ortho-Phosphorus (ug/L)	$NO_2 + NO_3$ Nitrogen (ug/L)	NH_3 Nitrogen (ug/L)	Total Kjeldahl Nitrogen (ug/L)	Dissolved Reactive Silicon (ug/L)	Cl (mg/L)	SO_4 (mg/L)
Spring											
Lake Michigan											
South	1.00	0.03	4.7	2.1	0.7	285.3	2.5	108.3	564.2	8.67	21.9
North	0.63	0.07	4.4	2.2	0.6	282.4	1.7	82.0	538.3	8.84	22.4
Lake Huron											
North	0.77	-0.01	3.9	1.4	0.6	300.9	2.2	100.9	771.8	5.37	15.9
South	0.94	-0.01	3.0	1.1	0.4	302.7	3.2	111.0	776.7	5.33	15.8
Lake Erie											
West	4.83	0.35	19.5	4.0	1.2	690.8	28.0	163.3	652.7	12.8	20.0
Central	2.60	0.02	12.0	3.9	1.0	210.6	3.2	133.9	9.0	14.7	23.3
East	0.45	0.07	12.7	6.6	2.5	278.9	6.4	118.7	65.8	14.8	23.0
Summer											
Lake Michigan											
South	1.07	0.25	3.0	1.6	0.2	165.1	3.5	185.0	104.1	8.74	21.7
North	1.05	0.17	3.9	1.8	0.5	161.3	3.9	168.7	98.9	8.50	21.7
Lake Huron											
North	0.96	0.16	2.2	1.2	0.2	273.0	2.1	135.9	446.1	5.29	15.8
South	1.52	0.10	3.0	1.0	0.4	278.3	2.1	250.0	358.0	5.62	16.1
Lake Erie											
West	10.05	3.20	18.3	5.6	2.7	193.6	26.2	352.9	347.9	9.36	18.6
Central	3.35	0.93	11.5	5.6	1.8	201.2	18.5	290.8	244.5	14.6	22.7
East	1.40	0.55	7.0	3.7	1.1	191.9	7.6	362.5	85.9	14.9	23.2
Fall-1											
Lake Michigan											
South	0.65	0.20	3.9	1.7	0.3	240.3	2.9	200.0	376.2	9.02	22.0
North	0.68	0.22	2.5	2.0	-0.3	221.4	1.8	72.0	321.6	8.58	21.5
Lake Huron											
North	0.57	0.10	2.9	1.4	-0.1	302.7	3.2	68.3	626.5	5.20	15.5
South	0.55	0.12	3.1	0.8	0.7	325.7	3.5	95.0	821.0	5.40	16.0
Fall-2											
Lake Michigan											
South	0.33	0.08	5.2	2.5	0.0	294.0	1.3	93.3	594.8	8.70	22.8
North	0.36	0.10	4.8	2.8	0.4	239.4	1.8	32.0	397.4	8.94	21.7
Lake Huron											
South	0.36	0.12	3.5	1.0	-0.3	294.4	2.6	138.0	693.0	5.38	16.1
North	0.46	0.10	3.4	1.7	-0.3	294.0	3.0	156.0	733.4	5.54	16.0
Fall 1/2											
Lake Erie											
West	2.02	0.78	37.2	7.4	4.4	423.7	50.0	255.0	734.8	11.1	18.5
Central	2.55	0.54	21.4	9.9	5.0	129.7	18.1	243.5	81.6	14.7	22.7
East	0.72	0.56	12.5	6.4	3.3	207.5	10.4	146.2	100.8	14.6	22.8

The composite samples provide a means of checking other data taken within the epilimnion. Scatter plots of parameter concentrations determined from the composite samples at each station versus the average of the concentrations determined from the discrete samples at master stations (or surface samples at regular stations) show that the general agreement between the two is quite good (Figures 33 to 42). Parameters with digestion procedures or ambient concentrations near the criterion of detection (e.g., total P, total dissolved P, TKN, or dissolved ortho phosphorus) show the highest scatter. The scatter, however, does not appear to be biased qualitatively indicating that surface samples and epilimnion averages are indeed representative of the upper 20 meters of the water column. The results reflect the homogeneity of the upper water column during the three survey periods (early spring, stable summer stratified, and fall overturn).

CONCENTRATION OF MAJOR IONS - ION BALANCES

Concentrations of the major anions (Cl^-, $SO_4^=$, and $CO_3^=$ + HCO_3^- as $CaCO_3$ equivalent alkalinity) were determined at every sample depth during each of the 1985 water quality surveys. Concentrations of the major cations (Ca^{++}, Mg^{++}, Na^+, and K^+) were determined at selected depths during the summer survey. Results (Tables 26 and 27) show little variation in the anion concentration within basins with either depth or time. Although basin differences within lakes are generally small, the three lakes are easily differentiated by both the absolute concentrations and the stoichiometric ratios of the major ions. Lake Huron has low concentrations of dissolved solids, while Lakes Michigan and Erie have relatively higher concentrations. Lake Michigan, however, has higher alkalinity and lower concentrations of sodium and chloride than Lake Erie.

Basin-average epilimnion concentrations of the major ions measured during survey 2 are listed in Table 26. The converted milliequivalent concentrations of these values are listed in Table 27, along with approximate ion balances for each basin. There is an excess of cations as in 1983, but this excess is generally less than 5 percent in all basins.

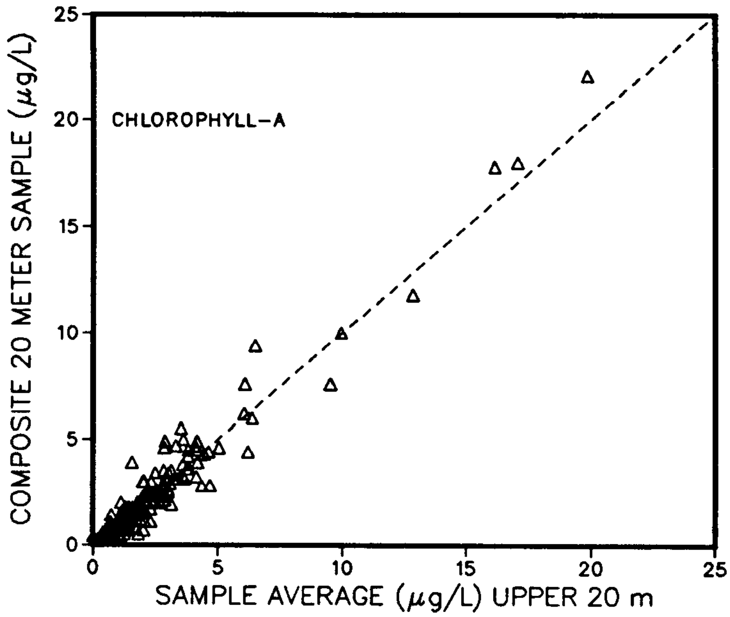


Figure 33. Comparison of average chlorophyll-a concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

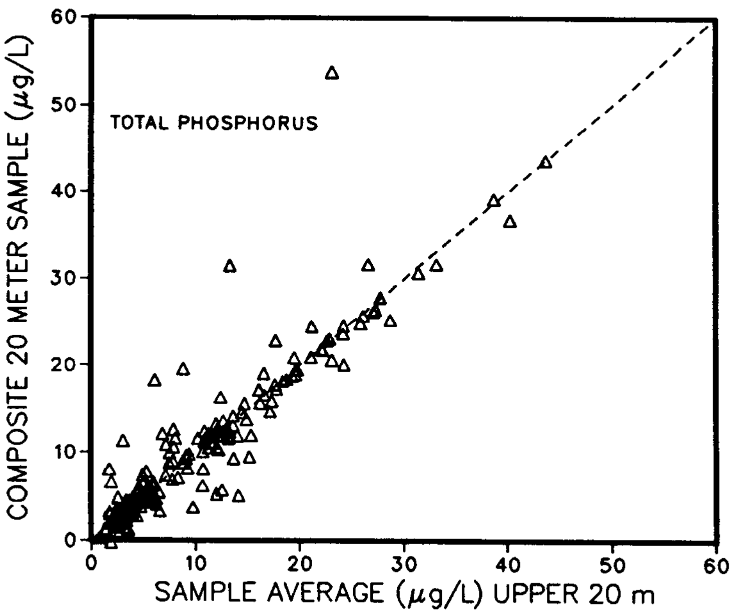


Figure 34. Comparison of average total phosphorus concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

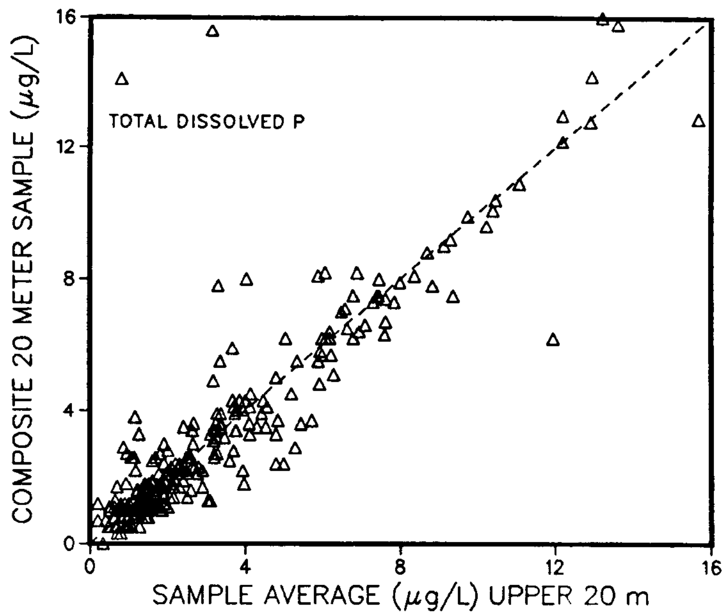


Figure 35. Comparison of average total dissolved phosphorus concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

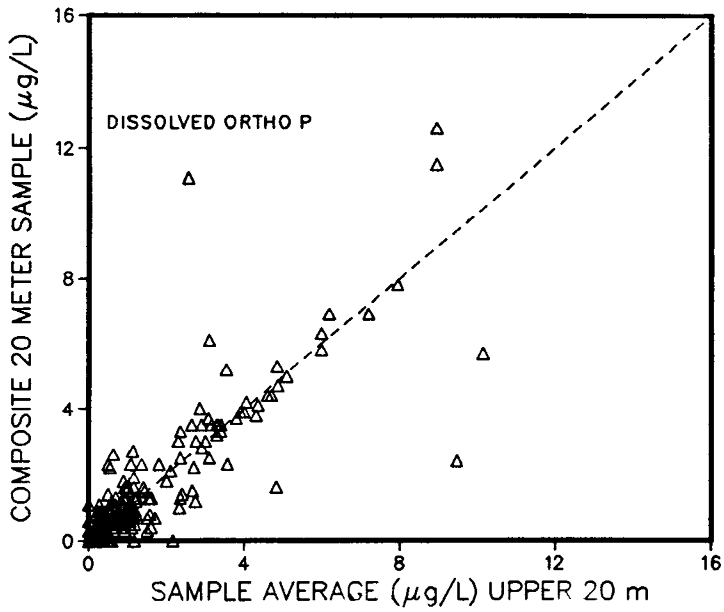


Figure 36. Comparison of average dissolved ortho phosphorus concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

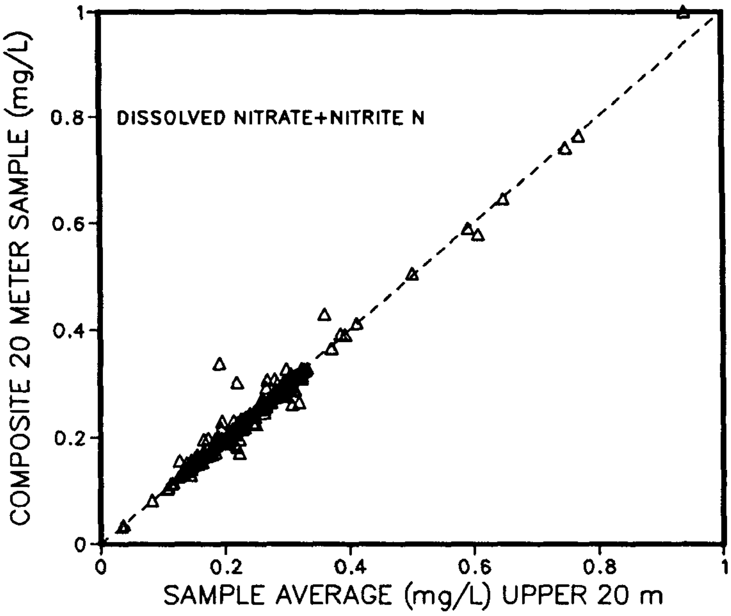


Figure 37. Comparison of average dissolved nitrate + nitrite nitrogen concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

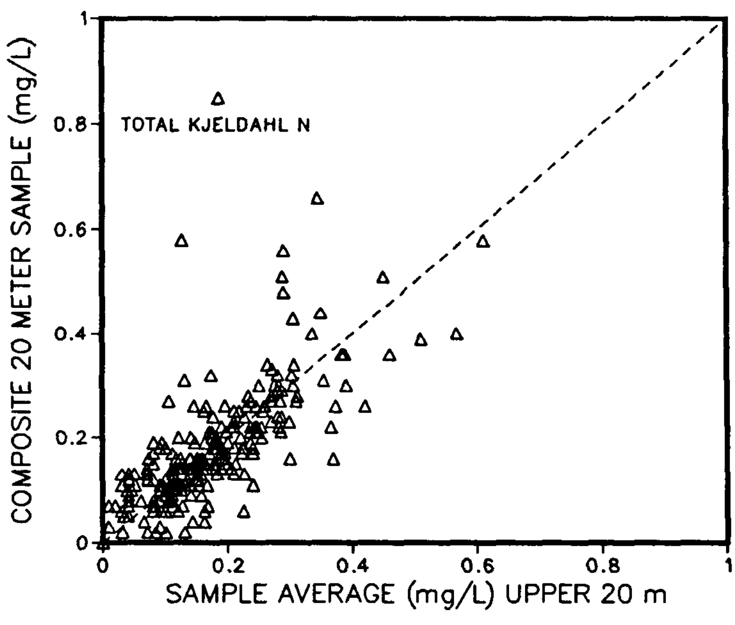


Figure 38. Comparison of average total Kjeldahl nitrogen concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

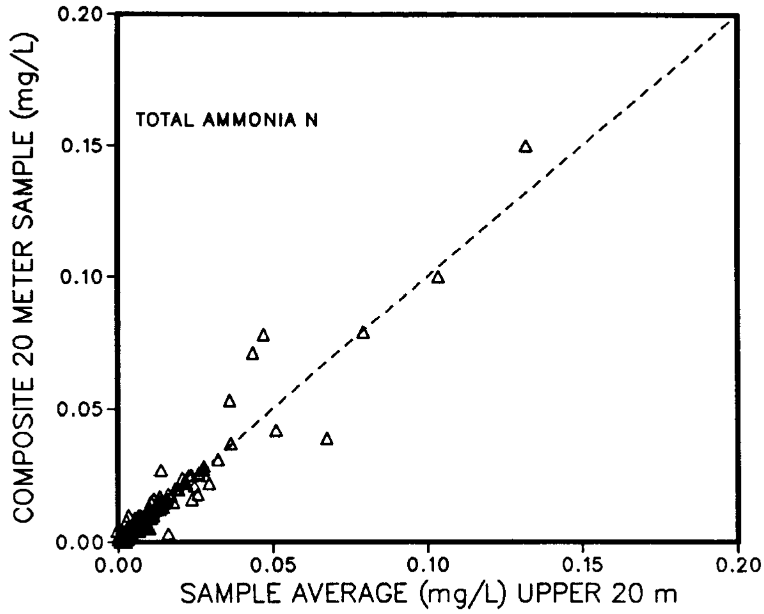


Figure 39. Comparison of average total ammonia nitrogen concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

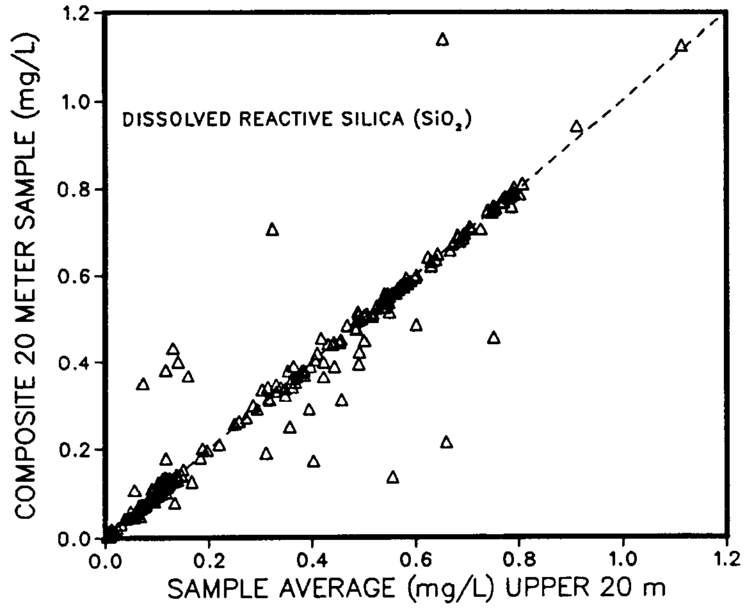


Figure 40. Comparison of average dissolved reactive silica concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

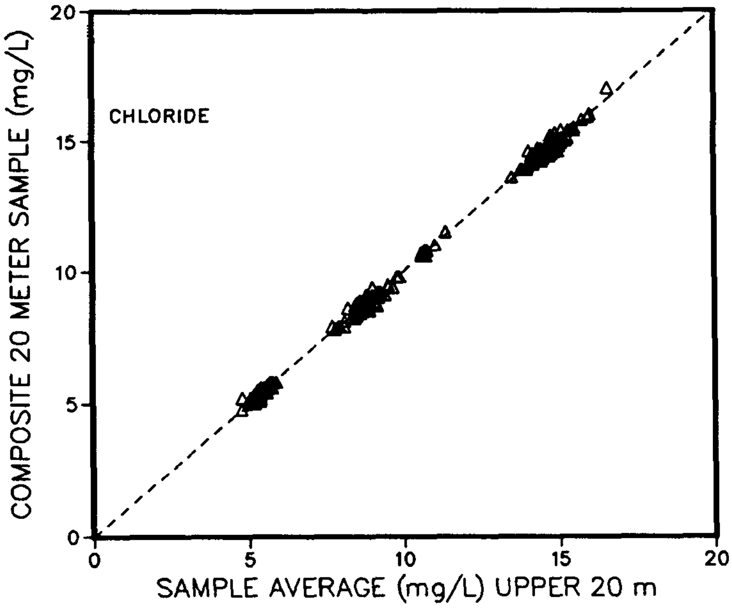


Figure 41. Comparison of average chloride concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

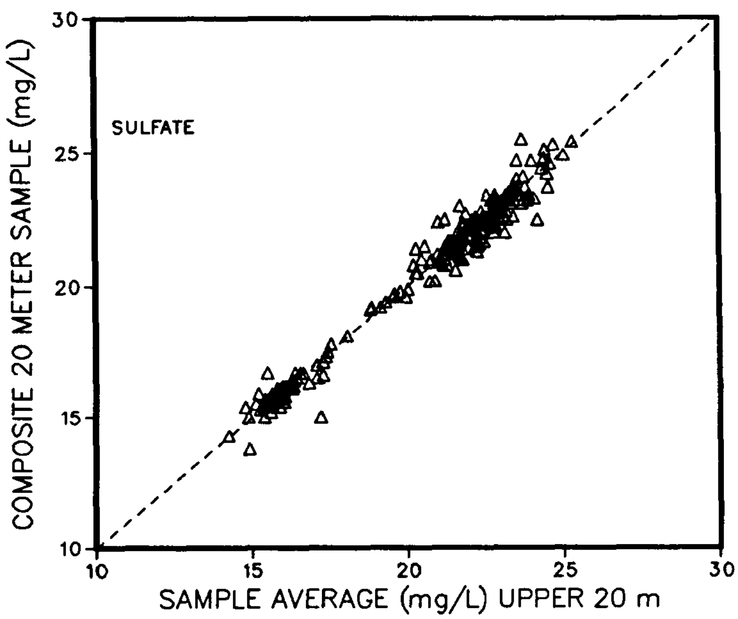


Figure 42. Comparison of average sulfate concentrations determined from discrete epilimnion samples with those determined from the composite 20-meter sample - all lakes, all surveys, 1985.

Table 26. Absolute concentrations (mg/l) of major ions in the epilimnion -- summer survey, 1985.

Basin	Alk.	Cl^-	$SO4^=$	Ca^{++}	Mg^{++}	Na^+	K^+
Lake Michigan							
South	108.13	8.82	21.71	36.00	11.17	5.46	1.23
North	108.04	8.56	21.58	35.20	11.00	5.37	1.21
Lake Huron							
North	75.09	5.23	15.74	26.25	7.10	3.34	0.87
South	77.58	5.63	16.08	27.77	7.38	3.57	0.90
Lake Erie							
West	82.78	9.53	18.88	29.94	8.06	6.04	1.18
Central	92.24	14.67	22.68	34.97	8.36	8.64	1.33
East	92.52	15.01	23.05	35.50	8.35	8.90	1.35

SECCHI DEPTH BY BASIN AND SURVEY

Secchi disc measurements could not be obtained at all stations due to the 24-hour-a-day operation; however, sufficient data were obtained to permit calculation of representative basin averages (Table 28). Secchi depths generally followed the expected pattern of increasing during the summer when the epilimnion was depleted of nutrients and particulates. Only in Lake Erie were the spring to summer changes significant (alpha=0.05).

Table 27. Stoichiometric concentrations (milliequivalent/L) of major ions in the epilimnion — summer survey, 1985.

Basin	Number of Samples: anions[1]	Number of Samples: cations[2]	$CO_3^{=}$	Cl^-	$SO_4^{=}$	Ca^{++}	Mg^{++}	Na^+	K^+	Total anions	Total cations	Ratio: anions / cations
Lake Michigan												
South	43	18	2.16	0.25	0.45	1.80	0.92	0.24	0.03	2.86	2.98	0.96
North	33	15	2.16	0.24	0.45	1.76	0.91	0.23	0.03	2.85	2.93	0.97
Lake Huron												
North	36	16	1.50	0.15	0.33	1.31	0.58	0.15	0.02	1.98	2.06	0.96
South	29	13	1.55	0.16	0.33	1.39	0.61	0.16	0.02	2.05	2.17	0.94
Lake Erie												
West	21	16	1.66	0.27	0.39	1.49	0.66	0.26	0.03	2.32	2.45	0.95
Central	83	29	1.84	0.41	0.47	1.75	0.69	0.38	0.03	2.73	2.84	0.96
East	25	8	1.85	0.42	0.48	1.77	0.69	0.39	0.03	2.75	2.88	0.96

[1]anion samples were collected at all depths.
[2]cation samples were collected at selected depths.

Table 28. Secchi depths (meters) averaged by basin and survey, 1985.[a]

Basin	Helicopter January	Helicopter February	Helicopter Average	Survey Spring	Summer	Fall 1	Fall 2	Fall 1 & 2 Average
L. Michigan								
South	–[b]	–	–	10.2±2.1 (6)	8.4±2.5 (7)	10.0±1.4 (2)	9.2±0.4 (2)	9.6±1.0 (4)
North	–	13.8±2.5 (2)	13.8±2.5 (2)	11.6±1.7 (8)	10.8±3.0 (10)	11.0±1.1 (2)	13.2±3.2 (2)	12.1±2.4 (4)
L. Huron								
North	12.5±3.5 (2)	12.3±1.0 (3)	12.4±1.9 (5)	11.1±0.9 (7)	12.7±2.7 (11)	11.7±0.6 (3)	9.2±0.4 (2)	10.7±1.4 (5)
South	–	11.3±0.8 (3)	11.3±0.8 (3)	9.3±1.3 (9)	10.9±1.2 (5)	–	–	–
L. Erie								
West	1.1±0.1 (3)	–	1.1±0.1 (3)	1.6±0.4 (6)	–	–	–	–
Central	–	–	–	3.4±0.8 (7)	7.4±1.0 (12)	–	–	3.0±0.5 (9)
East	3 (1)	2 (1)	2.5±0.7 (2)	2.4±0.1 (2)	9.2±1.1 (2)	–	–	3.3±1.5 (6)

a Secchi depths average ± one standard deviation. The number of samples is shown in parentheses.
b "–" indicates no data.

DISCUSSION

TROPHIC STATUS

Dobson et al. (1974) published a simple indexing system based on a limited number of water quality variables to classify areas within the Great Lakes in terms of their trophic status. In this system, Secchi depth, concentration of chlorophyll-a, and concentration of particulate phosphorus are used to classify a lake as oligotrophic, mesotrophic, or eutrophic. Since each of these variables is dynamic, the relationship between the values of the variables and the classification limits may change during the year. Thus, classification is still subjective; however, this simple system provides a convenient method of expressing the trophic status of a lake. The classification limits used by Dobson et al. (1974) are shown in Table 29, along with three other classification schemes. Two of the other systems are based on Secchi depth and nutrient concentrations made at the surface (Rast and Lee, 1978; International Joint Commission, 1976a); the third is based on the number of aerobic heterotrophs in the water (Rockwell et al., 1980).

Table 29. Classification limits for trophic status.

System/parameter	Oligotrophic	Mesotrophic	Eutrophic
Dobson et al. (1974)			
Chlorophyll-a (ug/L)	<4.4	4.4 to 8.8	>8.8
Particulate P (ug/L)	<5.9	5.9 to 11.8	>11.8
Secchi Depth (m)	>6.0	6.0 to 3.0	<3.0
30/Secchi Depth (m^{-1})	<5.0	5.0 to 10.0	>10.0
Rast and Lee (1978)			
Chlorophyll-a (ug/L)	<2.0	2.0 to 6.0	>6.0
Total Phosphorus (ug/L)	<10.0	10.0 to 20.0	>20.0
Secchi Depth (m)	>4.6	4.6 to 2.7	<2.7
International Joint Commission (1976a)			
Chlorophyll-a (ug/L)	<2.4	2.4 to 7.8	>7.8
Total Phosphorus (ug/L)	<6.6	6.5 to 14.1	>14.1
Secchi Depth (m)	>8.6	8.6 to 2.9	<2.9
Rockwell et al. (1980)			
Aerobic heterotrophs (number/mL)	<20	20 to 200	>200

Observed basin- and survey-averaged values for these index parameters are listed in Table 30. The observed values are plotted along with Dobson et al's. classification limits in Figures 43, 44 and 46, the International Joint Commission's in Figure 45, and Rockwell et al.'s in Figure 47. The Fall survey was divided into two runs for Lake Michigan and Lake Huron only (see Temporal Variation Within Surveys section).

The open waters of Lakes Michigan and Huron satisfied almost all of the criteria for oligotrophy during the 1985 surveys. Only in Lake Erie were the eutrophic criteria exceeded, and then primarily in the shallow western basin. The total phosphorus eutrophic criteria was exceeded in all the basins of Lake Erie in the fall. The eutrophic criteria based on chlorophyll-a concentration, however, was reached only during the summer in western Lake Erie. This may be because of the time lag required to convert soluble nutrients into particulate biomass or because sampling was restricted to open-lake waters, which are expected to be less productive than nearshore areas.

Within-year patterns of the indexing parameters are similar in the three lakes, except in Lake Michigan. Secchi depth was greatest during the summer in all basins, except in Lake Michigan (Table 30). As expected, total and particulate phosphorous concentrations were relatively low during the summer, except in northern Lake Michigan. The 1985 summer chlorophyll levels were the highest sampled in all basins in the summer and lowest in the fall. This pattern may be an artifact of the survey timing; the spring surveys were conducted before active phytoplankton growth, and the fall surveys were conducted when the epilimnion had mixed to great depths in Lakes Michigan and Huron and after autumn turnover in Lake Erie. As a result, the spring surveys probably are representative of pre-spring bloom conditions and the fall survey is representative of the post-fall bloom conditions.

The classification system presented by Rockwell et al. (1980) is different from the others considering that it is based on the number of aerobic heterotrophs in the water rather than on nutrient concentrations.

Table 30. Survey and basin mean values -- water quality index classification parameters, 1985.[a]

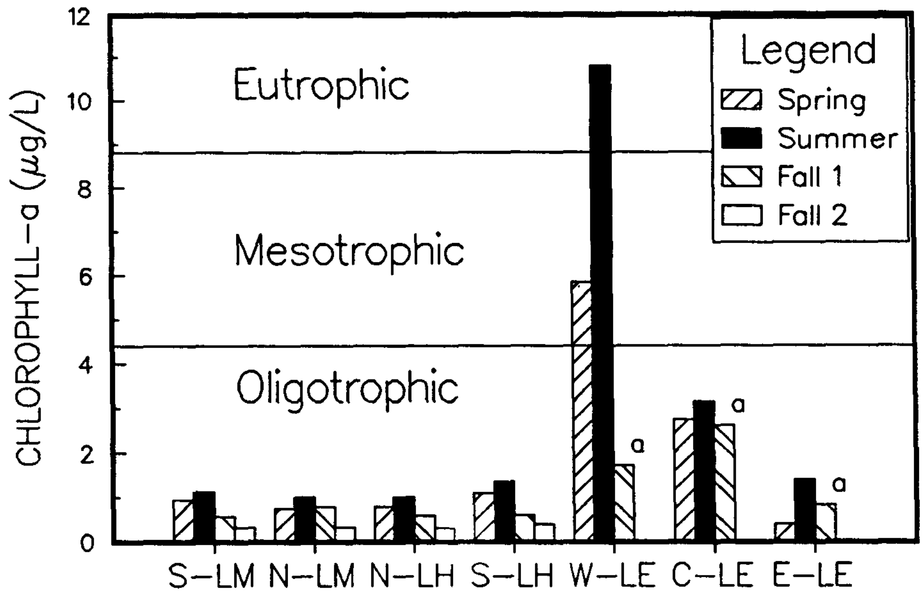
Basin	Chlorophyll-a (mg/L)	Total Phosphorus (ug/L)	Particulate Phosphorus (ug/L)	Secci Depth (m)	30/Secchi Depth (m)
		Winter-1 (January, 1985)			
Lake Michigan					
South	No Samples	Collected			
North	No Samples	Collected			
Lake Huron					
North	0.94	3.1	0.8	12.5	2.5
South	0.80	5.4	1.9	–[b]	–
Lake Erie					
West	3.09	17.0	12.9	1.1	26.7
Central	4.59	42.2	35.5	–	–
East	1.85	18.2	9.9	3.0	10.0
		Winter-2 (February, 1985)			
Lake Michigan					
South	0.90	5.7	1.4	–	–
North	0.98	6.0	1.7	13.8	2.22
Lake Huron					
North	0.90	3.0	0.6	12.3	2.44
South	1.30	6.7	4.7	11.3	2.65
Lake Erie					
West	2.14	7.9	–	–	–
Central	2.64	9.0	–	–	–
East	0.96	11.3	–	2.0	15.0
		Spring (April, 1985)			
Lake Michigan					
South	0.98	4.8	2.3	10.2	3.02
North	0.67	5.6	2.7	11.6	2.65
Lake Huron					
North	0.76	3.1	1.6	11.1	2.72
South	1.04	2.9	1.7	9.3	3.30
Lake Erie					
West	6.22	21.0	17.3	1.6	19.2
Central	2.92	12.1	8.1	3.4	9.45
East	0.44	13.0	6.5	2.4	12.5

[a] Concentration values from the surface (1 meter depth) samples.
[b] "–" indicates no data.

Table 30. (Continued) Survey and basin mean values — water quality index classification parameters, 1985.[a]

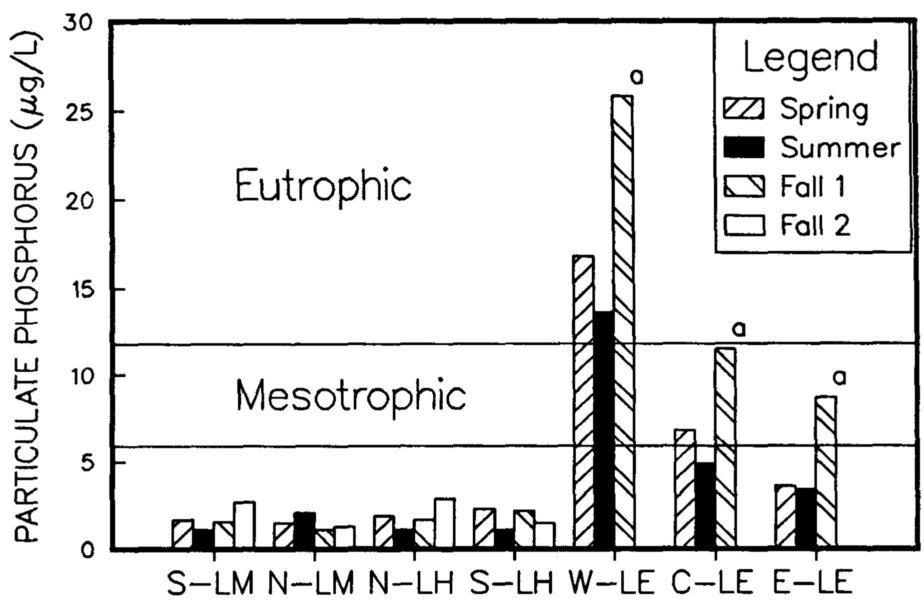
	Chlorophyll-a (mg/L)	Total Phosphorus (ug/L)	Particulate Phosphorus (ug/L)	Secchi Depth (m)	30/Secchi Depth (m^{-1})
		Summer (August, 1985)			
Lake Michigan					
South	1.05	2.5	1.1	8.4	3.90
North	0.98	4.3	2.6	10.7	3.10
Lake Huron					
North	0.80	2.8	0.8	12.7	2.45
South	1.25	2.2	1.0	10.9	2.78
Lake Erie					
West	10.6	18.3	14.1	–[b]	–
Central	3.17	8.6	5.1	7.4	4.12
East	1.31	5.5	3.2	9.2	3.26
		Fall-1 (November, 1985)			
Lake Michigan					
South	0.68	3.7	1.2	10.0	3.03
North	0.87	3.3	1.2	11.0	2.75
Lake Huron					
North	0.63	2.8	1.5	11.7	2.58
South	0.68	3.4	2.7	–	–
		Fall-2 (November-December, 1985)			
Lake Michigan					
South	0.38	5.1	2.4	9.2	3.25
North	0.34	4.2	1.2	13.2	2.33
Lake Huron					
North	0.34	2.9	2.0	9.2	3.25
South	0.42	3.8	1.8	–	–
		Fall 1 and 2 (November, 1985)			
Lake Erie					
West	1.67	32.5	25.4	–	–
Central	2.66	21.0	11.2	3.0	10.2
East	0.76	12.5	5.9	3.3	11.4

[a]Concentration values from the surface (1 meter depth) samples.
[b]"–" indicates no data.



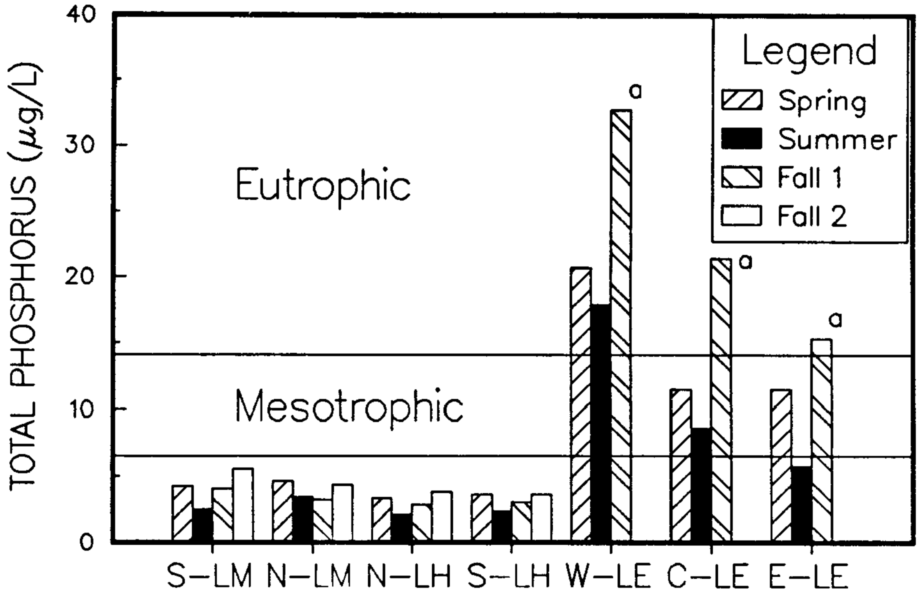
[a]Fall-1 and Fall-2 surveys are combined for Lake Erie.

Figure 43. Basin average 1985 values of chlorophyll-a in the surface waters compared with Dobson's (1974) water quality index.



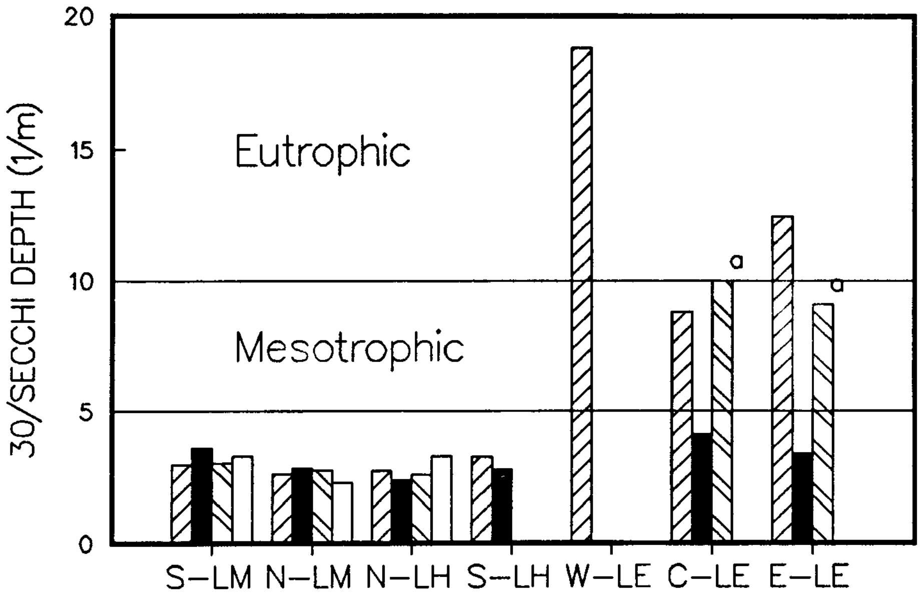
[a]Fall-1 and Fall-2 surveys are combined for Lake Erie.

Figure 44. Basin average 1985 values of particulate phosphorus in the surface waters compared with Dobson's (1974) water quality index.



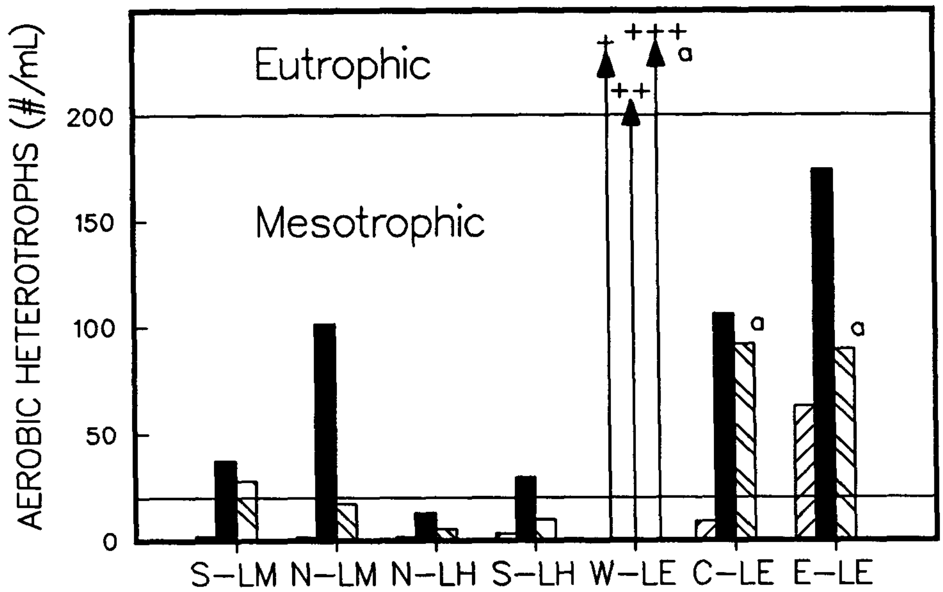
[a]Fall-1 and Fall-2 surveys are combined for Lake Erie.

Figure 45. Basin average 1985 values of total phosphorus in the surface waters compared with the International Joint Commission's (1976a) water quality index.



[a]Fall-1 and Fall-2 surveys are combined for Lake Erie.

Figure 46. Basin average 1985 values of 30/Secchi depth compared with Dobson's (1974) water quality index. See Figure 45. for the legend.



[a]Fall-1 and Fall-2 surveys are combined for Lake Erie.

Figure 47. Basin geometrical mean 1985 values of aerobic heterotrophs in the surface waters compared with Rockwell's (1980) water quality index. See Figure 45. for the legend. (+ value is 1423; ++ value is 810; and +++ value is 3165.)

Empirically derived from data collected in 1977 on Lake Michigan, this system uses the geometric mean of the aerobic heterotroph count as the classification criterion. These values are listed in Table 31 along with survey statistics for each basin. In the spring, the classification based on this bacteriological criterion is similar to that based on nutrient concentrations. In contrast, this bacteriological criteria indicated mesotrophic conditions in Lake Michigan and southern basin Lake Huron. Observed bacteria counts were the highest during the summer in Lake Michigan, Lake Huron, and the central and eastern basins of Lake Erie, while western Lake Erie had maximum levels during the fall survey. These seasonal changes may reflect a larger available particulate substrate during the summer.

COMPARISON WITH 1983 AND 1984 SURVEY RESULTS

One of the major objectives of the annual surveillance program is to collect data sufficient for the evaluation of water-quality trends. The

Table 31. Aerobic heterotrophs (count per mL) in surface samples collected during the 1985 surveillance program.[a]

Basin	Spring-1				Summer-1				Fall-1				All data
	Min.	Max.	Median	Geom. mean	Min.	Max.	Median	Geom. mean	Min.	Max.	Median	Geom. mean	Geom. mean
Lake Michigan													
South	1	3	1	1.4	15	64	32	33.4	8	45	33	22.7	9.6
North	1	2	1	1.1	26	150	100	80.0	8	64	11	17.9	11.8
Lake Huron													
North	1	4	1	1.4	0.9	12	5	4.4	3	8	4.5	4.4	2.9
South	1	6	2.5	2.4	4	63	32.5	21.3	3	16	7.5	7.0	7.1
Lake Erie													
West	98	6000	4900	1423	810	810	810	810	220	27200	5300	3165	1849
Central	5	21	8.5	8.8	37	200	59	76.8	34	180	83	84	40
East	7	140	53	40.6	75	300	160	153.3	42	140	62	69	71

[a]Min. = minimum; Max. = maximum; Geom. = geometric

term "trend" implies a change in the concentration of a specified water quality parameter over time. Trends may be indicative of either improving or degrading water quality, and changes in trends may provide information about the efficiency of remedial control programs or other environmental variations.

Since trends are usually established by comparison across data sets that often were collected years apart by different agencies using different techniques, it is important to avoid invalid comparisons. An annual average, for example, cannot be compared with a seasonal average for the purpose of establishing a temporal trend, and likewise it would be inappropriate to compare nearshore data collected one year with open-lake data collected in another. Therefore, any comparison involving data collected for different purposes and at different times must be conducted with extreme care.

As previously mentioned, the GLNPO surveillance program, begun in 1983 was designed to sample only the open waters of the three lakes. Nearshore areas were specifically excluded. This sampling design was based on the assumption that the open waters are relatively homogenous and, therefore, representative sample statistics could be calculated from a reduced set of sampling locations.

This hypothesis was tested (Lesht and Rockwell, 1985) using the more extensive survey data collected in Lake Michigan in 1976-1977 and in Lake Huron in 1971 and 1980. The test consisted of comparing concentration averages based on all open-lake stations similar to those sampled in 1983. This analysis was conducted for the means of surface samples taken during the well-mixed spring period. The results showed that the same subset of stations chosen for sampling in 1983 and 1984 was representative of open-lake conditions (as defined by the more extensive data sets), in those earlier years when the comparison could be made.

Another Lake Michigan test was done comparing the concentration averages based on all open-lake stations with concentration averages based on data collected at a subset of stations similar to those sampled in1985. This analysis was conducted for the means of surface samples taken during the well-mixed spring period. The results, listed in Table 32, show that the subset of stations chosen for sampling in 1985 was representative of open-lake conditions in each earlier year where the comparison was made.

A Lake Erie test was also undertaken comparing the 1985 concentration data from all spring central and eastern basin open-lake stations with 1985 concentration data from the subset of four stations which were also in the 1983 and 1984 station network. Except for chloride, this analysis showed (Table 33) no statistically significant differences in the means of surface samples taken during the well-mixed spring period. The chloride absolute concentration difference was 0.2 mg/L which is not environmentally significant. Thus, the additional stations chosen for sampling in 1985 could be represented by the four stations in the 1983/1984 subset of these sites for the spring of this year. Similar results are reported by Fay and Rathke (1987) in their analysis of the 1985 Great Lakes open lake water quality data sets for the entire season.

Another measure of the representativeness of the 1985 survey can be found in comparing the survey frequency. The annual means (Table 45-1985b) estimated from the three-survey program (USEPA-GLNPO reduced frequency survey program) can be compared with the annual means (Table 45-1985c) estimated from the intensive survey program (eight surveys) recommended by the Lake Erie GLISP. USEPA-GLNPO funded the Center for Lake Erie Area Research - Ohio University to implement the intensive program. These annual means differ by only 1.4% in the central basin and by 9.6% in the eastern basin. Both basin results in the reduced frequency program are well within the 95% confidence interval associated with the intensive survey program annual means.

In this section we compare the results of the 1985 surveillance effort with those obtained in 1983 and 1984. Three years of data may not be sufficient to establish a trend. This comparison is valuable,

Table 32. Comparison of Lake Michigan spring water quality statistics (mean ± standard deviation) calculated from subsets of stations similar to those sampled in 1983 with all open-lake stations stations using 1976 and 1977 intensive survey data.[a]

Year/Basin/Parameter	All open-lake stations	Subset of stations similar to those sampled in 1983[b]	Subset of stations similar to those sampled in 1985[c]
		Lake Michigan	
1976 Southern Basin			
	(N = 9)	(N = 8)	(N = 6)
Chlorophyll-a (ug/L)	1.81 ± 0.90	1.48 ± 0.96	1.75 ± 0.96
Chloride (mg/L)	7.90 ± 0.15	8.06 ± 0.29	7.92 ± 0.16
Specific conductance (uS/cm)	272.0 ± 1.5	272.3 ± 1.5	271.7 ± 1.4
Nitrate + nitrite nitrogen (ug/L)	230 ± 30	224 ± 32	230 ± 27
Total phosphorus (ug/L)	5.2 ± 0.9	5.62 ± 1.30	5.17 ± 0.75
Dissolved reactive silica (mg/L)[e]	1.10 ± 0.18	0.991 ± 0.290	1.09 ± 0.21
Temperature (°C)	7.3 ± 1.5	8.8 ± 1.7	7.8 ± 1.5
1976 Northern Basin			
	(N = 13)	(N = 6)	(N = 5)
Chlorophyll-a (ug/L)	1.48 ± 0.76	1.59 ± 0.60	1.10 ± 0.25
Chloride (mg/L)	7.8 ± 0.11	7.83 ± 0.082	7.70 ± 0.10
Specific conductance (uS/cm)	-[d]	298.3 ± 3.4	298.4 ± 3.8
Nitrate + nitrite nitrogen (ug/L)	230 ± 22	233 ± 20	240 ± 19
Total phosphorus (ug/L)	7.3 ± 1.44	7.83 ± 1.72	7.60 ± 1.52
Dissolved reactive silica (mg/L)[e]	0.96 ± 0.25	0.917 ± 0.160	1.08 ± 0.15
Temperature (°C)	3.0 ± 0.4	2.8 ± 0.1	3.1 ± 0.2
1977 Southern Basin			
	(N = 9)	(N = 8)	(N = 6)
Chlorophyll-a (ug/L)	1.19 ± 0.57	1.22 ± 0.39	1.35 ± 0.63
Chloride (mg/L)	8.2 ± 0.19)	8.12 ± 0.07	8.17 ± 0.19
Specific conductance (uS/cm)	275.0 ± 2.1	275.0 ± 1.4	275.3 ± 2.5
Nitrate + nitrite nitrogen (ug/L)	257 ± 24	250 ± 15	258 ± 11
Total phosphorus (ug/L)	4.6 ± 1.8	3.9 ± 0.6	5.2 ± 1.9
Dissolved reactive silica (mg/L)[e]	1.14 ± 0.06	1.12 ± 0.09	1.13 ± 0.08
Temperature (°C)	2.6 ± 0.6	3.0 ± 0.4	2.8 ± 0.4

[a] Table contains mean and standard deviation of spring survey surface samples with number of samples included in parentheses.
[b] network defined in Lesht and Rockwell (1985).
[c] network defined in Table 4.
[d] "-" data not available.
[e] Dissolved reactive silica (mg-SiO_2/L).

Table 33. Comparison of Lake Erie water quality statistics (mean ± standard deviation) calculated from subsets of stations similar to those sampled during 1983 and 1984 with all open-lake stations using 1985 spring survey data.[a]

Year/Basin/Parameter	Spring open-lake station network sampled in 1985	Subset of stations similar to those sampled in 1983/1984[b]	T
		Lake Erie	
1985 Central Basin			
	(N = 18)	(N = 8)	
Chlorophyll-a (ug/L)	2.92 ± 1.36	3.15 ± 1.42	-0.40
Chloride (mg/L)	14.6 ± 0.46	14.4 ± 0.17	2.07[c]
Specific Conductance (uS/cm)	276.2 ± 2.9	276.0 ± 1.9	0.20
Nitrate + nitrite nitrogen (ug/L)	203 ± 25	213 ± 15	-1.13
Total phosphorus (ug/L)	12.1 ± 1.4	12.5 ± 1.6	-0.70
Dissolved reactive silica (ug/L)	7.9 ± 3.5	7.6 ± 3.5	0.21
Turbidity (FTU)	1.60 ± 0.53	1.56 ± 0.15	0.24
Temperature (°C)	5.6 ± 1.2	5.6 ± 1.1	-0.20
1985 Eastern Basin			
	(N = 8)	(N = 4)	
Chlorophyll-a (ug/L)	0.44 ± 0.25	0.35 ± 0.13	0.70
Chloride (mg/L)	14.9 ± 0.28	14.9 ± 0.31	0.00
Specific Conductance (uS/cm)	76.4 ± 1.4	276.6 ± 2.0	-0.16
Nitrate + nitrite nitrogen (ug/L)	278 ± 17	280 ± 7	-0.19
Total phosphorus (ug/L)	13.0 ± 0.8	13.2 ± 0.3	-0.46
Dissolved reactive silica (ug/L)	67.1 ± 11.2	67.5 ± 13.9	-0.05
Turbidity (FTU)	2.21 ± 0.48	2.37 ± 0.59	-0.51
Temperature (°C)	2.0 ± 0.26	1.8 ± 0.08	+1.36

[a] Table contains mean and standard deviation of spring survey surface samples with number of samples in parentheses.

[b] Stations compared in the central basin are LE 42, LE 73, LE 37, and LE 78 (the network in 1983 and 1984 included one more site: LE 79). Stations compared in the eastern basin are LE 09 and LE 15.

[c] indicates that the means are statistically different at alpha=0.05.

however, as an indication of the annual variability in water quality measurements when uncertainty due to factors such as sample location, sample times and analytical technique are minimized.

Thermal Cycle - Sampling Times

The three surveys of 1985 were conducted within a few calendar days of the surveys of 1984. Both the 1984 and 1985 survey schedule differed from the 1983 survey schedule in that the fall survey was conducted later in the year to sample fall "overturn." Lesht and Rockwell (1987) discussed the effects of the mild, 1982-1983 winter on lake water temperature. The 1985 spring temperatures were below 3°C, which was similar to the 1984 spring water temperatures. Similar spring water temperatures might be expected since the winters of 1983-1984 and 1984-1985 each had a Great Lakes Winter Severity Index (WSI) (Quinn et al., 1978) of -4.9. The winter 1984-1985 value is based on the monthly mean air temperature data shown in Table 34, where WSI equals the average of the four monthly mean air temperatures at each of the four stations.

Table 34. Monthly mean air temperature at Great Lakes Winter Severity Index[a] stations in Centigrade (Fahrenheit) - Winter 1984-1985.

	1984				1985			
	November		December		January		February	
Duluth, MN	3.7	(38.6)	1.1	(34.0)	-6.4	(20.4)	-4.7	(23.5)
Sault Ste. Marie, MI	-0.2	(31.7)	-6.3	(20.6)	-11.2	(11.9)	-10.6	(12.9)
Buffalo, NY	2.8	(37.0)	2.0	(35.6)	-6.1	(21.1)	-4.0	(24.8)
Detroit, MI	-2.0	(28.4)	-10.4	(13.2)	-14.2	(6.5)	-11.3	(11.6)
Monthly sum	4.3		-13.6		-37.9		-30.6	
Normal monthly sum	7.3		-10.4		-33.9		-28.1	

[a]Great Lakes Winter Severity Index (Quinn et al., 1978) is the average of the monthly mean temperatures from November through February at these four stations. The "normal" value of the index is -4.1 =(7.3-10.4-33.9-28.1)/16, (i.e., the average monthly mean temperature value for these four cities during the four months).

During November, the surface temperatures in all three lakes were similar in 1983, 1984 and 1985. Figures 48 to 52 show that 1985 spring survey sampling occured while the surface water temperature was similar to 1984 and one to two degrees cooler than 1983 in Lakes Michigan and Huron. In contrast, 1985 western basin Lake Erie temperatures were 1 to 6° C warmer than in 1983 and 1984, respectively. The 1985 lake water column was vertically more homogeneous than in 1984 (Lesht and Rockwell, 1987), although there is some sugggestion of residual hypolimnetic (nepheloid) layer enrichment (Figures 17 and 18). The summer survey of 1985 occurred during the stable summer stratified period. Although the duration of the 1985 stratified period was compariable to previous years, greater depletion of silica is evident in all basins of Lakes Michigan and Huron (Figures 19 to 22, Figures 24 to 27, and Table 35). As planned, the 1985 fall survey was conducted late in the year so that "fall overturn" conditions would be sampled in all lakes. "Fall overturn" occurred and the resulting uniform chemical structure was clearly observed in all lake basins except in northern Lake Michigan (Figures 19 to 22).

Nutrient Concentrations

Spring surface samples: In the analysis of the 1983-1984 surveillance data, Lesht and Rockwell (1985 and 1987) made comparisons of water quality across years using basin-averaged nutrient concentrations calculated from samples taken at the surface during the spring. This subset of the data was chosen for comparison because it was assumed to be spatially unbiased and representative of the open-lake water column during spring isothermal conditions. Tables 36 and 37 show these data for Lakes Michigan and Huron updated through 1985. A comparison of the 1983 through 1985 spring surface nutrient concentrations in Lake Erie is presented in Table 38.

Due to the early warming in 1985 in Lake Erie, sampling during the spring of 1985 was reduced to two runs. The number of samples collected in spring 1985 is generally less than the number of samples collected in spring 1983 but similar to 1984 where all three spring survey runs were completed only in Lake Erie. The number of stations in 1985 was increased

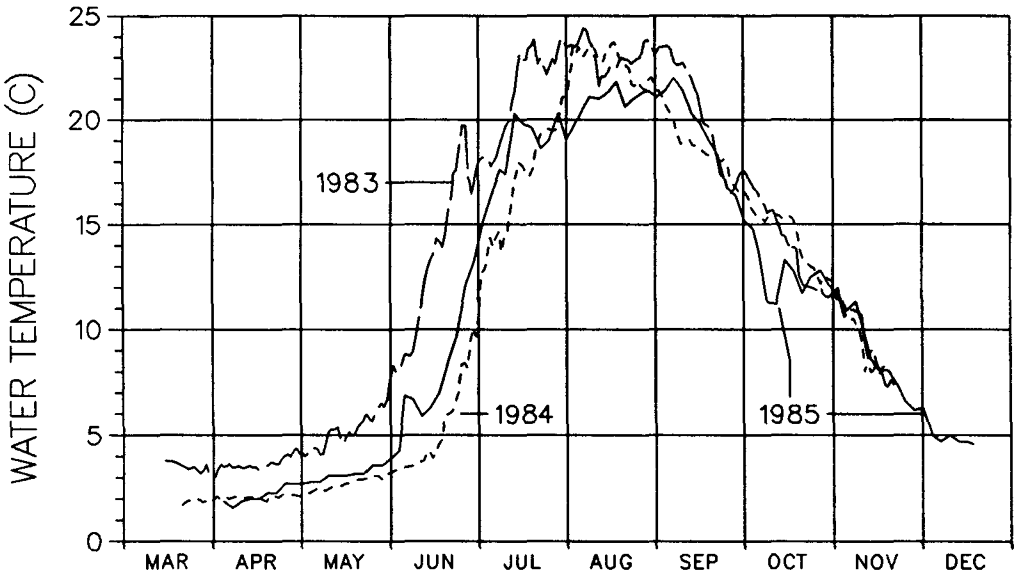


Figure 48. Comparison of surface water temperatures 1983, 1984 and 1985 in the southern basin of Lake Michigan. The data are from NDBO buoy 45007.

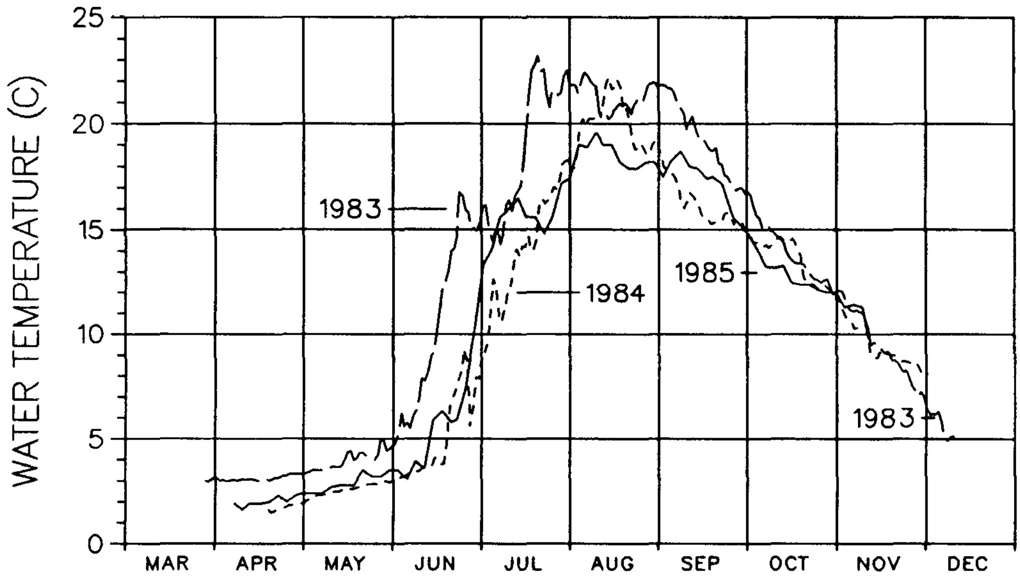


Figure 49. Comparison of surface water temperatures 1983, 1984 and 1985 in the northern basin of Lake Michigan. The data are from NDBO buoy 45002.

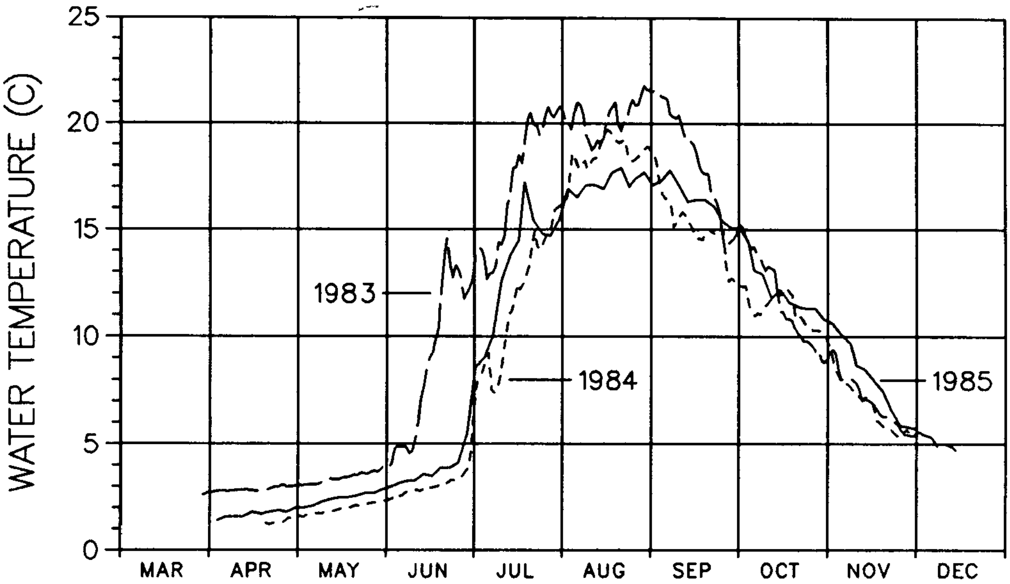


Figure 50. Comparison of surface water temperatures 1983, 1984 and 1985 in the northern basin of Lake Huron. The data are from NDBO buoy 45003.

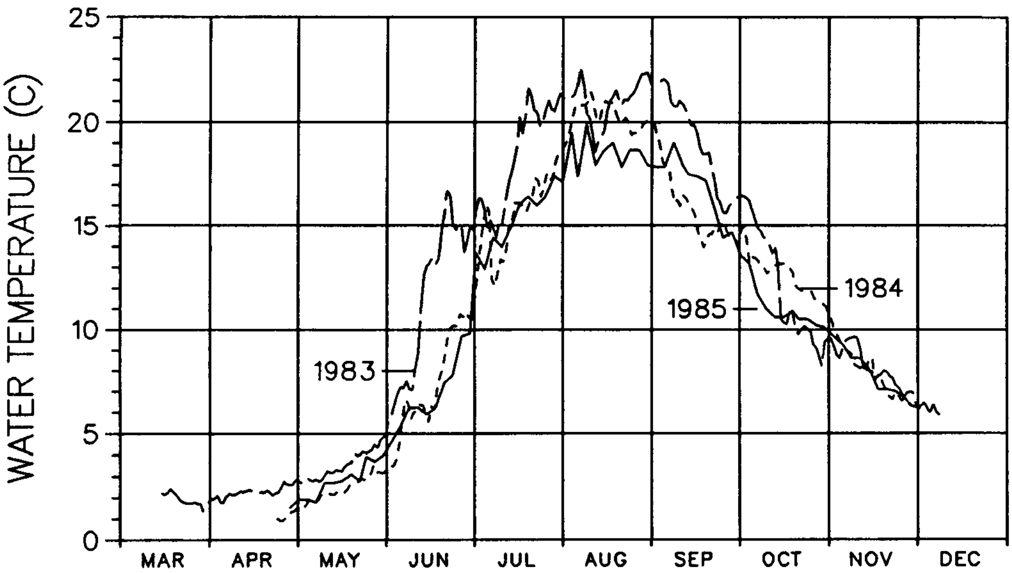


Figure 51. Comparison of surface water temperatures 1983, 1984 and 1985 in the southern basin of Lake Huron. The data are from NDBO buoy 45008.

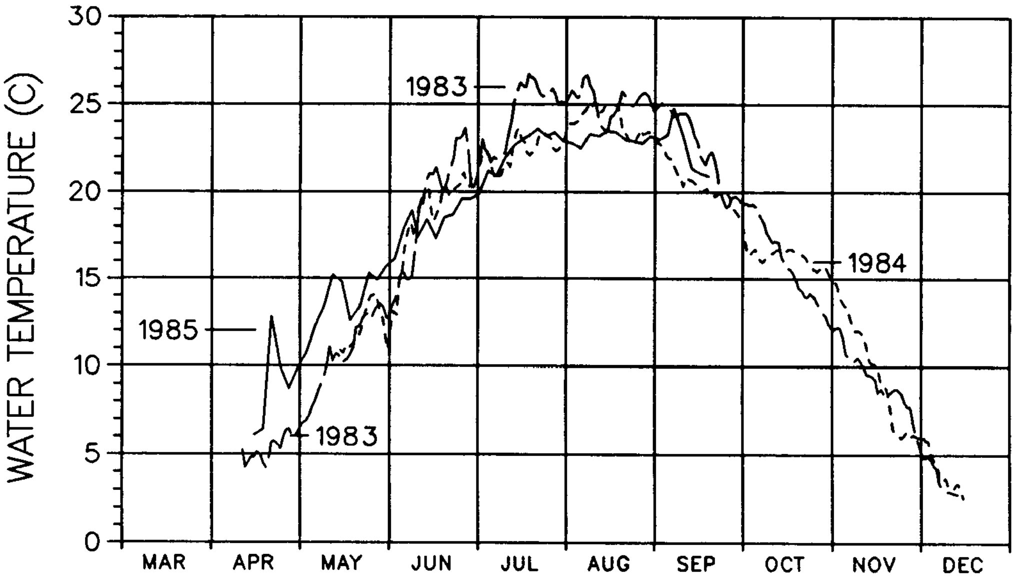


Figure 52. Comparison of surface water temperatures 1983, 1984 and 1985 in the western basin of Lake Erie. The data are from NDBO buoy 45005.

in the southern basin of Lake Michigan and in the central and eastern basins of Lake Erie reflecting recommendations from the respective IJC Task Forces. This somewhat compensated for reduced survey collections. The 1984 and 1985 sampling surveys were conducted at about the same time in the thermal cycle while the 1983 sampling was later in the thermal cycle. These differences complicate the comparison of the three data sets.

In general, we found fewer statistical similarities in basin-averaged values (Tables 39 and 40) than those found between similar 1983 and 1984 comparisons (Lesht and Rockwell, 1987).

The 1985 summer temperature structure, when compared to the two proceeding years, was found to be significantly (alpha=0.05) cooler. During the other two surveys (spring and fall), 1985 water temperatures were intermediate between 1983 and 1984 water temperatures. The 1985 spring survey temperatures were found to be significantly (alpha=0.05) cooler than 1983 and the fall survey temperatures were found to be significantly (alpha=0.05) warmer than 1984 water temperatures in all

Table 35. Observed nutrient depletion in Lakes Michigan and Huron comparing spring survey (maximum) concentrations with summer survey (minimum) concentrations.[a]

Lake Basin By Year	Dissolved Reactive Silicon (ug/L) 1983	1984	1985	Nitrate + Nitrite Nitrogen (ug/L) 1983	1984	1985
Lake Michigan						
Southern Basin Spring	571.9	570.5	565.8	271	270	294
Southern Basin Summer	154.7	107.6	95.3	170	168	161
Absolute Depletion	417.2	463.0	470.5	101	102	134
% Depletion	73.0	81.1	83.2	37.3	37.7	45.5
Northern Basin Spring	565.0	612.0	562.8	271	290	286
Northern Basin Summer	161.2	157.8	92.9	150	138	156
Absolute Depletion	403.7	459.2	470.0	121	152	131[b]
% Depletion	71.5	75.0	83.5	44.7	52.4	45.6
Lake Huron						
Northern Basin Spring	772.7	812.7	772.8	314	312	302
Northern Basin Summer	518.8	501.5	421.7	263	264	267
Absolute Depletion	253.8	311.1	351.2	52	48	35
% Depletion	32.9	38.3	45.4	16.4	15.4	11.7
Southern Basin Spring	758.0	765.3	782.4	299	294	301
Southern Basin Summer	473.4	351.7	338.2	287	282	276
Absolute Depletion	284.5	413.5	444.2	12	12	8
% Depletion	37.5	54.0	56.8	4.0	4.1	8.1

[a] Station networks as defined by 1985 network and basin definitions.
[b] Calculation affected by rounding.

basins except Lake Erie. The early spring warming had stratified the western basin of Lake Erie and had begun to stratify the central basin.

Other statistically significant differences in both 1983 and 1984, when compared to 1985, in the spring are: higher nitrate + nitrite concentrations in 1985 in Lake Michigan and the central and eastern basins of Lake Erie; lower total phosphorus levels in southern Lake Michigan and central Lake Erie; and higher dissolved reactive silica in southern Lake Huron and western Lake Erie. Summer epilimnion comparisons showed statistically significant, lower levels of dissolved reactive silica in Lakes Michigan and Huron.

Table 36. Inter-year basin comparisons -- Lake Michigan spring surface samples from open-lake stations.[a]

Year		N[b]	Temperature (°C)	Total Phosphorus (ug-P/L)	Dissolved Silica ($mg-SiO_2/L$)	Dissolved $NO_2 + NO_3$ (ug-N/L)
Southern Basin[c]						
	1	12	2.5 ± 0.32+	4.8 ± 0.7+	1.20 ± 0.04+@	287 ± 17+@
1985	2	12	2.5 ± 0.30+@	4.8 ± 0.7	1.20 ± 0.04	287 ± 17
	3	62	2.6 ± 0.28+	4.9 ± 1.0+	1.21 ± 0.04	293 ± 61+
	1	9	2.2 ± 0.55*	5.0 ± 1.0	1.12 ± 0.10	267 ± 14
1984	2	5	2.2 ± 0.26*	5.1 ± 0.5	1.17 ± 0.06	273 ± 12
	3	52	2.3 ± 0.46*	5.8 ± 2.0	1.17 ± 0.15	263 ± 18
	1	15	3.8 ± 0.52	5.7 ± 1.2	1.12 ± 0.14	258 ± 26
1983	2	7	3.9 ± 0.39	5.4 ± 0.8	1.21 ± 0.09	273 ± 18
	3	74	3.8 ± 0.42	6.2 ± 2.9	1.15 ± 0.15	261 ± 25
	1	9	2.6 ± 0.61	4.6 ± 1.8	1.14 ± 0.07	257 ± 10
1977	2	6	2.8 ± 0.42	5.2 ± 1.9	1.13 ± 0.08	258 ± 11
	3	39	2.5 ± 0.47	4.5 ± 1.3	1.16 ± 0.14	258 ± 12
	1	3	4.5 ± 0.55	8.3 ± 3.2	1.32 ± 0.07[e]	260 ± 10
1976[d]	2	1	4.6	12.0	1.32 [e]	260
	3	6	4.3 ± 0.22	7.7 ± 3.5	1.34 ± 0.01[e]	252 ± 04
	1	9	7.3 ± 1.58	5.2 ± 0.8	1.10 ± 0.18	230 ± 24
1976[f]	2	6	7.8 ± 1.47	5.2 ± 0.8	1.09 ± 0.21	230 ± 27
	3	38	5.9 ± 1.71	5.9 ± 1.7	1.19 ± 0.21	256 ± 93
Northern Basin						
	1	10	2.4 ± 0.24+@	5.6 ± 1.7	1.16 ± 0.06	297 ± 14+@
1985	2	10	2.4 ± 0.24+@	5.6 ± 1.7	1.16 ± 0.06	297 ± 14+
	3	62	2.5 ± 0.24+@	5.2 ± 2.2 @	1.20 ± 0.11+@	286 ± 15+@
	1	8	1.9 ± 0.41*	5.1 ± 0.6	1.18 ± 0.14	240 ± 57
1984	2	5	1.9 ± 0.38*	5.1 ± 0.8	1.19 ± 0.07	242 ± 57
	3	47	2.2 ± 0.57*	6.1 ± 2.0	1.30 ± 0.22	257 ± 39
	1	12	3.5 ± 0.30	5.4 ± 1.9	1.11 ± 0.15	264 ± 24
1983	2	7	3.7 ± 0.15	6.1 ± 1.6	1.18 ± 0.12	270 ± 22
	3	67	3.6 ± 0.23	5.8 ± 4.0	1.16 ± 0.14	270 ± 33
	1	7	2.9 ± 0.41	7.3 ± 1.6	1.01 ± 0.17	-
1976[g]	2	5	3.1 ± 0.23	7.6 ± 1.5	1.08 ± 0.15	-
	3	49	3.1 ± 0.23	6.9 ± 1.1	1.11 ± 0.11	-

Table 36. (Continued) Inter-year basin comparisons -- Lake Michigan spring surface samples from open-lake stations.[a]

	Year	Chlorophyll-a (ug/L)	Turbidity (FTU)	Chloride (mg/L)	Specific Conductance (uS/cm)
Southern Basin[c]					
	1	0.98 ± 0.75+	0.43 ± 0.13+	8.72 ± 0.23	279.8 ± 0.8
1985	2	0.98 ± 0.75	0.43 ± 0.13+	8.72 ± 0.23	279.8 ± 0.8
	3	0.95 ± 0.73+	0.40 ± 0.14+	8.69 ± 0.25+	279.9 ± 0.8+
	1	0.71 ± 0.28*	0.48 ± 0.15*	8.87 ± 0.25	278.4 ± 4.8
1984[d]	2	0.70 ± 0.31*	0.41 ± 0.12*	8.82 ± 0.33	277.0 ± 6.3
	3	0.66 ± 0.34*	0.53 ± 0.23	8.83 ± 0.25	278.3 ± 5.4
	1	2.01 ± 0.88	0.64 ± 0.19	8.74 ± 0.42	278.9 ± 1.6
1983	2	1.60 ± 0.56	0.56 ± 0.09	8.81 ± 0.27	279.4 ± 1.4
	3	1.97 ± 0.86			
	1	1.19 ± 0.57	0.79 ± 0.36	8.15 ± 0.17	275.1 ± 2.2
1977	2	1.35 ± 0.63	0.67 ± 0.12	8.17 ± 0.19	275.3 ± 2.5
	3	1.23 ± 0.47	0.72 ± 0.27	8.12 ± 0.16	275.0 ± 2.2
	1	1.27 ± 0.38	1.57 ± 1.25	8.05 ± 0.21	273.0 ± 1.73
1976[d]	2	1.02	0.70	8.20	274.0
	3	1.11 ± 0.37	0.75 ± 0.16	8.04 ± 0.19	273.8 ± 0.47
	1	1.81 ± 0.89	1.22 ± 0.51	7.90 ± 0.14	271.8 ± 1.4
1976[f]	2	1.75 ± 0.96	1.08 ± 0.49	7.92 ± 0.16	271.7 ± 1.4
	3	1.84 ± 1.10	1.08 ± 0.56	7.89 ± 0.15	272.8 ± 1.3
Northern Basin					
	1	0.67 ± 0.59	0.31 ± 0.09+	8.83 ± 0.40	279.3 ± 0.9
1985	2	0.67 ± 0.59	0.31 ± 0.09+	8.83 ± 0.40	279.3 ± 0.9
	3	0.75 ± 0.94+@	0.34 ± 0.29+	8.84 ± 0.31+	279.8 ± 0.9+@
	1	0.46 ± 0.19*	0.29 ± 0.10*	8.86 ± 0.24	278.2 ± 1.8
1984	2	0.36 ± 0.11*	0.24 ± 0.06*	8.90 ± 0.25	278.4 ± 2.3
	3	0.37 ± 0.19*	0.38 ± 0.33*	8.88 ± 0.23*	278.2 ± 4.4
	1	1.37 ± 1.01	0.67 ± 0.20	8.70 ± 0.36	278.3 ± 1.92
1983	2	0.91 ± 0.19	0.65 ± 0.21	8.73 ± 0.44	279.1 ± 1.07
	3	1.15 ± 0.81	0.61 ± 0.24	8.69 ± 0.30	279.2 ± 1.38
	1	1.29 ± 0.45	-	7.73 ± 0.10	-
1976[g]	2	1.10 ± 0.25	-	7.70 ± 0.15	-
	3	0.91 ± 0.26	-	7.73 ± 0.16	-

(Continued) Table 36 FOOTNOTES

[a] Values are means ± one standard deviation.
[b] Row 1, N = the surface samples from all stations sampled during the year. Row 2, N= surface samples from 1985 stations included in the annual network. Row 3, N= samples from all depths from the stations in the 1985 annual network sampled.
[c] Basin definition see Table 4, for 1983 and 1984 all stations numbered 27 and lower were used for the southern basin. See Lesht and Rockwell (1985 and 1987).
[d] First survey of 1976; sampled in early May along transect 6; stations depth of 80 meters or greater (Rockwell et al., 1980).
[e] SiO_2 is total.
[f] Second survey of 1976; sampled in late May all transects; station depth of 80 meters or greater (Rockwell et al., 1980).
[g] First survey in 1976; sampled in late April by the University of Michigan; station depth of 80 meters or greater (Rockwell et al., 1980).
* Denotes that the t value exceeds the critical value to reject the null hypothesis that 1983 and 1984 means are equal at alpha=0.05.
+ Denotes that the t value exceeds the critical value to reject the null hypothesis that 1983 and 1985 means are equal at alpha=0.05.
@ Denotes that the t value exceeds the critical value to reject the null hypothesis that 1984 and 1985 means are equal at alpha=0.05.

Table 37. Inter-year comparisons — Lake Huron, both basins, spring surface samples from open-lake stations.[a]

Year	N[b]	Total Phosphorus (ug/L)	Dissolved Silica (mg-SiO_2/L)	$NO_2 + NO_3$ Nitrogen (ug/L)	Chloride (mg/L)	Water Temperature (°C)	Turbidity (FTU)	Specific Conductance (uS/cm)	Chlorophyll-a (ug/L)
1985	20	3.0 ± 0.5+@	1.656 ± 0.039	302 ± 24	5.37 ± 0.12+@	1.60 ± 0.42	0.38 ± 0.08	202.7 ± 1.2	0.89 ± 0.56+@
1984[c]	20	3.6[d] ± 0.7	1.678 ± 0.125	309 ± 19	5.68 ± 0.32	1.33 ± 0.46*	0.41 ± 0.15*	203.1 ± 2.2	0.51 ± 0.23*
1983	30	3.7 ± 1.4	1.636 ± 0.050	305 ± 17	5.62 ± 0.31	3.02 ± 0.59	0.59 ± 0.16	204.2 ± 4.0	1.54 ± 0.59
1980	19	4.7 ± 1.4	1.529 ± 0.074	290 ± 12				202.9 ± 3.0	
1971	14	3.9 ± 0.9	1.410 ± 0.062	248 ± 10				207.9 ± 4.4	

[a] Values are means ± one standard deviation. Years 1983-1985 use the 1985 sampling network.
[b] N = number of stations sampled.
[c] = combined spring data from 1984-1 and 1984-2 (Lesht and Rockwell, 1987).
[d] Excludes one questionable value (12.0), with this value 4.0 ± 2.0, number of samples = 21.
+ 1985 is significantly different from 1983.
@ 1985 is significantly different from 1984.
* 1984 is significantly different from 1983.

Table 38. Inter-year basin comparisons -- Lake Erie spring surface samples from open-lake stations.[a]

Year	N[b]	Total Phosphorus (ug/L)	Dissolved Silica (mg-SiO_2/L)	NO_2 + NO_3 Nitrogen (ug/L)	Chloride (mg/L)	Water Temperature (°C)	Turbidity (FTU)	Specific Conductance (uS/cm)	Chlorophyll-a (ug/L)
Western Basin									
1985	6	21.0 ± 3.9	1.297 ± 0.283	683 ± 147*	12.9 ± 2.0@	12.28 ± 1.21+@	5.98 ± 1.84@	254.5 ± 10.5@	6.22 ± 3.76@
1984[c]	9	31.4 ± 16.5[d]	0.802 ± 0.600	874 ± 370*	16.7 ± 1.6	6.87 ± 1.58	19.02 ± 16.95	273.0 ± 19.1	4.21 ± 1.35
1983	9	25.6 ± 17.9	0.886 ± 0.591	497 ± 107	14.2 ± 4.9	8.31 ± 1.65	9.90 ± 5.96	259.4 ± 35.3	5.60 ± 2.76
Central Basin									
1985	18	12.1 ± 1.4	0.017 ± 0.008@	203 ± 25+@	14.6 ± 0.5*	5.55 ± 1.16@	1.60 ± 0.53	276.2 ± 2.9	2.92 ± 1.35+@
1984[c]	15	13.1 ± 3.3	0.029 ± 0.016*	129 ± 27	14.5 ± 0.4*	3.14 ± 1.02*	1.78 ± 1.37	276.0 ± 3.5	1.45 ± 0.48*
1983	15	13.4 ± 6.0	0.018 ± 0.011	151 ± 49	15.5 ± 0.5	5.42 ± 0.82	1.53 ± 0.43	28.1 ± 4.5	4.61 ± 0.97
Eastern Basin									
1985	8	13.0 ± 0.8@	0.144 ± 0.024+@	278 ± 17+@	14.9 ± 0.3*	1.99 ± 0.26+@	2.21 ± 0.48@	276.4 ± 1.4*	0.44 ± 0.25+@
1984[c]	9	15.0 ± 1.5	0.218 ± 0.056	216 ± 20	15.0 ± 0.5	1.26 ± 0.75	2.96 ± 0.44	281.7 ± 4.4	0.72 ± 0.19*
1983	9	14.9 ± 10.3	0.037 ± 0.011	239 ± 9	16.8 ± 0.8	4.23 ± 0.74	2.33 ± 0.55	289.1 ± 2.4	2.13 ± 0.69

a Values are means ± one standard deviation.
b N = Number of samples included in the average.
c Combined spring data from 1984-1 and 1984-2 (Lesht and Rockwell, 1987).
d Excludes one extreme value (125.0); with this value 41.8 + 34.8.
* Denotes that t value exceeds critical value to reject null hypothesis that 1983 and 1984 means are equal at alpha=0.05.
\+ Denotes that t value exceeds critical value to reject null hypothesis that 1983 and 1985 means are equal at alpha=0.05.
@ Denotes that t value exceeds critical value to reject null hypothesis that 1984 and 1985 means are equal at alpha=0.05.

Table 39. Comparison of epilimnion mean values of selected parameters, spring surveys, 1983-1985.[a]

Basin/Year	Water Temperature (°C)	t*	Chlorophyll-a (ug/L)	t*	Dissolved Reactive Silicon (ug/L)	t*	Dissolved Nitrate + Nitrite Nitrogen (ug/L)	t*
Lake Michigan-S								
1985	2.6 ± 0.28 (62)		0.95 ± 0.73 (62)		566.0 ± 19.2 (62)		292.5 ± 61.0 (62)	
1984 1 & 2[b]	2.3 ± 0.46 (52)	+3.67*	0.66 ± 0.34 (47)	+2.70*	547.1 ± 70.2 (50)	+1.85	262.9 ± 17.7 (51)	+3.64*
1983	3.8 ± 0.42 (74)	-21.5*	1.97 ± 0.85 (72)	-7.39*	536.2 ± 68.6 (73)	+3.55*	260.5 ± 25.0 (73)	+3.86*
Lake Michigan-N								
1985	2.5 ± 0.24 (62)		0.75 ± 0.94 (62)		562.8 ± 50.0 (62)		286.3 ± 15.2 (62)	
1984 1 & 2	2.2 ± 0.57 (47)	+4.16*	0.37 ± 0.19 (44)	+3.09*	605.4 ± 104.9 (47)	-2.57*	256.9 ± 38.9 (47)	+4.89*
1983	3.6 ± 0.23 (67)	-24.9*	1.15 ± 0.81 (67)	-2.60*	540.3 ± 64.2 (67)	+2.23*	269.7 ± 33.3 (67)	+4.79*
Lake Huron-N								
1985	1.5 ± 0.26 (58)		0.78 ± 0.59 (58)		772.8 ± 20.0 (58)		302.1 ± 26.5 (58)	
1984 1 & 2	1.3 ± 0.27 (57)	+ 2.75*	0.42 ± 0.17 (58)	+4.49*	812.7 ± 60.5 (58)	-4.76*	311.8 ± 20.2 (58)	+2.23*
1983	3.0 ± 0.32 (80)	-28.9*	1.30 ± 0.48 (48)	-5.64*	772.7 ± 22.4 (79)	+0.05	314.3 ± 12.6 (79)	-3.26*
Lake Huron-S								
1985	1.8 ± 0.46 (45)		1.09 ± 0.54 (45)		782.4 ± 13.4 (45)		300.9 ± 20.5 (45)	
1984 1 & 2	1.4 ± 0.58 (45)	+3.63*	0.67 ± 0.15 (45)	+5.12*	765.3 ± 26.1 (43)	+3.86*	293.9 ± 19.1 (44)	+1.68
1983	3.1 ± 0.57 (71)	-12.6*	1.88 ± 0.51 (70)	-7.98*	758.0 ± 23.3 (49)	+6.30	299.0 ± 16.7 (49)	+0.51
Lake Erie-W								
1985	12.0 ± 1.19 (14)		5.85 ± 3.35 (14)		633.1 ± 166.9 (14)		698.7 ± 163.8 (14)	
1984 1 & 2	6.7 ± 1.47 (21)	+11.2*	4.11 ± 1.37 (20)	+1.83	369.9 ± 259.4 (21)	+3.35*	856.2 ± 330.2 (21)	-1.86
1983	8.2 ± 1.63 (27)	+7.63*	5.47 ± 2.65 (27)	+0.39	413.9 ± 266.6 (24)	+2.77*	494.1 ± 97.9 (27)	+4.29*
Lake Erie-C								
1985	5.1 ± 1.06 (60)		2.75 ± 1.29 (60)		9.7 ± 5.8 (60)		204.5 ± 21.1 (60)	
1984 1 & 2	3.0 ± 0.86 (48)	+10.7*	1.48 ± 0.54 (48)	+6.93*	13.8 ± 7.4 (46)	-3.22*	129.6 ± 26.7 (47)	+16.2*
1983	5.4 ± 0.79 (48)	-1.67	4.48 ± 0.99 (47)	-7.58*	8.3 ± 4.4 (46)	+1.30	151.5 ± 46.8 (46)	+7.14*
Lake Erie-E								
1985	2.1 ± 0.39 (40)		0.40 ± 0.23 (40)		71.5 ± 11.0 (40)		287.6 ± 19.8 (40)	
1984 1 & 2	1.4 ± 0.76 (48)	+5.82*	0.67 ± 0.16 (48)	-6.32	97.4 ± 25.0 (48)	-6.47*	218.2 ± 16.0 (48)	+18.2*
1983	4.2 ± 0.78 (48)	-16.3*	1.98 ± 0.50 (48)	-19.4*	17.8 ± 3.7 (47)	28.1*	237.7 ± 10.7 (47)	+13.4*

[a]Values are mean ± one standard deviation with number of samples in parentheses. All stations sampled during respective years.

[b]Indicates 1984-1&2 combined spring data from April and May surveys (Lesht and Rockwell, 1987).

*Denotes t value exceeds the critical value to reject null hypothesis that means are equal with alpha=0.05, 1984 t value compares 1985 to 1984 means, 1983 t value compares 1985 to 1983 means.

Table 39. (Continued) Comparison of epilimnion mean values of selected parameters, spring surveys, 1983-1985[a].

Basin/Year	Total Phosphorus (ug/L)	t*	Total Dissolved Phosphorus (ug/L)	t*	Dissolved Reactive Ortho phosphorus (ug/L)	t*
Lake Michigan-S						
1985	4.9 ± 1.0 (62)		2.4 ± 0.8 (62)		0.9 ± 0.6	
1984 1 & 2[b]	5.8 ± 2.0 (51)	-2.73*	2.3 ± 0.8 (51)	+0.29	0.9 ± 1.2	-0.16
1983	6.2 ± 4.9 (73)	-3.60*	2.0 ± 1.4 (74)	+1.75	0.8 ± 0.9	+0.91
Lake Michigan-N						
1985	5.2 ± 2.2 (62)		2.8 ± 1.1 (62)		0.9 ± 0.6 (62)	
1984 1 & 2	6.1 ± 2.0 (47)	-2.04*	2.8 ± 1.8 (46)	-0.06	1.2 ± 1.8 (47)	-1.17
1983	5.8 ± 4.0 (66)	-1.0	2.6 ± 1.5 (49)	+0.82	1.4 ± 1.4 (45)	-2.13*
Lake Huron-N						
1985	3.3 ± 1.8 (57)		1.3 ± 0.5 (57)		0.3 ± 0.3 (58)	
1984 1 & 2	3.8 ± 1.4 (58)	-1.57	1.4 ± 0.5 (56)	-1.54	0.3 ± 0.7 (58)	-0.55
1983	4.8 ± 3.5 (80)	-3.38*	1.6 ± 1.1 (72)	-1.89	0.6 ± 0.6 (54)	-3.32*
Lake Huron-S						
1985	3.6 ± 1.7 (45)		1.3 ± 0.6 (45)		0.5 ± 0.4 (45)	
1984 1 & 2	3.7 ± 0.9 (44)	-0.53	1.4 ± 0.7 (44)	-0.63	0.2 ± 0.4 (44)	+3.83*
1983	4.7 ± 3.4 (70)	-2.39*	1.6 ± 0.9 (66)	-2.08*	0.6 ± 0.5 (45)	-0.41
Lake Erie-W	20.7 ± 3.9 (14)		3.9 ± 2.0 (14)		1.0 ± 1.0 (14)	
1984 1 & 2	38.9 ± 27.3 (21)	-3.00*	5.0 ± 3.3 (21)	-1.09	1.6 ± 2.3 (21)	-0.99
1983	25.7 ± 19.1 (26)	-1.27	4.9 ± 5.7 (25)	-0.75	1.1 ± 0.5 (23)	-0.35
Lake Erie-C						
1985	12.8 ± 2.3 (60)		3.8 ± 0.6 (60)		0.9 ± 0.3 (60)	
1984 1 & 2	14.0 ± 4.5 (47)	-1.71	3.9 ± 0.9 (47)	-1.04	0.4 ± 0.2 (47)	+10.5*
1983	13.4 ± 5.2 (47)	-0.78	3.3 ± 1.5 (45)	+1.94	0.9 ± 0.7 (45)	+0.55
Lake Erie-E						
1985	12.8 ± 1.3 (40)		6.2 ± 0.6 (40)		2.7 ± 0.7 (40)	
1984 1 & 2	15.7 ± 3.9 (48)	-4.76*	6.5 ± 1.6 (48)	-1.52	2.4 ± 1.2 (48)	+1.21
1983	11.1 ± 5.8 (48)	+2.02*	3.5 ± 1.8 (42)	+8.66*	1.9 ± 1.6 (47)	+3.07*

[a] Values are mean ± one standard deviation with number of samples in parentheses. All stations sampled during respective years.
[b] Indicates 1984-1&2 combined spring data from April and May surveys (Lesht and Rockwell, 1987).
* Denotes t value exceeds the critical value to reject null hypothesis that means are equal with alpha=0.05. 1984 t value compares 1985 to 1984 means. 1983 t value compares 1985 to 1983 means.

Table 40. Summary of statistically significant differences (two-tailed t-test, alpha=0.05) between epilimnion data collected in 1985 with 1983 and 1984 for selected parameters.[a]

Basin	W Temp[b]		Chl-a[b]		Silicon[b]		NO_x-N[b]		Total P[b]		Total DP[b]		SRP[b]	
	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5
SPRING														
LMS	−	+	−	+	+		+	+	−	−				
LMN	−	+	−	+	+	−	+	+		−			−	
LHN	−	+	−	+		−	−	−	−				−	
LHS	−	+	−	+	+	+			−		−			+
LEW	+	+			+	+	+			−				
LEC		+	−	+		−	+	+						+
LEE	−	+	−	−	+	−	+	+	+	−	+		+	
	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5
SUMMER														
LMS	−	−	+	+	−	−	−			−		−		
LMN	−	−	+		−	−		+			−	−		
LHN	−	−	+	+	−	−								+
LHS	−	−	+	+	−		−			−			+	+
LEW	−	−	+	+				−						+
LEC		−	+		+		+	−						+
LEE		−					+	+	−	−	−	−	+	+
	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5	83-5	84-5
FALL														
LMS	−	+	−	−	+		+		+		+	−	−	−
LMN	−	+	−	−	+	−	+		−	−			−	−
LHN	−	+	−	−		−	+	−			−	−	−	−
LHS	−	+	−	−	+		+				+		−	−
LEW	−	+	−	−	+	+	+			+		+		+
LEC	−	+	−	−	−	+	+	−			+	+	+	+
	−	+	−	−	−	−	+	−	+		+	+	+	+

[a] A plus sign indicates a higher parameter mean in 1985 and a negative sign indicates a lower mean in 1985.
[b] W Temp=Water Temperature,
Chl-a=Chlorophyll-a,
Silicon=Dissolved Reactive Silicon,
NO_x-N=Dissolved Nitrite+Nitrate-Nitrogen,
Total P=Total Phosphorus,
Total DP=Total Dissolved Phosphorus,
and SRP=Soluble Reactive Phosphorus.

DETECTION OF SIGNIFICANT CHANGES

One question of interest when comparing surveillance data across years is whether there has been a statistically significant change in the mean value of a parameter over the period of comparison. Statistically, this question is cast in terms of using an appropriate test to either reject or accept the null hypothesis that there has been no change. The value of the test statistic used in most cases will depend on the difference between sample means, the parameter variance, and the size of the samples. In the case of the current surveillance program we are interested in estimating, given observed variances and known number of samples, how large a mean concentration change would be required to reject the null hypothesis that there has been no change. Such an estimate is useful in evaluating both the program design and the application of the program results to analysis of water quality trends.

If we make the assumption that the true variance of a parameter is constant across sample periods, we can calculate the difference in means that would be required for rejection of the null hypothesis from the expression for the Student's t statistic (Walpole and Myers, 1978):

$$t = ((\bar{x}_1 - \bar{x}_2) - d_0) / (S_p((1/n_1) + (1/n_2))^{1/2}) \qquad (1)$$

in which $\bar{x}_i$ are the mean values, d_0 is the true difference being tested for (in this case $d_0 = 0$), n_i are the number of samples, and S_p is the pooled standard deviation calculated by

$$S_p^2 = ((n_1 - 1)S_1^2 + (n_2 - 1)S_2^2) / (n_1 + n_2 - 2) \qquad (2)$$

where the S_i^2 are the sample variances. The appropriate t distribution has $n_1 + n_2 - 2$ degrees of freedom.

Making the further assumptions that future sampling will follow the sampling plan used in 1983 and 1984, have an equal number of sampling points and that the sample variance of a parameter will be unchanged, we can simplify the expression for t (equation 1) to

$$t = (\text{delta}) \;/\; (2(S_1^2/n_1))^{1/2} \qquad (3)$$

from which, given a confidence level, the required difference, delta, can be calculated.

This expression for the required difference, delta, can be generalized by defining

$$\text{delta} = \bar{x}_1 - \bar{x}_2 = S_1 t(2/n_1)^{1/2} \qquad (4)$$

and calculating the percent change required for detection of a significant difference as a function of the parameter coefficient of variation and the sample size. This may be written

$$(\bar{x}_1 - \bar{x}_2) \;/\; \bar{x}_1 = (S_1/\ \bar{x}_1)\ t\ (2/n_1)^{1/2} \qquad (5)$$

Thus for a given sample size, n_1, assumed to be equal in both years, the percent change required to detect a significant difference is a linear function of $S_1/\ \bar{x}_1$, the parameter coefficient of variation, which also is assumed to be constant in this example. This function is graphed for several sample sizes in Figure 53. Minimum concentration differences in spring surface parameters are compared by basin in Table 41.

The true variance of any sampled parameter is necessarily unknown, and the significance of the sampled variance must be considered carefully. Calculating sample means and variances and using parametric tests for statistical estimation is based on the assumption that the samples are independent, random samples from a normal population. For limnological data, this assumption translates into sampling from a homogeneous water mass in which the variable to be measured is spatially uniform. Thus, sampling and analysis would be the major sources of error in an individual measurement. Given similar sampling and analysis techniques, then, we could expect similar sample variances from year to

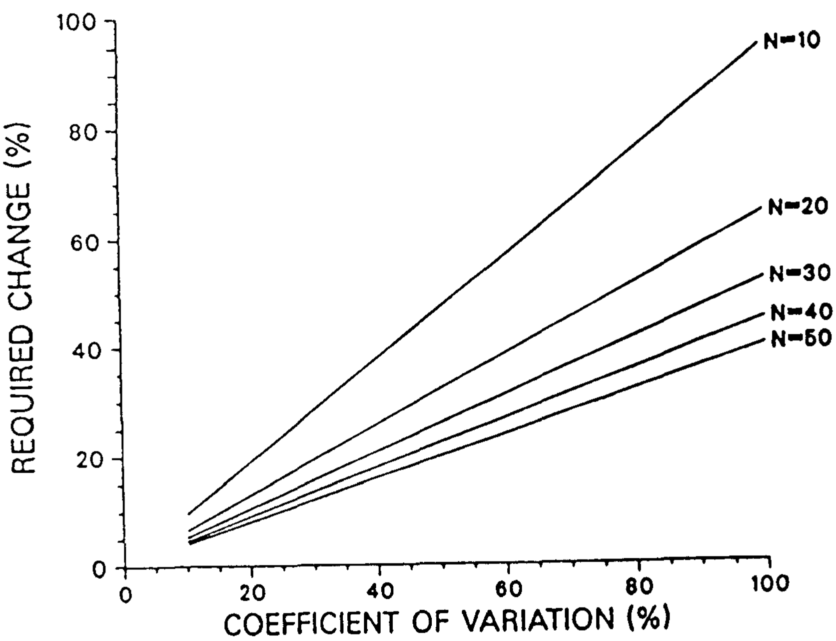


Figure 53. The change required for the detection of significant (alpha=0.05) differences using the two-tailed t-test as a function of the parameter coefficient of variation and the sample size.

year. Sample variances for selected parameters measured in 1983 through 1985 are compared by basin in Tables 42 to 44.

Tables 42 to 44 show that the parameter variance may not be constant from year to year. The degree to which this is true depends on the data subset used. We find that, as may be expected, the subset of all samples (Table 42) has many more cases of differing parameter variances than does the subset of spring surface values (Table 43). This occurs because the degrees of freedom for the first subset increases faster than the sample variance, thereby increasing the sensitivity of the F-test.

Similarly, we find that the number of cases in which the parameter variances are statistically different is greater for the subset of spring surface samples (Table 43) than for the subset of spring station averages (Table 44). In general, this is due to the reduction in sample variance resulting from representing each station by an average of several samples rather than by one sample.

Table 41. Minimum difference of means (delta) for rejection of null hypothesis, H_0: $\bar{x}_1 = \bar{x}_2$ (alpha=0.05) for all spring samples.[a]

Parameter	Number of Samples 1983	1984	1985	$\bar{x}$ Mean of Samples 1983	1984	1985	s^2 Variance of Samples 1983	1984	1985	1983 to 1984 d.f.	t	delta	1984 to 1985 d.f.	t	delta
Lake Michigan Southern Basin															
Total Phos. (ug/L)	73	51	62	6.24	5.79	4.94	8.4419	4.1927	0.9771	122	1.980	0.935	111	1.982	0.584
Silica (mg-SiO_2/L)	73	50	62	1.147	1.170	1.211	0.0216	0.0226	0.0017	121	1.980	0.054	110	1.982	0.040
NO_2+NO_3-N (ug/L)	73	51	62	261	263	293	0.6	0.3	3.7	122	1.980	8	111	1.982	18
Turbidity (FTU)	74	51	58	0.65	0.53	0.40	0.0465	0.0517	0.0196	123	1.980	0.079	107	1.982	0.071
Conductivity (uS/cm)	74	51	62	278.9	278.3	279.9	1.1494	29.301	0.6354	123	1.980	1.279	111	1.982	1.379
Chloride (mg/L)	72	51	62	8.72	8.83	8.69	0.1441	0.0606	0.0602	121	1.980	0.120	111	1.982	0.092
Chlorophyll-a (ug/L)	72	47	62	1.97	0.66	0.95	0.7356	0.1190	0.5282	117	1.980	0.261	107	1.982	0.228
Lake Michigan Northern Basin															
Total Phos. (ug/L)	66	47	62	5.80	6.07	5.23	16.158	4.1902	4.9702	111	1.982	1.266	107	1.982	0.825
Silica (mg-SiO_2/L)	67	47	62	1.156	1.295	1.204	0.0189	0.0504	0.0114	112	1.982	0.067	107	1.982	0.064
NO_2+NO_3-N (ug/L)	67	47	62	270	257	286	1.1	1.5	0.2	112	1.982	13	107	1.982	11
Turbidity (FTU)	67	41	62	0.61	0.38	0.34	0.0567	0.1060	0.0825	106	1.982	0.108	101	1.984	0.121
Conductivity (uS/cm)	67	45	62	279.2	278.2	279.8	1.9069	19.233	0.7742	110	1.982	1.136	105	1.982	1.132
Chloride (mg/L)	66	41	62	8.69	8.88	8.84	0.0887	0.0518	0.0961	105	1.982	0.108	101	1.984	0.112
Chlorophyll-a (ug/L)	67	44	62	1.15	0.37	0.75	0.6514	0.0363	0.8785	109	1.982	0.246	104	1.984	0.285
Lake Huron Northern Basin															
Total Phos. (ug/L)	80	58	57	4.85	3.78	3.31	12.303	2.0312	3.0913	136	1.977	0.964	113	1.982	0.591
Silica (mg-SiO_2/L)	79	58	58	1.653	1.739	1.653	0.0023	0.0168	0.0018	135	1.977	0.031	114	1.982	0.035
NO_2+NO_3-N (ug/L)	79	58	58	314	312	302	0.2	0.4	0.7	135	1.977	6	114	1.982	9
Turbidity (FTU)	76	58	56	0.60	0.37	0.39	0.4008	0.0177	0.0203	132	1.979	0.167	112	1.982	0.051
Conductivity (uS/cm)	79	58	58	203.3	203.4	202.7	4.3815	3.4618	1.3092	135	1.977	0.683	114	1.982	0.568
Chloride (mg/L)	78	58	53	5.51	5.49	5.41	0.0508	0.0192	0.1448	134	1.979	0.066	109	1.982	0.106
Chlorophyll-a (ug/L)	76	58	58	1.30	0.42	0.78	0.2315	0.1704	0.3455	132	1.979	0.156	114	1.982	0.187
Lake Huron Southern Basin															
Total Phos. (ug/L)	70	44	45	4.73	3.73	3.57	11.463	0.7500	3.0137	112	1.982	1.034	87	1.987	0.580
Silica (mg-SiO_2/L)	49	43	45	1.622	1.637	1.674	0.0025	0.0031	0.0008	90	1.987	0.022	86	1.987	0.019
NO_2+NO_3-N (ug/L)	49	44	45	299	294	301	0.3	0.4	0.4	91	1.987	7	87	1.987	8
Turbidity (FTU)	60	44	45	0.65	0.58	0.53	0.0346	0.0412	0.1074	102	1.984	0.076	87	1.987	0.115
Conductivity (uS/cm)	71	44	45	205.0	204.2	203.4	5.2712	5.5037	1.7387	113	1.982	0.880	87	1.987	0.799
Chloride (mg/L)	50	45	45	5.76	5.79	5.38	0.1318	0.0453	0.0180	93	1.987	0.123	88	1.987	0.075
Chlorophyll-a (ug/L)	70	45	45	1.88	0.67	1.10	0.2593	0.0221	0.2865	113	1.982	0.155	88	1.987	0.165

[a] Samples are from each year's entire network using the 1985 basin definitions.

Table 41. (Continued) Minimum difference of means (delta) for rejection of null hypothesis, H_0: $\bar{x}_1 = \bar{x}_2$ (alpha=0.05) for all spring samples.[a]

Parameter	Number of Samples 1983	1984	1985	$\bar{x}$ Mean of Samples 1983	1984	1985	s^2 Variance of Samples 1983	1984	1985	1983 to 1984 d.f.	t	delta	1984 to 1985 d.f.	t	delta
Lake Erie Western Basin															
Total Phos. (ug/L)	26	21	14	25.66	38.87	20.71	365.91	746.42	15.218	45	2.013	13.661	33	2.037	15.047
Silica (mg-SiO_2/L)	24	21	14	0.885	0.791	1.354	0.3252	0.3080	0.1274	43	2.017	0.339	33	2.037	0.342
NO_2+NO_3-N (ug/L)	27	21	14	494	856	699	9.6	109	26.8	46	2.013	135	33	2.037	195
Turbidity (FTU)	27	21	14	10.20	18.47	6.39	31.951	246.41	2.1019	46	2.013	6.553	33	2.037	8.613
Conductivity (uS/cm)	27	21	14	260.6	270.4	256.2	1204.0	288.80	227.70	46	2.013	16.629	33	2.037	11.435
Chloride (mg/L)	27	21	14	14.48	16.60	13.11	25.148	2.0773	5.7888	46	2.013	2.277	33	2.037	1.322
Chlorophyll-a (ug/L)	27	20	14	5.47	4.12	5.85	7.0336	1.8846	11.244	45	2.014	1.310	32	2.035	1.691
Lake Erie Central Basin															
Total Phos. (ug/L)	47	47	60	13.41	14.00	12.78	27.059	19.993	5.1752	92	1.987	1.988	105	1.982	1.319
Silica (mg-SiO_2/L)	46	46	60	0.018	0.030	0.021	0.0001	0.0003	0.0002	90	1.987	0.005	104	1.984	0.005
NO_2+NO_3-N (ug/L)	46	47	60	152	130	205	2.2	0.7	0.4	91	1.987	16	105	1.982	9
Turbidity (FTU)	48	48	60	1.67	2.05	1.77	0.1984	3.0618	0.5125	94	1.987	0.518	106	1.982	0.492
Conductivity (uS/cm)	48	48	60	278.2	276.9	276.5	14.483	10.221	6.0501	94	1.987	1.425	106	1.982	1.079
Chloride (mg/L)	47	46	60	15.44	14.59	14.65	0.2524	0.1811	0.2009	91	1.987	0.192	104	1.984	0.171
Chlorophyll-a (ug/L)	47	48	60	4.48	1.48	2.76	0.9795	0.2946	1.6682	93	1.987	0.325	106	1.982	0.395
Lake Erie Eastern Basin															
Total Phos. (ug/L)	48	48	40	11.09	15.69	12.84	33.815	15.288	1.6040	94	1.987	2.010	86	1.987	1.282
Silica (mg-SiO_2/L)	47	48	40	0.038	0.208	0.153	0.0001	0.0029	0.0006	93	1.987	0.016	86	1.987	0.018
NO_2+NO_3-N (ug/L)	47	48	40	238	218	288	0.1	0.3	0.4	93	1.987	6	86	1.987	8
Turbidity (FTU)	48	48	40	2.468	3.38	2.63	0.4913	1.9327	0.6849	94	1.987	0.447	86	1.987	0.497
Conductivity (uS/cm)	48	48	40	289.7	283.7	278.2	4.3894	32.509	4.1071	94	1.987	1.742	86	1.987	1.885
Chloride (mg/L)	47	48	40	16.85	15.10	14.94	0.3848	0.2426	0.0574	93	1.987	0.228	86	1.987	0.169
Chlorophyll-a (ug/L)	48	48	40	1.98	0.68	0.40	0.2530	0.0270	0.0551	94	1.987	0.152	86	1.987	0.085

[a] Samples are from each year's entire network using the 1985 basin definitions.

Table 42. Comparison of standard deviations of selected parameters, spring survey, all samples, 1983-1985.[a]

	Total Phosphorus (ug/L)						Dissolved Reactive Silica (mg-SiO_2/L)						Nitrate + Nitrite Nitrogen (ug/L)					
	1983	1984	1985	83/84 F*	83/85 F*	84/85 F*	1983	1984	1985	83/84 F*	84/85 F*	84/85 F*	1983	1984	1985	83/84 F*	83/85 F*	84/85 F*
Lake Michigan																		
Southern Basin	2.91	2.05	0.99				0.147	0.150	0.041				25	18	61			
	(73)	(51)	(62)	2.01*	8.64*	4.29*	(73)	(50)	(62)	1.05	12.8*	13.4*	(73)	(51)	(62)	2.00*	5.93*	11.96*
Northern Basin	4.02	2.05	2.23				0.137	0.224	0.107				33	39	15			
	(66)	(47)	(62)	3.86*	3.25*	1.19	(67)	(47)	(62)	2.67*	1.65*	4.41*	(67)	(47)	(62)	1.37	4.79*	6.57*
Lake Huron																		
Northern Basin	3.51	1.43	1.76				0.048	0.130	0.043				13	20	26			
	(80)	(58)	(57)	6.06*	3.98*	1.52	(79)	(58)	(58)	7.26*	1.27	9.20*	(79)	(58)	(58)	2.57*	4.43*	1.72*
Southern Basin	3.39	0.87	1.74				0.050	0.056	0.029				17	19	20			
	(70)	(44)	(45)	15.29*	3.80*	4.02*	(49)	(43)	(45)	1.25	3.04*	3.80*	(49)	(44)	(45)	1.30	1.49	1.15
Lake Erie																		
Western Basin	19.1	27.3	3.90				0.570	0.555	0.357				98	330	164			
	(26)	(21)	(14)	2.04	24.0*	49.05	(24)	(21)	(14)	1.06	2.55	2.42	(27)	(21)	(14)	11.38*	2.80*	4.06*
Central Basin	5.20	4.47	2.27				0.009	0.035	0.012				47	27	21			
	(47)	(47)	(60)	1.35	5.23*	3.86*	(46)	(46)	(60)	13.5*	1.76	7.69*	(46)	(47)	(60)	3.07*	4.91*	1.60
Eastern Basin	5.82	3.91	1.27				0.008	0.053	0.024				11	16	21			
	(48)	(48)	(40)	2.21*	21.1*	9.53*	(47)	(48)	(37)	45.1*	8.95*	5.04*	(47)	(48)	(37)	2.24*	3.73*	1.66

[a] Values are sample standard deviations with the number of samples in parentheses. Samples are from each year's entire network using the 1985 basin definitions.

* F value exceeds the critical value required to reject the null hypothesis that variances are equal (alpha=0.05).

Table 43. Comparison of standard deviations of selected parameters, spring survey, surface samples, 1983-1985.[a]

	Total Phosphorus (ug/L)						Dissolved Reactive Silica (mg-SiO_2/L)						Nitrate + Nitrite Nitrogen (ug/L)					
	1983	1984	1985	83/84 F*	83/85 F*	84/85 F*	1983	1984	1985	83/84 F*	84/85 F*	84/85 F*	1983	1984	1985	83/84 F*	83/85 F*	84/85 F*
Lake Michigan																		
Southern Basin	1.23 (15)	1.02 (8)	0.72 (12)	1.45	3.0	2.0	0.137 (15)	0.104 (9)	0.036 (12)	1.7	14.1*	8.2*	26 (15)	14 (9)	17 (12)	3.36	2.22	1.64
Northern Basin	1.94 (12)	0.60 (8)	1.69 (9)	10.1*	1.3	7.7*	0.152 (12)	0.140 (8)	0.063 (10)	1.2	5.7*	4.8*	24 (12)	57 (8)	14 (10)	5.57*	3.05	17.0*
Lake Huron																		
Northern Basin	1.29 (15)	0.38 (10)	0.50 (10)	11.8*	6.8*	1.7	0.048 (16)	0.151 (11)	0.044 (11)	10.1*	1.2	11.6*	15 (16)	15 (11)	27 (11)	1.00	3.13*	3.12
Southern Basin	1.51 (14)	0.85 (8)	0.52 (9)	3.1	8.5*	2.7	0.055 (10)	0.056 (8)	0.029 (9)	1.01	3.7	3.8	18 (10)	17 (9)	23 (9)	1.00	1.65	1.72
Lake Erie																		
Western Basin	17.9 (8)	16.6 (8)	3.8 (6)	1.2	21.6*	18.4*	0.591 (8)	0.600 (9)	0.283 (6)	1.0	4.4	4.5	370 (9)	147 (9)	147 (6)	12.0*	1.90	6.32
Central Basin	6.0 (15)	3.3 (15)	1.4 (18)	3.3	19.4*	5.9*	0.011 (15)	0.056 (15)	0.008 (18)	2.1	2.1	4.3*	49 (15)	29 (15)	25 (15)	3.27*	3.94*	1.20
Eastern Basin	10.4 (9)	1.5 (9)	0.8 (8)	50*	179*	3.6*	0.011 (9)	0.056 (9)	0.024 (8)	25.5*	4.7*	5.5*	9 (9)	20 (9)	17 (8)	4.70*	3.45	1.36

[a] Values are sample standard deviations with the number of samples in parentheses. Samples are from each year's entire network using the 1985 basin definitions.

* F value exceeds the critical value required to reject the null hypothesis that variances are equal (alpha=0.05).

Table 44. Comparison of standard deviations of selected parameters, spring survey, station averages, 1983-1985.[a]

	Total Phosphorus (ug/L) 1983	1984	1985	83/84 F*	83/85 F*	84/85 F*	Dissolved Reactive Silica (mg-SiO_2/L) 1983	1984	1985	83/84 F*	83/85 F*	84/85 F*	Nitrate + Nitrite Nitrogen (ug/L) 1983	1984	1985	83/84 F*	83/85 F*	84/85 F*
Lake Michigan																		
Southern Basin	2.30 (15)	1.29 (10)	0.61 (12)	3.19	14.1*	4.43*	0.152 (15)	0.151 (10)	0.041 (12)	1.02	13.8*	13.5*	26 (15)	17 (10)	36 (12)	2.30	1.92	4.42*
Northern Basin	2.83 (12)	1.39 (8)	1.71 (10)	4.17	2.74	1.52	0.145 (12)	0.071 (8)	0.067 (10)	4.17	4.62	1.11	36 (12)	41 (8)	12 (10)	1.26	9.17*	11.6*
Lake Huron																		
Northern Basin	2.79 (16)	0.73 (11)	0.63 (11)	14.5*	19.5*	1.34	0.048 (16)	0.137 (11)	0.042 (11)	8.23*	1.27	10.46*	13 (16)	17 (11)	29 (11)	1.60	4.49*	2.81
Southern Basin	2.23 (14)	0.75 (9)	0.87 (9)	8.79*	6.54*	1.34	0.057 (10)	0.056 (9)	0.032 (9)	1.06	3.23	3.06	18 (10)	17 (9)	21 (9)	1.13	1.27	1.43
Lake Erie																		
Western Basin	19.5 (9)	32.8 (6)	3.13 (6)	2.84	38.7*	110	0.597 (8)	0.656 (6)	0.351 (6)	1.21	2.89	3.50	101 (9)	406 (6)	158 (6)	16.1*	2.43	6.61*
Central	3.11 (15)	3.84 (10)	1.56 (18)	1.53	3.97*	6.09*	0.009 (15)	0.020 (10)	0.009 (18)	5.06*	1.07	4.72*	48 (15)	28 (10)	23 (18)	2.96*	4.61*	1.56
Eastern Basin	4.03 (9)	2.62 (6)	1.11 (8)	2.37*	13.1*	5.55*	0.009 (9)	0.054 (6)	0.023 (8)	33.4*	5.90*	5.66*	10 (9)	19 (6)	19 (8)	3.97	3.93	1.01

[a] Values are sample standard deviations with the number of samples in parentheses. Samples are from each year's entire network using the 1985 basin definitions.

*F value exceeds the critical value required to reject the null hypothesis that variances are equal (alpha=0.05).

The sample variance of the station averages (Table 44) is in the range of the analytical variance of the low and high check standards (Table 7) (e.g., NO_2 + NO_3 and SiO_2). A similarity between sample variances of the station averages and analytical variance would be expected if the true spatial variability is small relative to the analytical variability. Comparing basins, the variances of the spring station averages (Table 44) were similar within a given year in most basins except for Lake Erie's western basin. Western basin Lake Erie's variance is one to two orders of magnitude higher than other basins. This may be because western Lake Erie is very shallow and is a mixing zone for several significant rivers that pass through large metropolitan areas resulting in spatial heterogeneity.

COMPARISON WITH RECENT HISTORICAL DATA

In our reports describing the results of the 1983 and 1984 surveillance program, we compared the data collected in 1983 and 1984 with similar subsets of data collected in earlier years. In this section we will update these comparisons using the data collected in 1985.

Lake Michigan

Inter-year comparisons based on similar subsets of spring open-lake surface data collected in Lake Michigan were listed in Table 36. Lake Michigan was sampled intensively in 1976 (whole lake) and in 1977 (southern basin only). Results of the 1976 sampling are described by Rockwell et al. (1980) and by Bartone and Schelske (1982). Comparison of the 1977 data with that from 1976 show a significant (alpha = 0.05) decline in the concentration of total phosphorus and in turbidity. Significant increases occurred in nitrate + nitrite nitrogen and chloride concentrations. The magnitude of the changes shown in Table 36 are different from those reported in Rockwell et al. (1980) because the subset of stations used here was different from those used for the earlier calculations.

Comparison of the 1983 data with the 1977 and 1976 values showed that total phosphorus levels in the northern basin and, by extension, the southern basin were still significantly lower than they were in 1976, but significantly higher than in 1977. The 1984 data showed that levels of total phosphorus in Lake Michigan continue to be low. The 1985 data show no change in southern Lake Michigan total phosphorus concentrations from 1984 levels and a return in the northern basin concentration to the 1983 level. Reactive silica and nitrate + nitrite values in 1985 were the highest measured since 1977. The 1985 chloride values were unchanged in the northern basin and lower in the southern basin. Previously the annual rate of increase of chloride between 1976 and 1983 was 0.103 mg/L. This rate is almost identical to that calculated from chloride measurements made at water intakes (Rockwell et al., 1980).

From 1983 to 1984 the increase in chloride concentration was 0.12 mg/L in the southern basin and 0.16 mg/L in the northern basin. The annual rate of increase between 1976 and 1984 was 0.195 mg/L. The rate of increase appears to have slowed in the northern basin over the last three years to 0.075 mg/L. In the southern basin the 1985 concentration levels were lower than the 1983 concentration levels. If real, southern basin chloride decreases may be due to several causes. Lower road salt usage may be expected over the last three years since winter snow falls in Milwaukee (42.6") and Chicago (38.2") have averaged below the average forty-year snowfalls of 47.2" and 40.4", respectively. Water levels increased in Lake Michigan by one foot between April 1984 and April 1985 which would contribute 0.37% more volume or at most 0.04 mg/L decrease in chloride concentrations from the 1984 levels (8.8-8.9 mg/L). Errors in field data determination are also possible. Table 8 shows a slight negative bias in the low chloride check standard (5.5 verses the expected 5.6 mg/L). This latter effect would contribute 1.8% decrease or 0.16 mg/L. For a one-year decrease in chloride concentrations of 0.2 mg/L magnitude in all of Lake Michigan, chloride loading would have to decrease about 700,000 metric tons. This would represent about a 20% decrease in total lake loading as compared to the mid-to-late 1970 loadings (Sonzogni et al., 1983).

In addition to inter-year comparisons based on standard statistical descriptions of the spring surface samples we also used graphical techniques to examine recent trends in Lake Michigan water quality.

Figure 54 shows the variable width notched box plot (McGill et al., 1978) that we used in analysis. The purpose of the box plot is to display many characteristics of a set of data in a concise format. Based on order statistics, the variable width, notched box plot gives the viewer a more complete sense of the data set than is provided by examining just the simple mean and standard deviation. This is especially important in water quality analyses where one spurious value often can have a disproportionate influence on the sample statistics. Box plots have been applied to water quality data by Reckhow (1980) and Neilson (1983).

As illustrated in Figure 54, the box plots show the mean and median of the data sets, the maximum and minimum values, and the upper and lower quartiles. Thus half of the observations fall within the box. The notch represents the 95% confidence internal for the median, which may, on occasion, fall outside of either the upper of lower quartiles. Two boxes with notches which do not overlap have significantly different medians from each other. The width of the box is proportional to the square root of the number of observations. These features allow easy comparisons across data sets.

Figure 55 (DISSPLA software) shows the distribution of total phosphorus data collected during the spring in Lake Michigan from 1976-1985. These data show the major decline that occurred between 1976 and 1977 as well as the increase between 1977 and 1983. The spread of data is much wider in 1984 than in 1983 and 1985, and the 1985 median value is significantly lower than 1983 and 1984 but comparable to the 1977 levels.

The decline in total phosphorus observed between 1976-1977 has been hypothesized to represent loss to the sediments. This loss seems to be related to the extremely harsh winter and extensive ice cover that occurred on Lake Michigan during the winter of 1976-1977 (Rockwell et al., 1980; Rodgers and Salisbury, 1981a). The fact that similar concentrations of total phosphorus were measured in the northern and southern basins in 1976 by different agencies lends credence to the reported values. The increase in total phosphorus concentration that seems to have occurred in

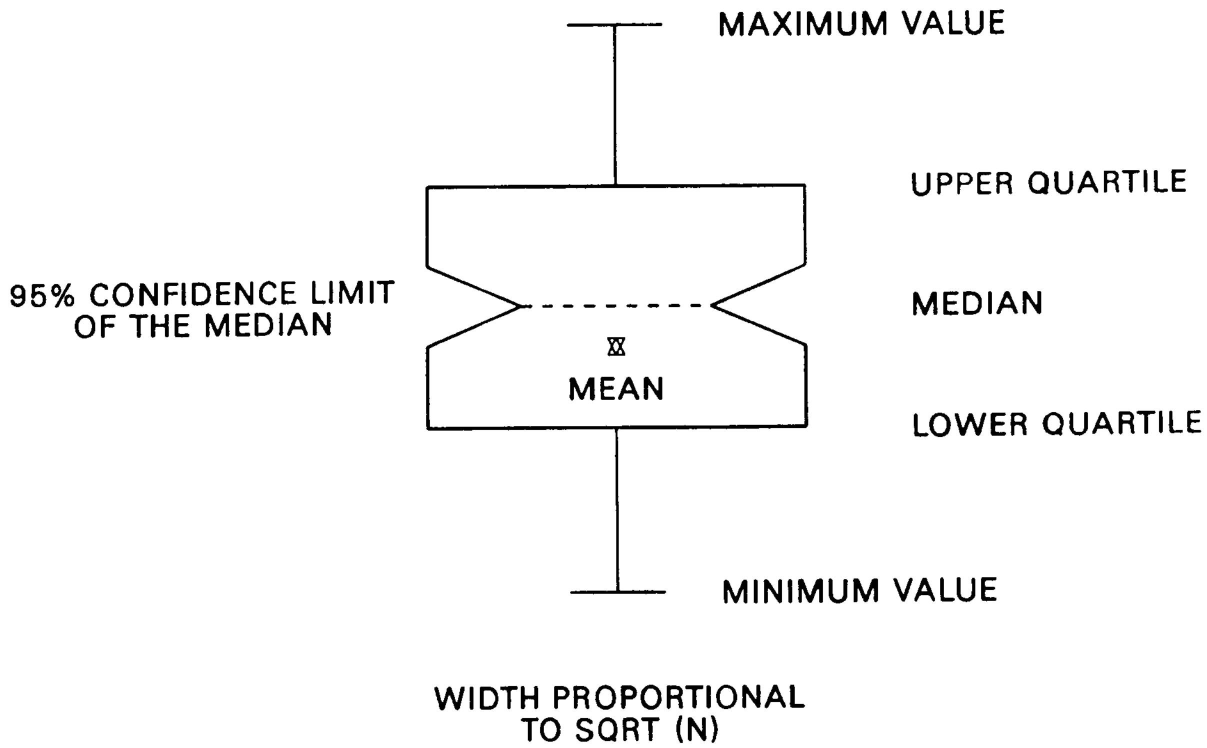


Figure 54. Key to variable width, notched box plots (McGill et al., 1978.)

Lake Michigan since 1977 may represent a return of phosphorus from the sediments.

Recent loadings to Lake Michigan (Table 49) suggest fairly stable inputs. Model calculations, presented in the following section, suggest that phosphorus concentrations in Lake Michigan declined from 1976-1977 and have remained fairly stable since then, in rough agreement with these observations. Thus, these year-to-year changes appear to represent the normal variability of a oligotrophic system.

Surface Lake Michigan spring silica values seem to have remained fairly constant since 1977. However, the open-lake spring 1985 values in the northern basin were higher than the 1984 values. Silica is a particularly important nutrient in Lake Michigan. Some researchers have asserted that silica is the limiting nutrient for diatom growth in the spring (Schelske and Stoermer, 1971), and there has been a continuing controversy about long-term depletion of silica in the lake (Shapiro and Swain, 1983; Schelske et al., 1983).

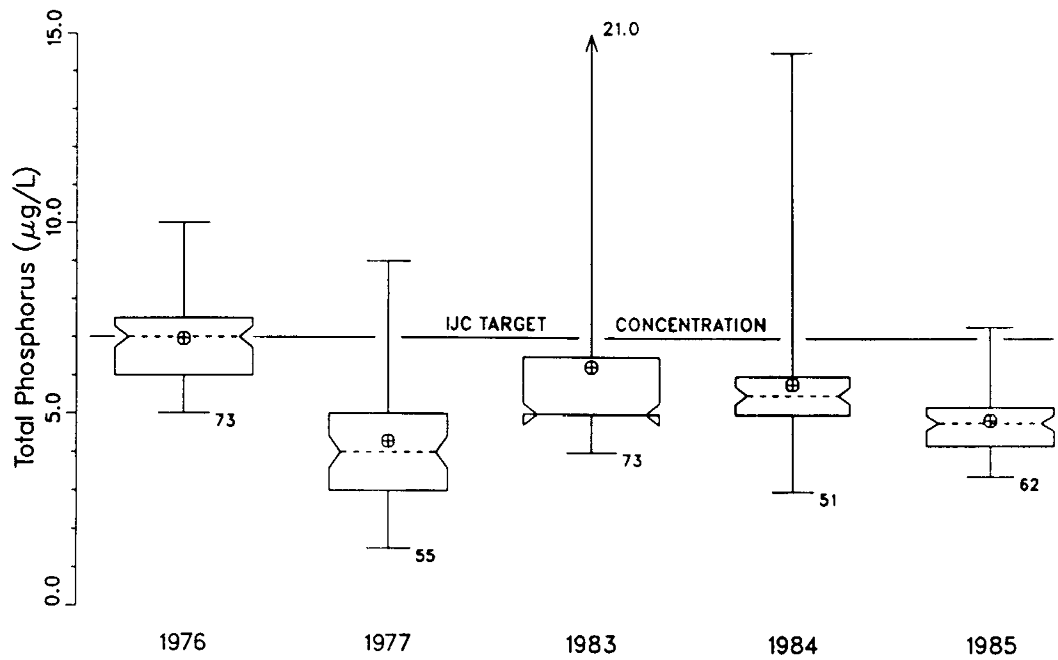


Figure 55. Box plot comparison of spring total phosphorus concentrations in the southern basin of Lake Michigan, 1976-1985. The values shown for 1976 and 1977 intensive surveys represent stations with depths of 80 meters or greater.

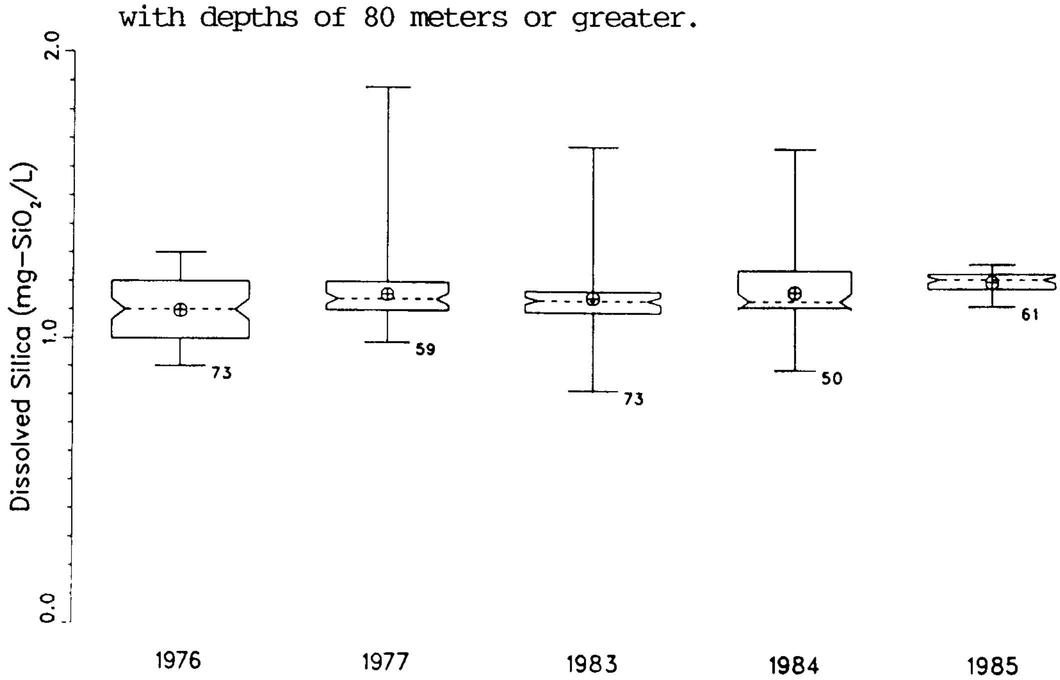


Figure 56. Box plot comparison of spring dissolved reactive silica concentrations in the southern basin of Lake Michigan, 1976-1985. The values shown for 1976 and 1977 intensive surveys represent stations with depths of 80 meters or greater.

The distribution of dissolved reactive silica in Lake Michigan during the spring is shown in Figure 56. These data show a rather steady increase in the concentration of silica from 1976 to 1985 both in average as well as median values. Minimum concentrations are at their greatest concentrations in 1985. It should be noted that these plots include all of the samples collected during the spring; not just the surface samples, upon which the statistics presented in Table 36 are based.

Comparison of all dissolved nitrate + nitrite data for the period 1976-1985 (Figure 57) also shows a steady, significant increase in median concentrations. The mean calculated for 1985 is higher than the 1983 mean. Increases in the concentration of dissolved nitrate and nitrite have been noted in Lake Huron (Moll et al., 1985; Dolan et al., 1983), Lake Erie (Rathke and Edwards, 1985), and Lake Ontario (Neilson, 1983). Lesht and Rockwell (1987) suggest that nitrate + nitrite nitrogen is rapidly cycled during the year in the benthic nepheloid layer and in the sediment-water interface, thus returning to the water column inorganic nitrogen that may have been removed earlier by settling detritus. Loading of nitrogen from atmospheric sources 1982-1985 (Klappenbach, 1986) and from tributary loads (Lang, 1984) provide sufficient soluble nitrogen (35000 to 45000 metric tons) to account for the increases.

We also examined summertime epilimnion depletion of nutrients using box plots. Figure 58 shows the distribution of epilimnion silica during the spring and summer surveys for 1976-1985. This plot allows us to compare spring and summer concentrations as well as the difference between the two. The summer decline of epilimnion silica (SiO_2) was more extensive in 1985, resulting in the lowest observed mean concentration (0.199 mg/L) in previous years: 1983 (0.326 mg/L), 1976 (0.213 mg/L), and 1977 (0.235 mg/L). The total depletion in 1985 based on the difference (1.00 mg/L) between observations made during the spring and summer surveys is also greater than any of the previous years and greater than in 1984 where it was the largest previously observed depletion (0.973 mg/L). The spring surveys in 1984 and 1985 were conducted earlier in the thermal cycle than the 1983 or earlier surveys reported here. The 1985 stratified season was somewhat longer than in 1984 which may account for

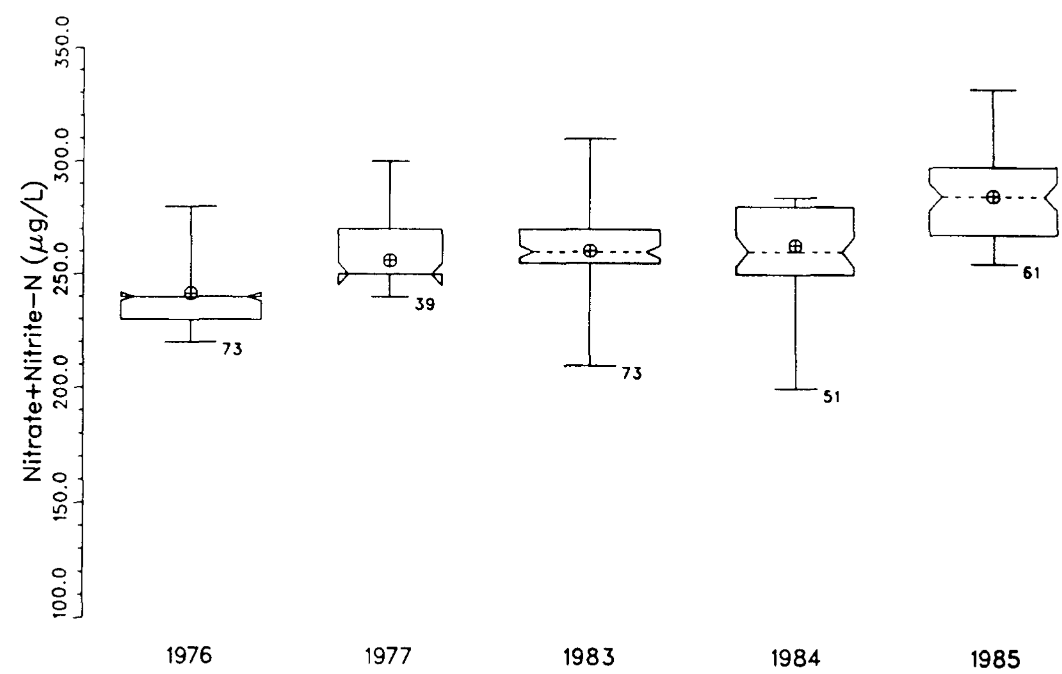


Figure 57. Box plot comparison of spring dissolved nitrate+nitrite nitrogen concentrations in the southern basin of Lake Michigan, 1976-1985. The values shown for 1976 and 1977 intensive surveys represent stations with depths of 80 meters or greater.

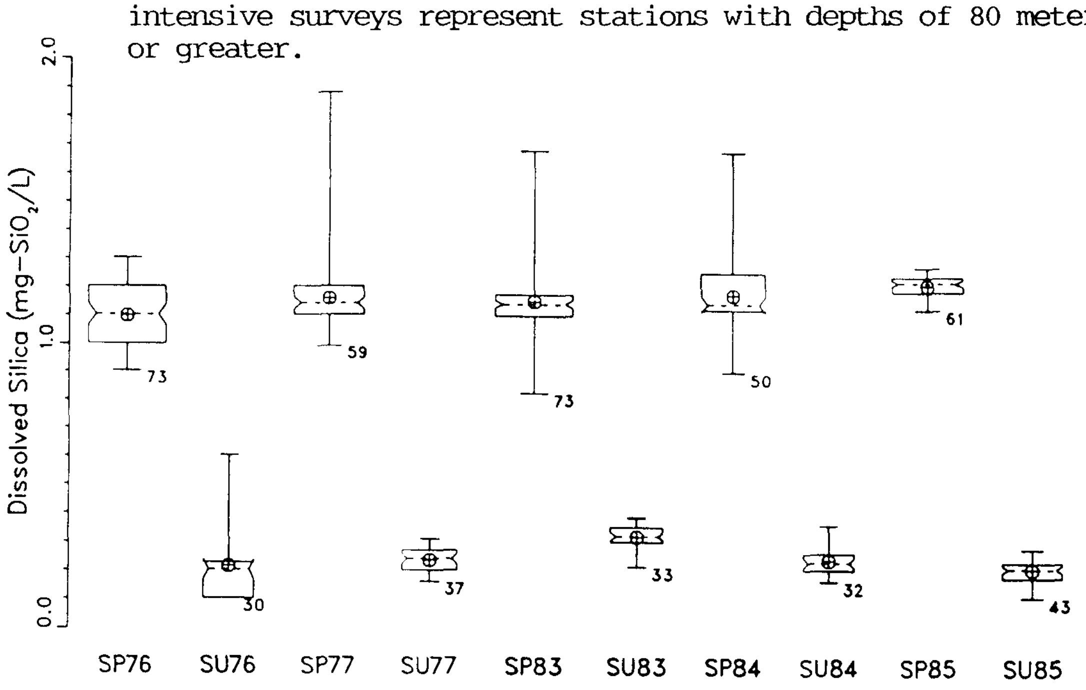


Figure 58. Box plot comparison of epilimnion depletion of dissolved reactive silica in the southern basin of Lake Michigan, 1976-1985. The values shown for 1976 and 1977 intensive surveys represent stations with depths of 80 meters or greater.

the greater epilimnetic depletion. However, the magnitude of the decline in 1984 and 1985 is less than the 1.3 mg/L decline reported by Schelske et al. (1983) as typical of Lake Michigan in the late 1960s and early 1970s.

Nitrogen depletion in the epilimnion is considered to be an indication of eutrophication (Schelske and Roth, 1973) since nitrogen depletion increases with eutrophication. Figure 59 shows the distribution of epilimnion nitrate + nitrite during the spring and summer for the surveillance years since 1976. The levels of spring nitrate + nitrite nitrogen have increased since 1976 through 1984 and, similarly, summer nitrate + nitrite nitrogen through 1984. The 1985 summer concentration levels are lower than 1984 and are similar to the 1983 concentration levels. The difference between spring and summer concentration levels in 1985 was the largest in the last three years. This would appear to be a contradiction to the phosphate limitation model, however, this may be related to the longer stratification period in which greater depletion of the isolated epilimnetric waters could occur.

One measure of water quality in Lake Michigan that made dramatic changes in recent years (1976-1984) was summertime Secchi depth. This parameter may be affected by transient events that affect the clarity of the surface waters. The increasing clarity observed (Figure 60) through 1984 was reversed in 1985. To a certain extent, the increase in Secchi depth reflects a decline in the summertime phytoplankton population that has been observed in Lake Michigan (Kitchell et al., 1988). The causes of the apparent phytoplankton decline are, as yet, uncertain.

<u>Lake Huron</u>

The most recent intensive survey of Lake Huron was conducted in 1980. Two reports have been written describing the results of that survey: Dolan et al., (1983) and Moll et al., (1985). Both of these studies include comparisons of the 1980 survey data with earlier surveys; Dolan et al. concentrating on comparison with data collected in 1971, and Moll et al. including data collected since 1954 with emphasis on changes since 1974. In general, the two studies are in agreement in their conclusions, although some differences in technique and detail exist.

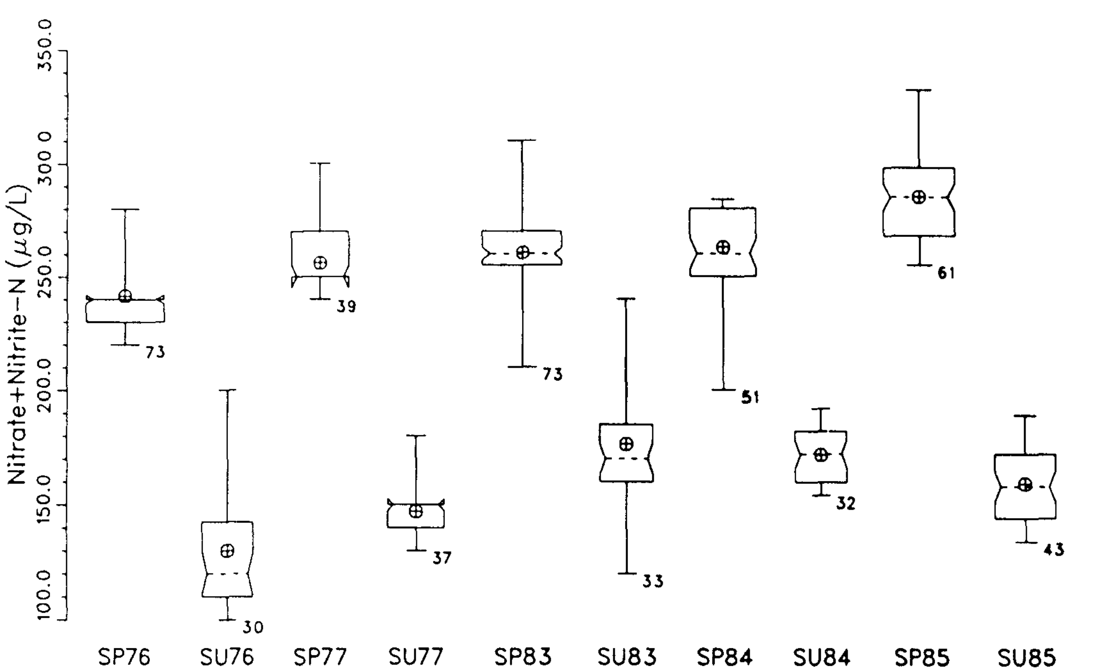


Figure 59. Box plot comparison of epilimnion depletion of dissolved nitrate+nitrite nitrogen in the southern basin of Lake Michigan, 1976-1985. The values shown for 1976 and 1977 intensive surveys represent stations with depths of 80 meters or greater.

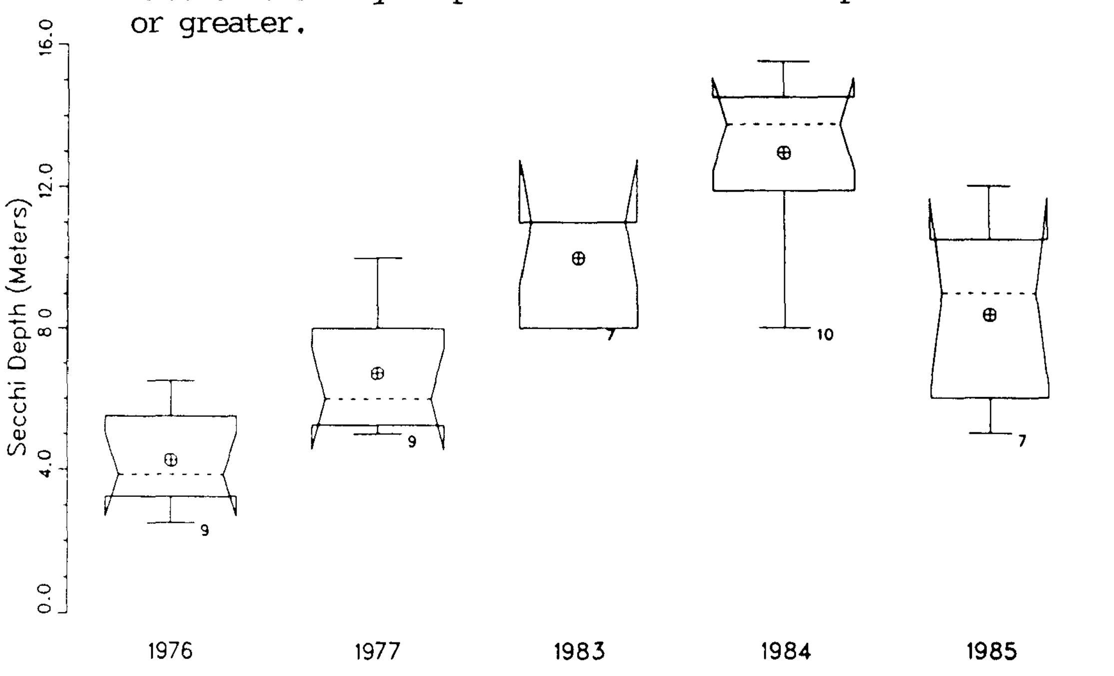


Figure 60. Box plot comparison of summer Secchi depth in the southern basin of Lake Michigan, 1976-1985. The values shown for 1976 and 1977 intensive surveys represent stations with depths of 80 meters or greater.

Dolan et al. found that there had been little apparent change in total phosphorus concentration from 1971 to 1980 but that concentraions of nitrate + nitrite nitrogen and dissolved reactive silica were significantly (alpha = 0.05) higher in 1980 than they were in 1971. This comparison was based on "only those stations that were uniformly sampled in both years" and on spring surface values.

Moll et al. report that 1980 concentrations of total phosphorus and dissolved reactive silica were less than those reported in 1974, and nitrate + nitrite concentration was greater in 1980 than in 1974. In the longer term, however, Moll et al. found that the pattern of changes for about one-half of the parameters they studied was curvilinear or oscillatory, showing the complexity involved in attempting to determine unequivocal water quality trends from historical data.

The approach taken as part of the present study is similar to that adopted by Dolan et al. in which a year-against-year comparison is made using similar subsets of data. This approach was not taken in preference to the techniques used by Moll et al., but only because of its relative simplicity and aptness to the data collected in 1983 through 1985. Table 37 shows the data used by Dolan et al. for inter-year comparisons recalculated to correspond to the station subset used in 1983 through 1985. These data are plotted in Figures 61 to 64. Two-sided t-tests were used to examine the differences in nutrient concentrations from 1983 through 1985. (The t values and degrees of freedom calculated all for 1983-1985 comparisons are shown in Table 39.) Based on these subsets, total phosphorus concentration in Lake Huron appears to have increased significantly (alpha = 0.05) from 1971 to 1980 and to have decreased significantly from 1980 to 1983 and again in 1984 to 1985. There were no significant changes from 1983 to 1984. Figure 61 shows that the mean spring surface concentration of total phosphorus in Lake Huron has moved downward since 1980.

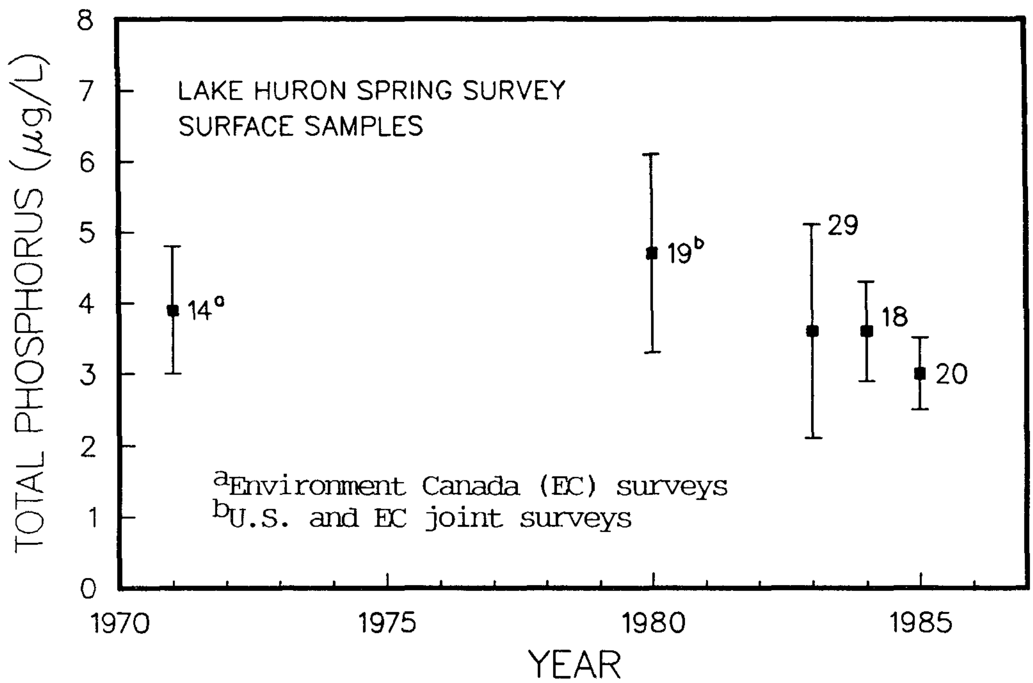


Figure 61. Total phosphorus (mean ± standard deviation, n) in the surface waters of Lake Huron, spring 1971 to 1985.

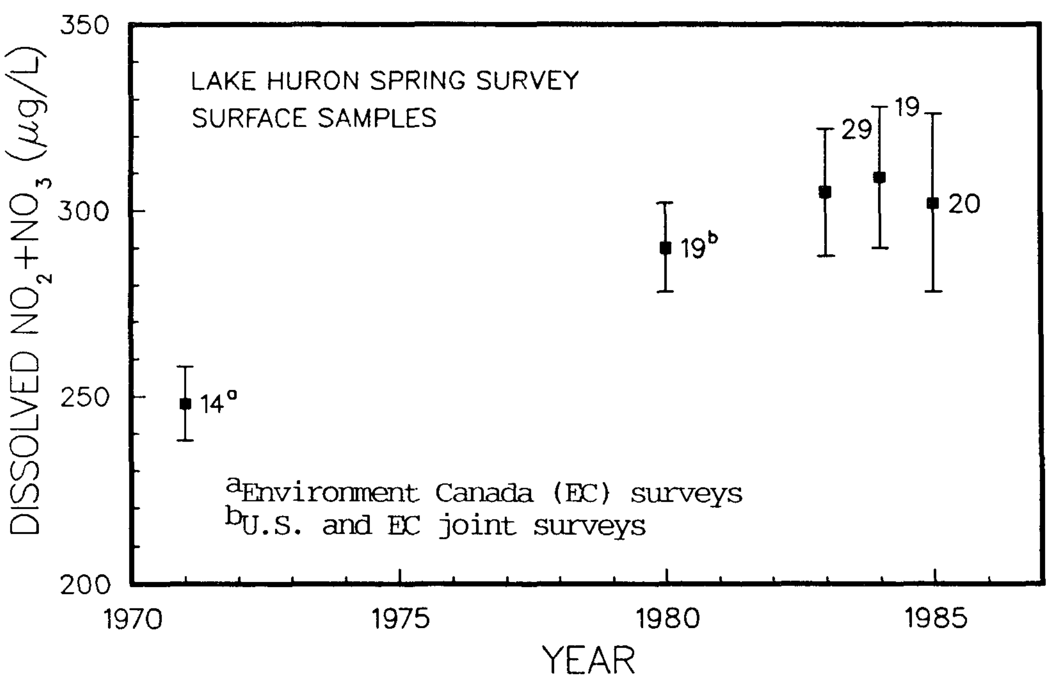


Figure 62. Dissolved nitrite+nitrate nitrogen (mean ± standard deviation, n) in the surface waters of Lake Huron, spring 1971 to 1985.

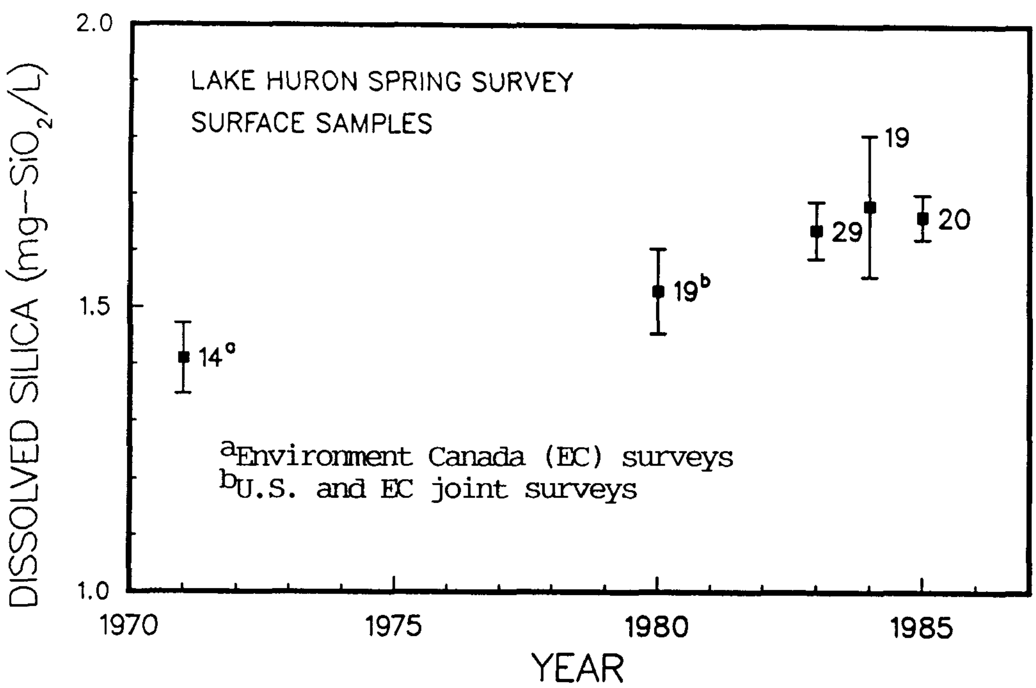


Figure 63. Dissolved reactive silica (mean ± standard deviation, n) in the surface waters of Lake Huron, spring 1971 to 1985.

The rate of increase of nitrate + nitrite calculated here (3.9 ug-N/L), assuming a linear increase from 1971 to 1985, is less than that calculated by Dolan et al. (1983) (5.4 ug-N/L). The measured increase from 1983 to 1984 was 4.0 ug-N/L, although we observed a decrease between 1984 to 1985. This behavior is not unexpected given that soluble nitrogen is not a conservative substance and the ambient concentration is a function of nutrient uptake as well as loadings. The surface data plotted in Figure 62 show a gradual increase in nitrate + nitrite concentration.

Silica concentration (Figure 63) also seems to have increased since 1971, although the rate of increase has not been constant during the period 1971-1985. When data from years between 1971 and 1980 were included in the analysis by Moll et al. (1985) silica concentration appears to have peaked in 1974 and to have declined from 1974 to 1980.

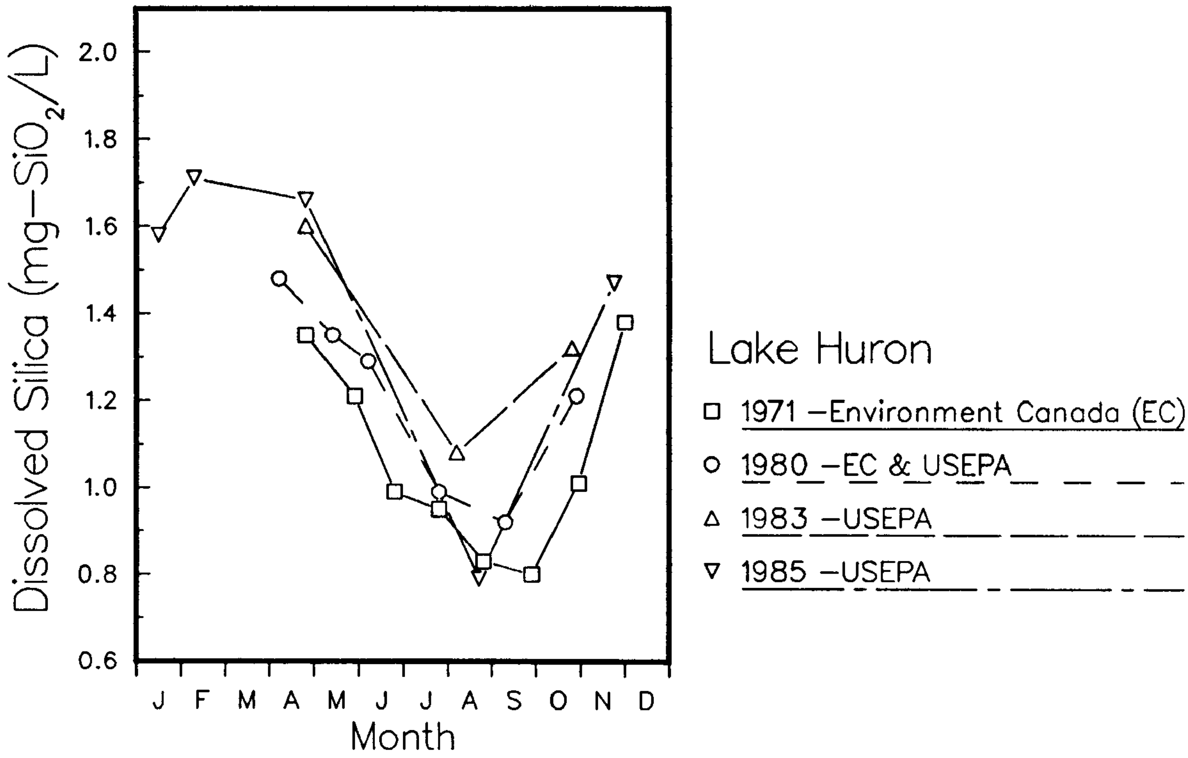


Figure 64. Seasonal dissolved reactive silica (mean) in the surface waters of Lake Huron - 1971, 1980, 1983, and 1985. After Lesht and Rockwell, 1985.

In more recent years, soluble reactive silica levels are generally seen to be increasing throughout the annual cycle (Figure 64), with the exception in summer 1985 when a longer stratification period may have permitted greater depletion in surface concentrations.

Lake Erie

Considerable historical information exists for Lake Erie, much of which has been summarized in a series of reports by the Center for Lake Erie Area Research (CLEAR) of the Ohio State University and in a review of water quality trends in Lake Erie with emphasis on the 1978-1979 intensive survey (Rathke and Edwards, 1985). This document, as well as the CLEAR reports by Fay and Herdendorf (1981), Fay et al. (1982), Herdendorf (1984), and Fay and Rathke (1987) were used as the source of historical data for Lake Erie used in comparisons with the 1983 through 1985 surveillance results presented here.

Although the data reports presented by CLEAR are extensive, only average values, rather than raw data, are presented. Therefore, only limited comparisons with data from the current program were conducted. The approach taken here is to use averages of the 1983 through 1985 data that are thought to be at least generally comparable to those presented in the CLEAR data reports rather than to recalculate the historical values to account for varying station location and survey times.

Annual average values of total phosphorus, nitrate + nitrite nitrogen, and chlorophyll-a concentrations in Lake Erie are shown in Tables 45 to 47. The data are separated into the western, central, and eastern basins, corresponding to the usual lake division based on bathymetry. The mean of the 1985 data for each basin has been appended to the means for the years 1970-1982 already compiled by Herdendorf (1984) and updated by Lesht and Rockwell (1985 and 1987) for data collected in 1983 and 1984. Graphic representations of the data (also after Herdendorf, 1984) are presented in Figures 65 through 73, which show the mean ± one standard error and the maximum and minimum of the survey-averaged values.

Differences between the total phosphorus values plotted in Figure 57 and those listed in Table 45 for the years 1979 and 1982 result from editing of the spring survey data to eliminate unrepresentative, storm-dominated values in the western basin data. The data plotted in Figures 65 through 67, therefore, are the more accurate estimates of annual average conditions in Lake Erie.

The general trend seems to be toward lower concentrations of total phosphorus. Although there is considerable variability in the data, all of the annual average values recorded since 1980 are lower than the peak values reached during the mid-1970s. In the western basin, the average (edited) values have declined for five consecutive years. In the central basin the average values have decreased in four of the last five years. These declines may be explained partially by increased water levels in the Lake Erie although the relationship between such hydrologic factors and in-lake nutrient concentrations is not clear.

Table 45. Lake Erie total phosphorus concentrations, 1970 - 1985.[a]

	Western Basin					Central Basin					Eastern Basin				
Year	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (±)	Surveys (number)	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (+)	Surveys (number)	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (±)	Surveys (number)
1970	33.4	60.0	44.6	3.0	10	11.6	36.0	20.5	2.5	10	8.8	30.9	17.5	2.2	10
1973	21.7	48.4	34.7	6.9	3	14.3	25.6	18.5	3.6	3	11.8	68.8	31.1	11.3	4
1974	22.9	45.9	35.1	3.6	6	13.6	20.1	16.8	1.1	6	7.9	66.8	20.8	2.8	4
1975	32.4	56.6	42.3	3.5	6	14.6	31.7	20.3	2.8	6	14.1	42.9	27.6	4.1	5
1976	29.5	67.0	44.9	6.7	5	16.5	28.8	22.5	2.3	5	—	—	—	—	—
1977	33.9	53.3	40.7	6.3	3	12.2	33.1	24.1	3.1	7	13.0	22.9	18.3	2.1	4
1978	—	—	—	—	—	12.0	15.7	14.2	0.5	6	9.9	16.5	13.0	1.0	6
1979	19.1	98.0	33.9	8.2	9	10.0	18.4	13.4	0.9	8	5.2	18.6	10.8	2.4	5
1980	17.7	37.7	28.8	2.2	9	4.0	23.2	13.9	2.4	9	9.3	23.7	13.8	2.6	5
1981	24.1	55.3	36.7	3.1	9	13.4	26.0	19.0	1.4	9	—	—	—	—	—
1982	23.2	139.7	46.9	15.7	7	10.4	34.8	16.3	1.6	7	—	—	—	—	—
1983	22.6	36.5	28.1	4.2	3	10.0	22.9	15.5	3.8	3	8.9	12.2	10.9	1.0	3
1984	14.8	29.7	23.7	3.0	3	9.5	21.7	14.3	3.8	3	10.6	15.9	13.3	1.5	3
1985[b]	17.9	32.6	23.6	4.6	3	11.8	21.4	15.0	3.2	3	6.3	15.3	11.0	2.6	3
1985[c]	—	—	—	—	—	9.0	25.2	14.8	2.3	8	7.9	11.7	10.0	0.7	5

[a]After Herdendorf, 1984.
[b]This study.
[c]Fay and Rathke, 1987
"—" indicates data not available.

Table 46. Lake Erie nitrate + nitrite nitrogen concentrations, 1965 - 1985.[a]

Year	Western Basin					Central Basin					Eastern Basin				
	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (±)	Surveys (number)	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (±)	Surveys (number)	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (±)	Surveys (number)
1965	—	—	120	—	—	—	—	90	—	—	—	—	90	—	—
1970	53	465	213	47	10	18	135	79	13	10	57	172	113	12	10
1973	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1974	111	644	275	82	6	46	263	142	30	6	—	—	—	—	—
1975	129	575	290	66	6	101	195	142	15	6	—	—	—	—	—
1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1978	42	727	290	86	8	88	238	168	22	7	156	232	180	11	7
1979	98	796	368	101	8	68	163	120	12	8	117	210	164	12	8
1980	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1981	430	1,149	742	98	9	143	369	220	24	9	—	—	—	—	9
1982	107	625	336	87	7	124	307	205	25	7	—	—	—	—	—
1983	221	494	321	87	3	112	177	147	19	3	193	238	219	13	3
1984	314	817	502	159	3	128	328	219	58	3	218	234	226	5	3
1985	181	725	446	157	3	128	209	178	25	3	205	287	255	25	3

[a]After Herdendorf, 1984.
"-" indicates data not available.

Table 47. Lake Erie chlorophyll-a concentrations, 1970 - 1985.[a]

Year	Western Basin					Central Basin					Eastern Basin				
	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (±)	Surveys (number)	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (±)	Surveys (number)	Min. (ug/L)	Max. (ug/L)	Mean (ug/L)	Std. error (±)	Surveys (number)
1970	3.3	19.3	8.6	2.7	10	2.5	9.2	4.5	0.7	10	1.4	5.4	3.3	0.4	10
1973	8.3	12.0	10.7	1.2	3	2.4	7.9	4.6	1.7	3	2.8	6.6	5.1	0.9	4
1974	8.8	17.1	13.4	1.4	6	2.4	9.4	4.2	1.1	6	3.3	7.1	5.1	0.5	6
1975	4.7	21.1	13.7	2.4	6	2.7	10.0	5.9	1.1	6	2.5	5.9	3.6	0.6	5
1976	6.4	16.9	12.4	2.1	5	2.5	8.5	5.2	1.1	5	—	—	—	—	—
1977	6.5	15.1	10.8	4.3	2	2.3	6.0	4.0	0.5	7	2.0	4.4	3.0	0.5	6
1978	5.2	17.8	12.5	1.5	8	2.9	8.3	5.2	0.7	8	1.7	5.4	3.2	0.5	8
1979	4.6	17.5	11.5	1.7	7	2.5	7.9	5.1	0.6	7	1.4	3.9	2.7	0.4	5
1980	4.2	12.8	8.4	1.0	9	1.5	4.6	3.1	0.3	10	1.2	3.6	1.9	0.4	6
1981	4.5	13.0	8.3	0.8	9	2.1	7.1	4.9	1.5	9	—	—	—	—	—
1982	3.1	16.7	8.4	2.1	7	1.5	5.6	3.7	0.6	7	—	—	—	—	—
1983	4.8	5.5	5.2	0.2	3	2.8	5.7	4.3	0.9	3	1.2	2.5	1.9	0.4	3
1984	3.6	7.3	5.4	1.1	3	1.2	6.6	3.7	1.6	3	0.6	1.8	1.4	0.4	3
1985[b]	1.7	10.8	5.8	2.7	3	2.5	3.2	2.8	0.2	3	0.4	0.9	0.7	0.2	3
1985[c]	—	—	—	—	—	1.1	5.9	4.1	1.1	8	0.9	1.4	1.1	0.5	5

[a]After Herdendorf, 1984.
[b]This study.
[c]Fay and Rathke, 1987.

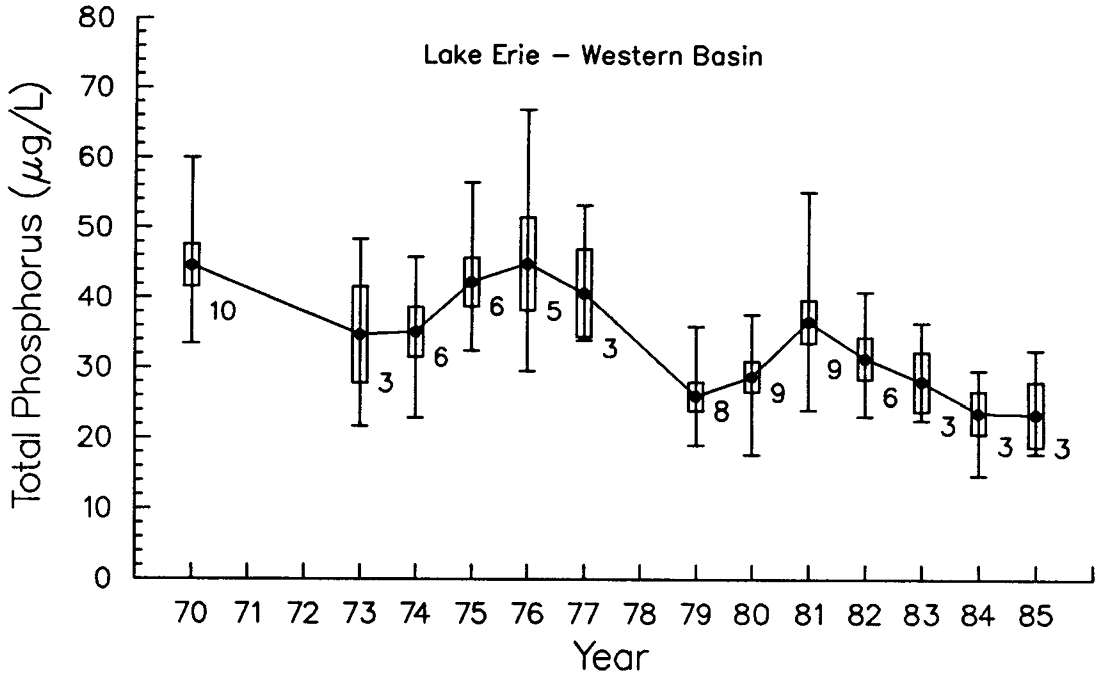


Figure 65. Total phosphorus in the western basin of Lake Erie - 1970 to 1985. Data are annual averages of survey averages. Plots show mean, maximum, minimum, and one standard error about the mean with the number of surveys contributing to the average. After Herdendorf, 1984.

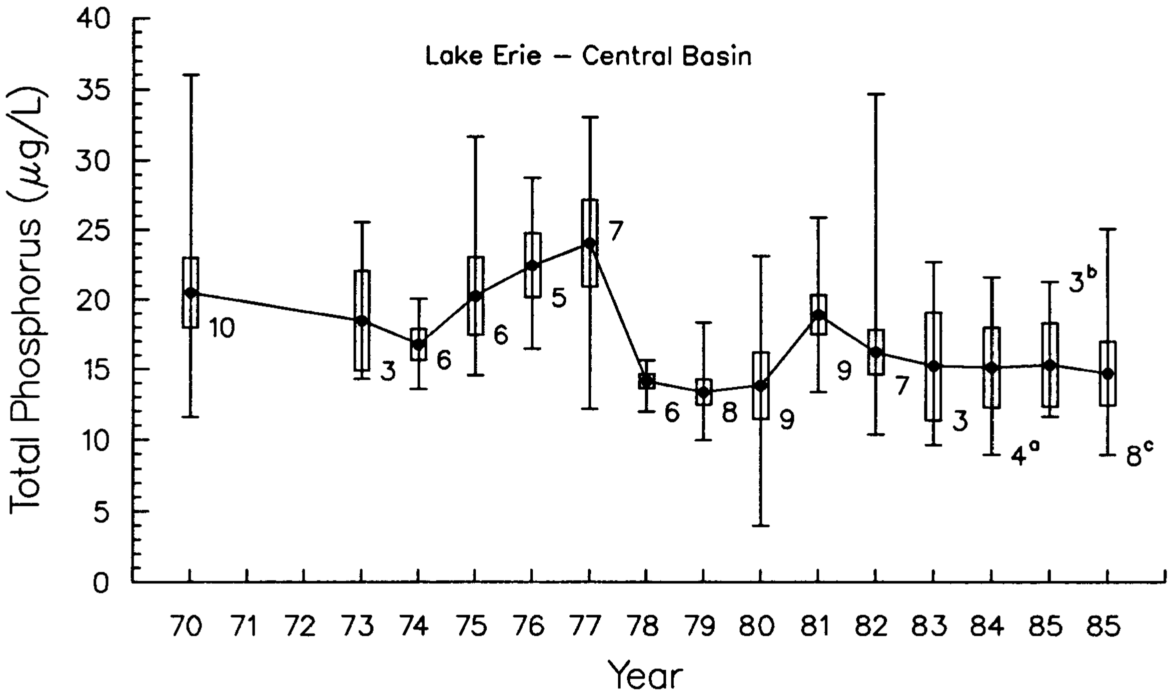
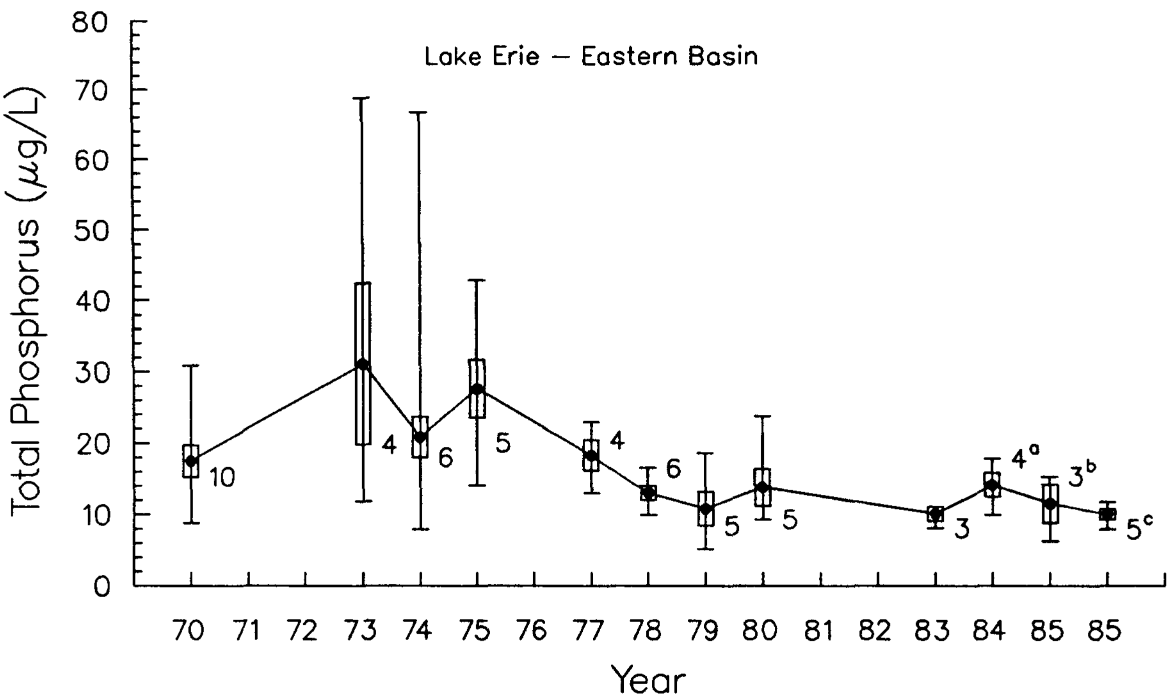


Figure 66. Total phosphorus in the central basin of Lake Erie - 1970 to 1985. See Figure 67 for footnote descriptions. After Herdendorf, 1984.



[a]Includes winter results and spring-1 and spring-2 as separate surveys for 1984.
[b]This study.
[c]Fay and Rathke, 1987.

Figure 67. Total phosphorus in the eastern basin of Lake Erie - 1970 to 1985. After Herdendorf, 1984.

The determination of phosphorus trends in Lake Erie is made more difficult by the fact that both the western and central basins of the lake are relatively shallow and the bottom sediments are frequently subject to physical resuspension. Furthermore, anoxic regeneration of phosphorus from the sediments usually occurs during the late summer in the central basin. Thus the bottom sediments act as an uncontrollable phosphorus source with the potential to mask any changes in water column concentration that may result from reductions in phosphorus loading.

Total phosphorus data from the eastern basin are more sparse than from the western and central basins but seem to confirm the pattern shown by the western and central basin annual averages. The 1985 average was lower than all previously recorded values except the 1979 and 1983 averages. Although the phosphorus concentration increased in 1984, the

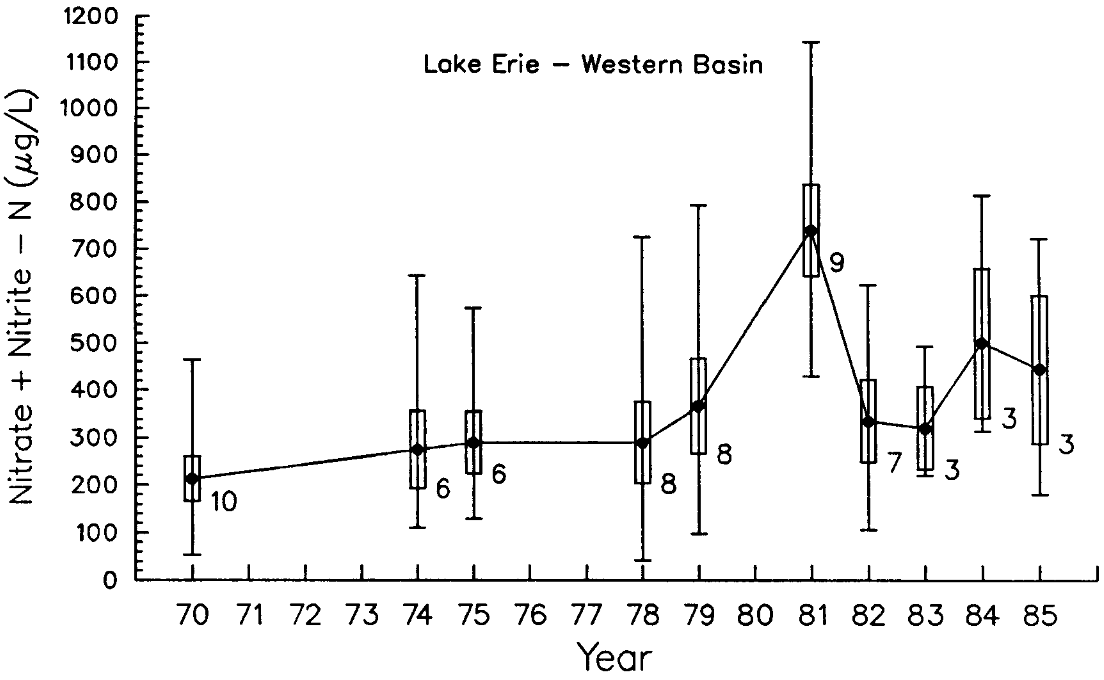


Figure 68. Nitrate + nitrite nitrogen in the western basin of Lake Erie - 1970 to 1985. After Herdendorf, 1984.

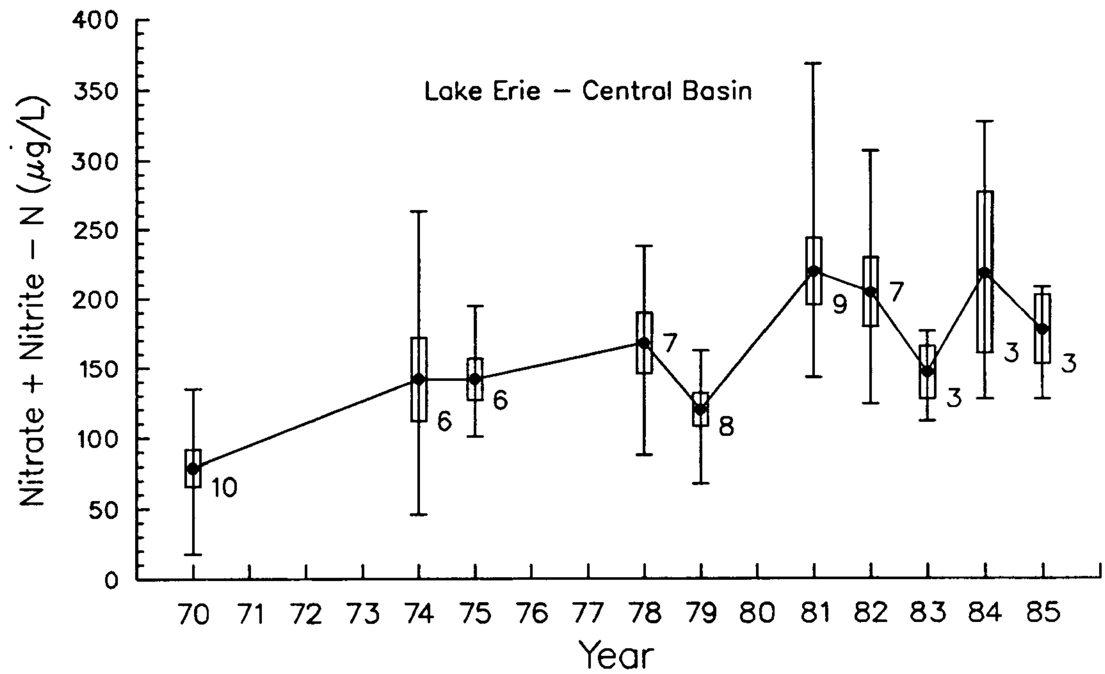


Figure 69. Nitrate + nitrite nitrogen in the central basin of Lake Erie - 1970 to 1985. After Herdendorf, 1984.

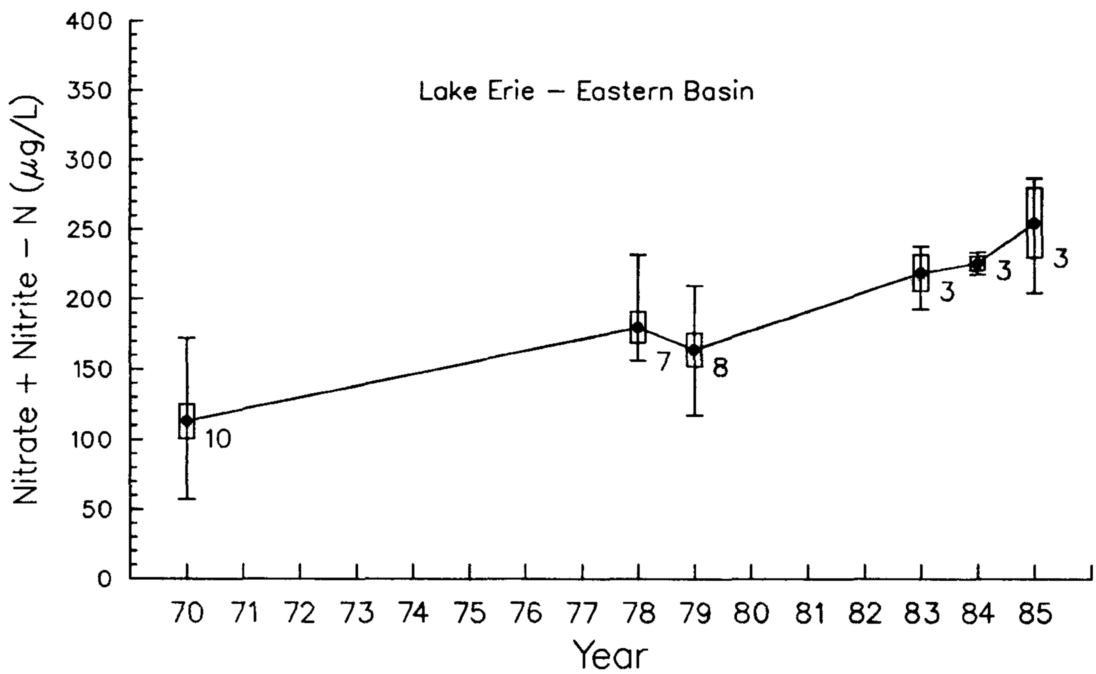


Figure 70. Nitrate + nitrite nitrogen in the eastern basin of Lake Erie - 1970 to 1985. After Herdendorf, 1984.

level has returned to near the minimum levels observed earlier. The eastern basin total phosphorus concentration remains considerably lower than either the central or western basin concentrations. Fay and Rathke (1987), using a more extensive 1985 data set, show concentration levels that were lower in both the central and eastern basins than found in this study. Given the large variance in the data, the small concentration declines recorded are not statistically significant. However, the recent lower levels both for annual means, maximums, and minimums indicate that there has been some improvement in Lake Erie water quality with respect to phosphorus since the late 1970s.

Herdendorf (1984) reports that nitrogen (primarily nitrate + nitrite) is the only major dissolved nutrient to have shown a dramatic increase in concentration in Lake Erie over the last decade (1970-1980). Table 46 and Figures 68 through 70 show the annual average values of nitrate + nitrite nitrogen concentrations for the years 1965-1985. The increase noted from 1965 to 1982 has not continued in the western and

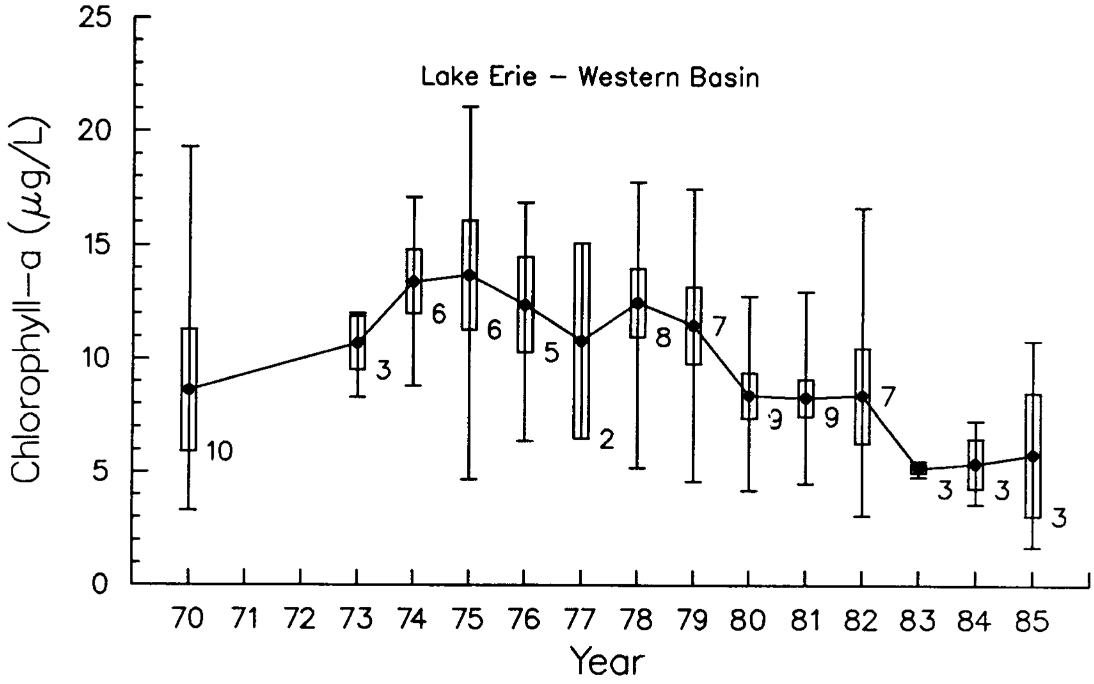


Figure 71. Chlorophyll-a in the western basin of Lake Erie - 1970 to 1985. After Herdendorf, 1984.

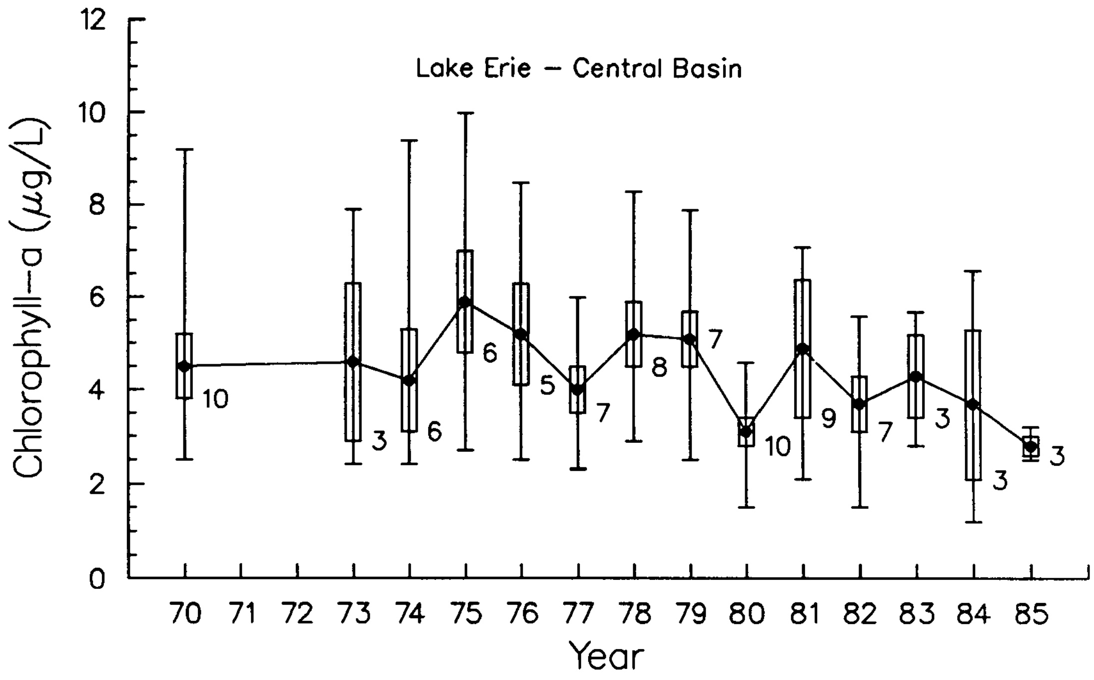


Figure 72. Chlorophyll-a in the central basin of Lake Erie - 1970 to 1985. After Herdendorf, 1984.

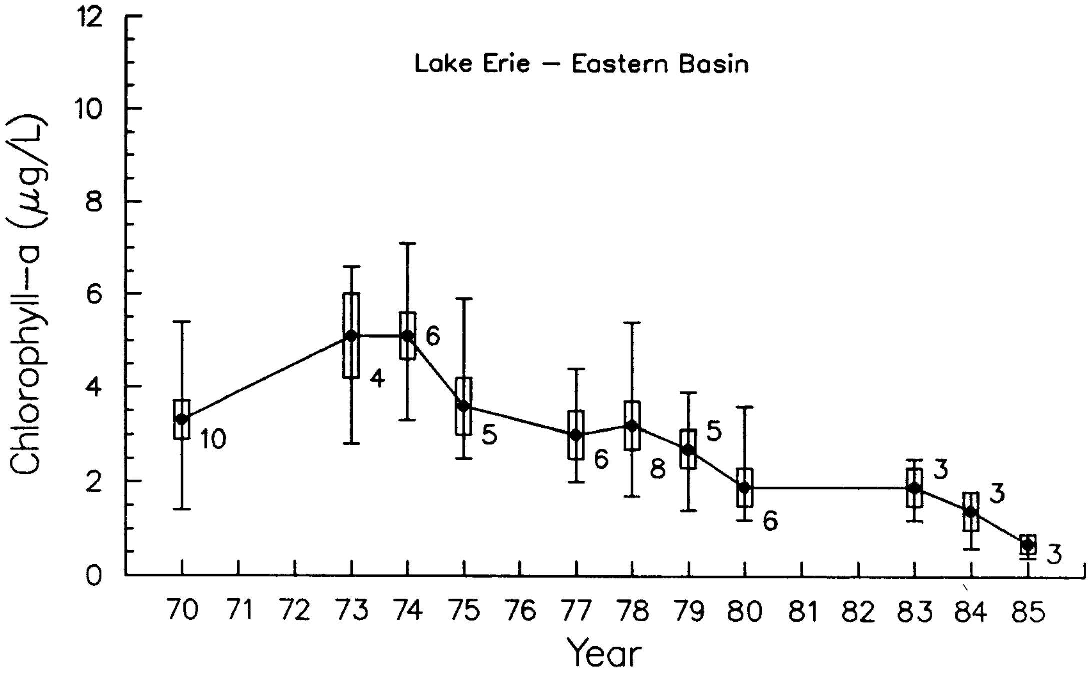


Figure 73. Chlorophyll-a in the eastern basin of Lake Erie - 1970 to 1985. After Herdendorf, 1984.

central basins. Eastern basin nitrate + nitrite nitrogen concentrations have averaged 233 ± 19 ug/L during 1983 to 1985. This represents a statistically significant (alpha=0.05) increase over the levels of 172 ± 8 ug/L observed during 1978-1979. Although both the western and central basin concentrations were higher than in 1983, only the eastern basin shows year-to-year increases in concentration (Figure 70). The 1983 concentrations were lower than for the two previous years (1981 and 1982). The 1983 values were similar to those observed between 1973 and 1980.

One consequence of high nutrient concentrations in Lake Erie is high algal productivity. Chlorophyll-a concentrations were much higher in 1985 in the western and central basin than in the eastern basin or in either of the other lakes sampled in 1984. Although again not statistically significant, year-to-year chlorophyll-a trends in both the western and eastern basins of Lake Erie seem to be downward (Table 47 and Figures 71 to 73). When analyzed on the basis of 5-year averages, Herdendorf (1984) found that concentrations of chlorophyll-a in all three basins were declining at statistically significant levels.

Anoxia has been a persistent problem in Lake Erie's central basin hypolimnion (Table 48). Dissolved oxygen concentrations typically decline during the year, reaching a minimum in August or September (Herdendorf, 1984; Lesht and Rockwell, 1985 and 1987). Anoxic conditions (0.25 mg/L DO, n=1) were observed in the summer survey in 1985 in the nepheloid layer (Table 24).

DiToro and Connolly (1980) developed a simple, empirical method of relating basin mean values of hypolimnetic dissolved oxygen concentration to the occurrence of anoxia. Their method was developed to permit calculation of basin wide anoxic conditions using large-scale eutrophication models. The method is based on the assumption that the basin sample mean value of dissolved oxygen concentrations will decline, more or less proportionately, as absolute concentrations in the basin decline. Therefore, at some sample mean value, which is determined empirically, anoxic conditions, defined as dissolved oxygen concentration below 0.5 mg/L, will occur somewhere in the basin. Using this method, for the hypolimnion (17-22 meters) we estimate that 60% the central basin hypolimnion was anoxic during the second survey (summer) of 1985.

Another statistical method relates the probability of anoxia to total phosphorus concentration, Lake Erie water level, and hypolimnion temperatures El-Shaarawi (1984b). Using the data collected in 1985, this model predicts a 70% probability of anoxia in the central basin hypolimnion.

In addition to the availability of nutrient and dissolved oxygen data, a fairly complete record exists for chloride concentration and specific conductance in the central basin of Lake Erie. In Figures 74 and 75, the 1985 annual average values for these parameters have been appended to those originally compiled by Fay et al. (1982) for the years 1966-1980, and updated by Lesht and Rockwell (1985 and 1987) for 1983 and 1984. Chloride concentrations in the central basin of Lake Erie have been declining steadily since the late 1960s. Examination of chloride loading data calculated by Sonzogni et al. (1983) shows a decline in chloride loads to Lake Erie from the Detroit River. Whyte (1985) observed a

Table 48. Lake Erie central basin hypolimnion characteristics, 1970-1985.[a]

Month/Characteristics	1970	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
<u>May</u>														
Thickness (m)	3.0	-	-	-	-	-	8.6	5.6	-	-	5.7	-	-	-
Dissolved oxygen (mg/L)	9.6	-	-	-	-	-	12.2	12.0	-	-	11.0	-	-	-
Temperature (°C)	7.5	-	-	-	-	-	7.0	9.8	-	-	6.4	-	-	-
<u>June</u>														
Thickness (m)	3.9	-	6.2	7.7	6.6	6.8	5.6	-	7.3	7.4	3.9	-	-	-
Dissolved oxygen (mg/L)	6.5	-	9.9	10.0	9.6	8.3	11.0	-	9.7	9.4	8.3	-	-	-
Temperature (°C)	8.8	-	8.8	6.5	9.4	10.4	9.3	-	6.7	9.1	8.2	-	-	-
<u>July</u>														
Thickness (m)	3.1	5.0	4.6	6.7	-	4.6	7.1	4.4	6.2	5.2	4.7	-	-	-
Dissolved oxygen (mg/L)	4.0	4.9	5.2	7.8	-	5.1	7.5	7.2	7.8	7.7	5.2	-	-	-
Temperature (°C)	10.0	10.3	11.8	7.7	-	11.0	12.5	14.0	12.7	9.9	10.8	-	-	-
<u>August</u>														
Thickness (m)	2.7	4.4	4.3	6.8	3.0	3.0	5.5	-	5.8	4.3	4.0	5.4	4.3	1.6
Dissolved oxygen (mg/L)	1.2	1.6	2.1	3.3	0.7	2.1	5.4	-	4.5	2.2	2.7	3.7	3.9	1.3
Temperature (°C)	11.6	11.9	13.5	10.2	13.7	11.9	11.5	-	13.1	12.8	11.4	10.7	10.5	14.2

[a]After Henderdorf, 1984.
"-" indicates data not available.

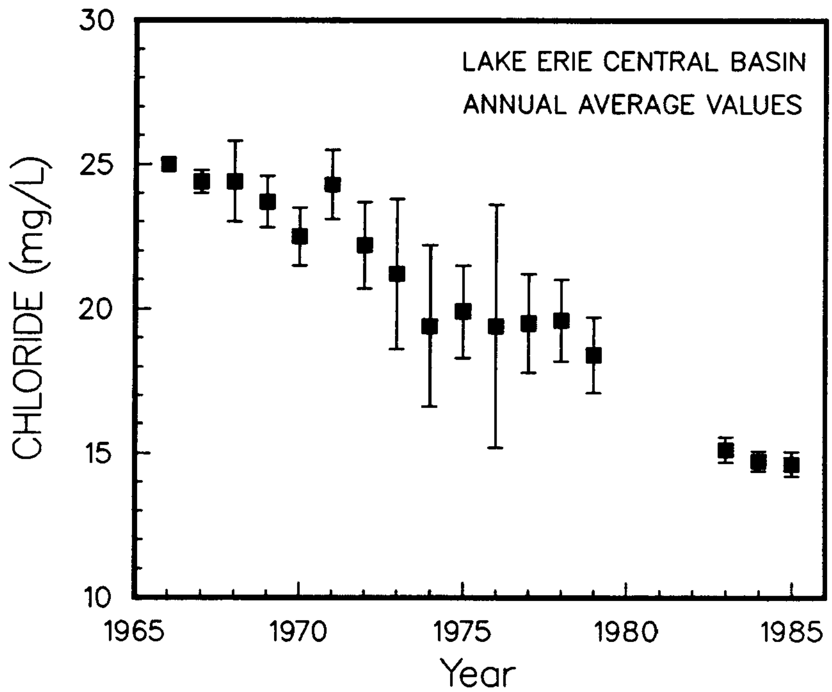


Figure 74. Chloride in the central basin of Lake Erie - 1966 to 1985. Data represent survey mean values ± standard deviation from periods of isothermal lake conditions (March-May and October-December).

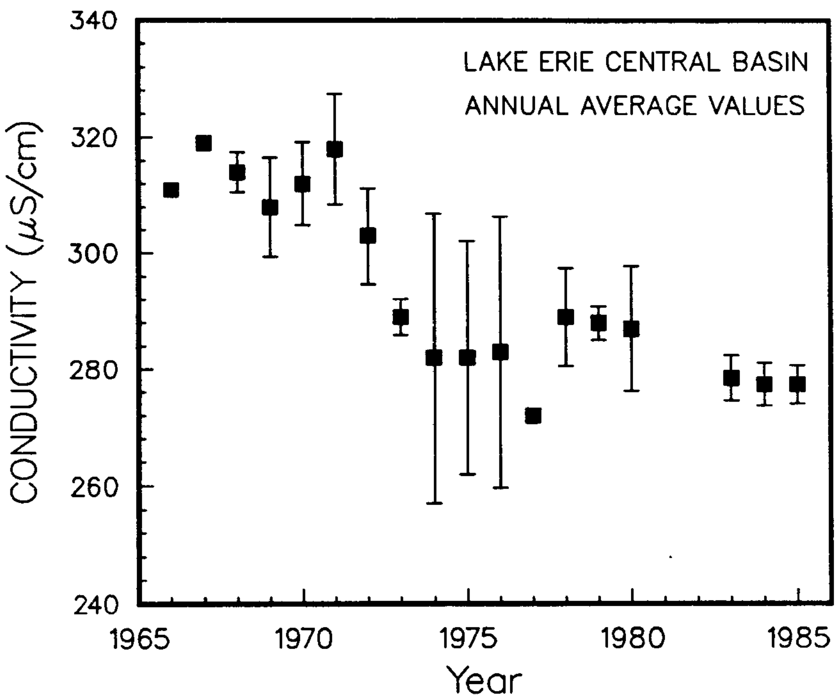


Figure 75. Specific conductance in the central basin of Lake Erie - 1966 to 1985. Data represent survey mean values ± standard deviation from periods of isothermal lake conditions (March-May and October-December).

decreasing chloride trend at municipal inlets ranging from 0.47 to 0.88 mg/L/year (mean, 0.7 mg/L/year) for the period between the late 1960s and the early 1980s. Annual mean values of chloride concentrations from surveys conducted during isothermal lake water periods (March to May and October to December) are shown in Figure 74. The chloride decline over the last two years is consistent with the declines observed by Whyte (1985).

As is expected, annual average specific conductance (Figure 75) is well correlated with chloride concentration. Although detailed data are not available for all of the other major dissolved solids, the decline in specific conductance would seem to indicate overall reduction in total dissolved solids over the period of record as well.

COMPARISON WITH EUTROPHICATION MODELS

Several types of numerical models have been developed to investigate some of the processes affecting nutrient-based eutrophication in the Great Lakes. These models range from simple single-variable, mass-balance models (Chapra, 1977; Lesht, 1985) to complex dynamic models involving many variables (Thomann et al., 1975; DiToro and Connolly, 1980; DiToro and Matystik, 1980; Rodgers and Salisbury, 1981a). They have been widely applied to such problems as phosphorus loading and designing optimal nutrient-control strategies to achieve specific water quality objectives.

All of these models were developed using field data for specification of numerical coefficients. To assess the validity of the models and to evaluate their output, frequent comparison with field data is necessary. Indeed, one of the purposes of the Great Lakes Surveillance Program, as defined in Annex 11 of the 1978 Water Quality Agreement is to "provide information which will assist in the development and application of predictive techniques." This section presents the results of a study in which water quality predictions made using two types of numerical models were compared to surveillance data, including some of the results of the 1985 survey. In our reports on the 1983 and 1984 surveillance programs (Lesht and Rockwell, 1985 and 1987) the output of the models was compared to surveillance data and found to generally reflect the decreasing or stable trends in total phosphorus concentration observed in the surveillance data.

The reader should understand that numerical models are necessarily idealized conceptualizations of the processes that they are intended to represent. As such, the models are limited by their structure and by the assumptions that were made when the models were developed. Field data, on the other hand, are only samples of the integrated result of both the modeled processes and other processes, not modeled, that may or may not be significant. Therefore, comparisons must be conducted with the understanding that both the model output and the surveillance data are only imperfect representations of the true state of the lakes.

Since a major goal of the overall surveillance effort is to assess the effectiveness of remedial measures, the following discussion is concerned with the response of the lakes to external phosphorus loading control efforts. The basic questions to be answered are: (1) what lake responses to phosphorus loading reductions do the models predict and (2) are those responses in agreement with the surveillance data. The surveillance data will be examined with two types of models, one a simple, multi-segment, mass-balance model for total phosphorus (Chapra, 1977), and the other a dynamic eutrophication model relating several water-quality variables to phosphorus loading (DiToro and Connolly, 1980; DiToro and Matystik, 1980; Rodgers and Salisbury, 1981a).

Great Lakes Mass Balance Model

The Great Lakes Mass Balance (GLMB) model is an elementary, multi-segment, mass balance model of total phosphorus concentrations (Chapra, 1977). The Great Lakes are simulated as eleven segments. The GLMB model treats each segment as a completely mixed reactor connected to adjacent segments via turbulent transport and/or advective flow. Total phosphorus concentration is assumed uniform throughout each segment. Concentration changes occur instantaneously on an annual temporal scale. The GLMB model computes annual average total phosphorus concentrations for each segment.

The model may be represented as:

$$V_i(dP_i/dt) = W_i - (Q_i + v_iA_i)P_i + \sum_{j=1}^{k}(Q_jP_j) + \sum_{j=1}^{l}(E_{ij}(P_i - P_j)) \quad (6)$$

where for segment i and adjacent segment j, V is the volume, P is the total phosphorus concentration, W is the external total phosphorus loading, Q is the advective flow rate, v is the net apparent settling velocity of total phosphorus, A is the surface area, and E is the turbulent exchange rate. The GLMB model was solved in full time-dependent form using the technique presented by Lesht (1985).

As can be seen (equation 6), the model is driven by external total phosphorus loading (W) to each model segment (i). Annual estimates of total phosphorus loadings to the Great Lakes are compiled by the International Joint Commission (IJC) and periodically by other agencies. Total phosphorus loading estimates for each of the Great Lakes for 1974-1984 (and partial 1985) by the IJC, Great Lakes Water Quality Board, Surveillance Subcommittee Reports (IJC, 1976b, 1977, 1978, 1979, 1981, 1984 and personal communication, J. Clark, IJC) are listed in Table 49. For the GLMB model these IJC loading estimates were primarily used. For the Lake Erie segments, Army Corps of Engineers, Buffalo District estimates were used for years 1974 to 1980 (Salisbury et al., 1984; Yaksich et al., 1982) since the authors felt that these estimates better reflect total phosphorus trends in the observed data. For the unknown categories in 1985 (Table 49), 1984 estimates were used. Each total load, without upstream load, was divided into subbasin loads based on ratios used by Chapra and Sonzogni (1979). The resulting loads used in the GLMB model are shown in Table 50.

The GLMB model also requires data to represent segment volumes, surface areas, flow rates, turbulent exchange rates, total phosphorus initial conditions and net apparent settling velocities. For most input parameters constant values used by Chapra and Sonzogni (1979) were used for the 12-year modeling period of 1974 to 1985 (Tables 51 and 52). Most values represent Great Lakes conditions of the mid-1970s. Flow rates

Table 49. Total phosphorus loadings (metric ton/year) to the Great Lakes. Loads are reported for Water Years 1974-1984 (partial 1985), (IJC estimates, except as noted).

Lake	Discharge Source	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983[1]	1984[1]	1985
Superior	Direct Industrial	93	97	102	108	73	45	42	36	33	51	48	
	Direct Municipal	114	62	59	64	123	159	143	116	128	82	93	
	Tributary (Monitored)[2]	1995	1397	1708	1625	1480	1479	1109	1259	1338	1470	1505	1258
	Tributary (Unmon. Adj)			592	775	793	939	1121	1495	1008	1156	1197	
	Atmospheric	800	800	1089	1089	3521	3997	3997	506	653	630	797	
	Total (target=3400[3])	3002	2357	3550	3661	5990	6619	6412	3412	3160	3389	3640	3393[7]
Michigan	Direct Industrial	45	61	32	50	46	13	37	42	53	19	26	
	Direct Municipal	1088	1067	1040	660	494	371	431	243	246	349	239	
	Tributary (Monitored)[2]	4967	4231	3179	1967	3540	3690	2381	2966	2808	3005	2220	2704
	Tributary (Unmon. Adj)			715	299	475	616	756	534	671	683	520	
	Atmospheric	1000	1000	1690	1690	1690	2969	2969	306	306	475	527	
	Total (target=5600[3])	7100	6359	6656	4666	6245	7659	6574	4091	4084	4531	3532	4016[7]
Huron	Direct Industrial	0	129	31	181	1	6	2	3	5	2	9	
	Direct Municipal	141	120	123	162	169	144	121	141	113	127	152	
	Tributary (Monitored)[2]	3669	2330	2490	1359	1700	1363	1553	1638	1921	1801	1427	2692
	Tributary (Unmon. Adj)			439	342	608	380	643	429	819	772	477	
	Atmospheric	620	620	1062	1062	2120	2331	2331	613	1174	847	846	
	Subtotal	4430	3199	4145	3106	4598	4224	4650	2824	4032	3549	2911	4176[7]
	Upstream (Sup/Mich)[4]	657	657	657	657	657	657	657	657	657	657	657	
	Total (target=4360[3])	5087	3856	4802	3763	5255	4881	5307	3481	4689	4206	3568	4833[7]
Erie	Direct Industrial	126	68	275	135	191	50	82	55	67	54	124	
	Direct Municipal	6977	6632	5731	5697	4440	2840	2370	1843	1388	1710	1928	
	Tributary (Monitored)[2]	8963	4903	5553	5285	10037	5323	8260	5582	7483	5406	7445	6753
	Tributary (Unmon. Adj)			1658	1260	2804	1098	1513	1163	1671	1065	1918	
	Atmospheric	560	560	1119	1119	879	1550	1550	729	660	362	392	
	Subtotal	16626	12163	14336	13496	18351	10861	13775	9372	11269	8597	11807	11115[7]
	Upstream (L. Huron)[4]	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080	
	Total (target=11000[3])	17706	13243	15416	14576	19431	11941	14855	10452	12349	9677	12887	12195[7]
Ontario	Direct Industrial	118	187	80	124	117	103	62	62	54	32	40	
	Direct Municipal	1858[5]	3091[5]	2039	2470	1913	2316	2060	1756	1589	1259	1423	
	Tributary (Monitored)[2]	2021[5]	2136[5]	3254	2413	2297	2509	2383	1822	2581	1612	2361	1685
	Tributary (Unmon. Adj)			1236	557	674	691	676	613	737	480	531	
	Atmospheric	350	350	473	623	764	311	311	328	600	181	242	
	Subtotal	4347	5763	7082	6187	5765	5930	5492	4581	5561	3564	4597	3921[7]
	Upstream (L. Erie)	5613[6]	5613[6]	5613[6]	2748	3782	3058	3087	2856	3330	3116	3464	
	Total (target=7000[3])	9960	11376	12695	8935	9547	8988	8579	7437	8891	6680	8061	7385[7]

[1] Figures for 1983 and 1984 are DRAFT estimates; IJC anticipates revisions.
[2] Tributary (Total) for years 1974 and 1975.
[3] Target load, 1978 Great Lakes Water Quality Agreement.
[4] Upper Lakes Reference Group 1974-1975 estimates for Upstream loads.
[5] L. Ontario 1974 and 1975 Municipal and Tributary loads are 95% of IJC figures for L. Ontario and St. Lawrence River.
[6] Hydroscience 1974 estimates for Upstream loads.
[7] Figures for 1985 are based on 1984 estimates and 1985 tributary (monitored) estimates.
Source: International Joint Commission, Great Lakes Water Quality Board, Surveillance Subcommittee Reports

Table 50. Annual total phosphorus loadings (metric ton/year) used for the GLMB model, by segment.

Model Year	Lake Superior	Lower Green Bay	Upper Green Bay	Lake Michigan	Georgian Bay	Saginaw Bay	Lake Huron	Western L. Erie	Central L. Erie	Eastern L. Erie	Lake Ontario
1974	3002	1207	213	5680	842	1373	2215	13208	4230	2045	4347
1975	2357	1081	191	5087	608	992	1600	12747	3841	1660	5763
1976	3550	1132	200	5325	788	1285	2073	12734	3588	2336	7082
1977	3661	793	140	3733	590	963	1553	12644	4366	2305	6187
1978	5990	1062	187	4996	874	1425	2299	7602	5139	998	5765
1979	6619	1302	230	6127	803	1309	2112	6433	5091	1423	5930
1980	6412	1118	197	5259	884	1442	2325	5935	3517	848	5492
1981	3412	695	123	3273	537	875	1412	5717	2343	1312	4581
1982	3160	694	123	3267	766	1250	2016	6874	2817	1578	5561
1983	3389	770	136	3625	674	1100	1775	5244	2149	1204	3564
1984	3640	600	106	2826	553	902	1456	7202	2952	1653	4597
1985	3393	683	120	3213	793	1295	2088	6780	2779	1556	3921

Source: International Joint Commission, Great Lakes Water Quality Board, Surveillance Subcommittee; Army Corps of Engineers, Buffalo District (1974 to 1980 Lake Erie).

Table 51. Constant parameters used for the GLMB model, by segment.

Parameter	Units	Lake Superior	Lower Green Bay	Upper Green Bay	Lake Michigan	Georgian Bay	Saginaw Bay	Lake Huron	Western L. Erie	Central L. Erie	Eastern L. Erie	Lake Ontario
Volume	(km^3)	11920.0	7.5	55.4	4846.0	665.0	8.1	2842.0	28.0	274.0	166.0	1631.0
Surface area	(km^2)	82100.0	953.0	3260.0	53537.0	15108.0	1376.0	43086.0	3680.0	15390.0	6150.0	18960.0
Flow rate	(km^3/yr)	67.2	5.4	10.8	36.0	17.9	4.7	160.8	171.1	177.5	182.0	211.7
Initial TP (1973)	(ug/l)	4.6	40.0	15.0	8.5*	4.5	30.9	5.5	34.7**	18.5**	20.8*	21.0
Settling velocity	(m/yr)	9.8	12.7	11.2	***	12.9	13.5	12.6	10.1	33.6	36.7	13.9

Sources: Chapra and Sonzogni (1979); * Rousar (1973); and ** Herdendorf (1984).

*** Variable settling velocity values were used for the L. Michigan segment (see Table 52).

Table 52. Turbulent exchange coefficients used for the GLMB model, by segment.

Segments	Exchange rate (km^3/yr)
Lower Green Bay/ Upper Green Bay	20.0
Upper Green Bay/ Lake Michigan	30.0
Lake Michigan/ Lake Huron	70.0
Georgian Bay/ Lake Huron	100.0
Saginaw Bay/ Lake Huron	25.0
Western L. Erie/ Central L. Erie	140.0
Central L. Erie/ Eastern L. Erie	490.0

Source: Chapra and Sonzogni (1979).

represent long-term averages. For most model segments the initial concentrations of total phosphorus are from Chapra and Sonzogni (1979); values used for Lake Michigan and the three basins of Lake Erie were adjusted to better represent the conditions observed in the early 1970s (Rousar, 1973; Herdendorf, 1984).

For the Lake Michigan segment annual total phosphorus settling velocity values were allowed to vary as a function of winter ice cover. Past modeling efforts have shown the need to increase the apparent settling velocity by eight-fold during periods of extensive (>30% of surface area of lake) ice cover (Rodgers and Salisbury, 1981a; Lesht, 1984b; Lesht and Rockwell, 1985). For this modeling effort a linear regression was developed between the winter severity index (WSI) (Quinn et al., 1978) and the number of days with 30% or greater ice cover (ICD), determined by planimeter, for the model years 1976-1981 ($n=6$, $r^2=0.992$):

$$ICD = -18.22(WSI) - 55.16 \quad (7)$$

The number of days with 30% or greater ice cover was then calculated for each model year from 1974 to 1985 based on this linear relationship (equation 7). The settling velocity (v) was increased eight-fold during the period of extensive ice cover, based on work by Rodgers and Salisbury (1981a), over the long-term average of 12.4 meter/year (Chapra and Sonzogni, 1979):

$$v = 0.237(ICD) + 12.4 \quad (8)$$

The resulting settling velocities, as well as the submodel (equations 6, 7 and 8) input values are shown in Table 53.

Table 53. Data used to represent the total phosphorus (TP) settling velocity for the Lake Michigan segment of the GLMB model.

Model Year	Winter Severity Index*	Days of Ice Cover (planimeter)	Days of Ice Cover (linear regression)	TP settling velocity (m/yr)
1974	-4.9		34	20.5
1975	-3.3		5	13.6
1976	-3.6	7	10	14.8
1977	-7.7	83	85	32.6
1978	-6.0	56	54	25.2
1979	-6.8	70	69	28.8
1980	-4.0	21	18	16.7
1981	-5.0	35	36	21.0
1982	-5.8		50	24.3
1983	-2.2		0	12.4
1984	-4.9		34	20.5
1985	-4.9		34	20.5

*WSI Source: Quinn et al. (1978).

Comparison of the GLMB model output to surveillance data: The surveillance data compared to the GLMB computations were compiled from several sources. The values for this modeling effort for 1983 through 1985 are annual averages of three or four seasonal volume-weighted means of individual surveys calculated from GLNPO surveillance data stored in the U.S. EPA STORET database. The values for Lake Michigan 1976 and 1977 are from Rockwell et al. (1980). Those for Lakes Michigan and Huron 1980 are from Lesht and Rockwell (1985). Lake Erie 1974-1982 values are from Herdendorf (1984) and Lesht and Rockwell (1987). The surveillance data are represented as means ± standard errors (when available).

The GLMB model was used to hindcast total phosphorus concentrations from 1974 to 1985, the period for which total phosphorus loading estimates are available. The model output illustrates how the lakes might be expected to respond to recent historical changes in phosphorus loading. In all five model segments, predicted concentrations of total phosphorus decreased over the modeled period (Figures 76-80). The magnitude of the predicted decreases varied from segment to segment, from less than 1 ug/l in Lake Huron to more than 20 ug/l in the western basin of Lake Erie from the mid 1970s to the mid 1980s. The GLMB model predicts the decreasing long-term trends observed in the field data very well. However, short-term (year-to-year) variations of the GLMB model are often in disagreement with the observed data.

Possible origins of these discrepancies between the GLMB model predictions and surveillance data include unrealistic model input data, an overly simplistic model structure, or unrepresentative loading and/or open lake surveillance data. Most of the model input data parameters were kept constant over the modeled 12-year period and all of the input parameters are estimated based, in part, on field data. Perhaps a more rigorous compilation of the input parameters over the 12-year modeling period would improve the 12-year hindcast. The structure of the GLMB model is very simple, by design, and, therefore, should not be expected to exactly reproduce the annual averages of the surveillance data. The annual averages of the loading and open lake surveillance data are based on temporally incomplete records of total phosphorus concentrations with loading errors as much as 20-30% and open lake data based on only three survey periods.

For Lake Michigan over the 12-year simulation a decreasing total phosphorus concentration trend is hindcast by the model and observed in the surveillance data (Figure 76). Although the substantial 2.5 ug/L

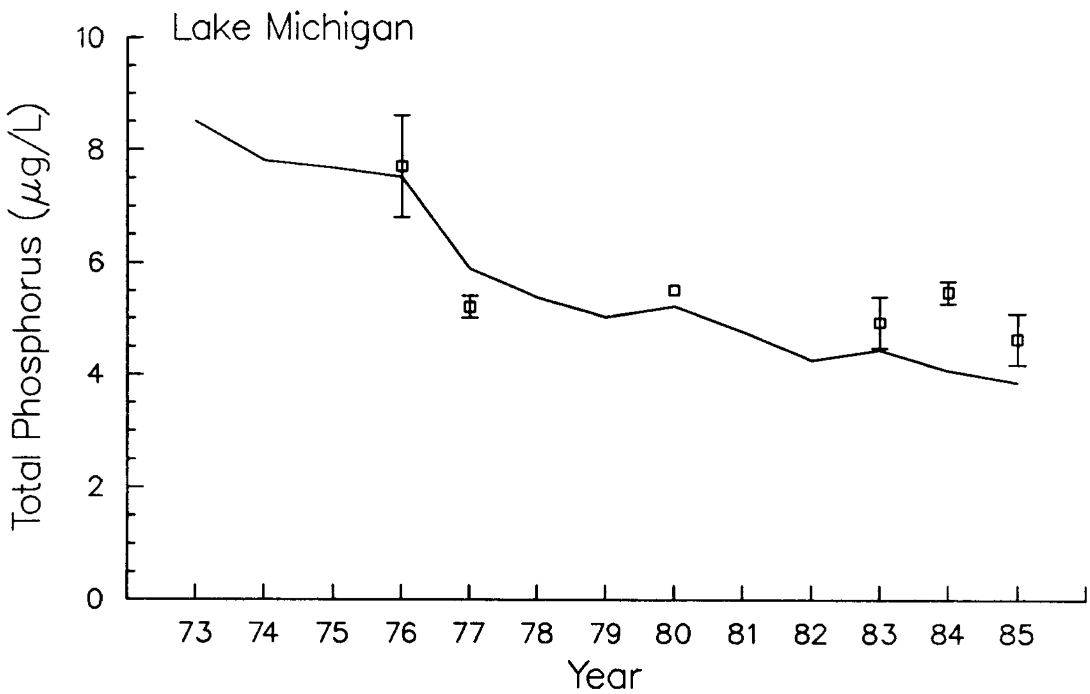


Figure 76. GLMB model simulation of total phosphorus in Lake Michigan. Model results (line) are compared to surveillance data (mean ± 1 standard error).

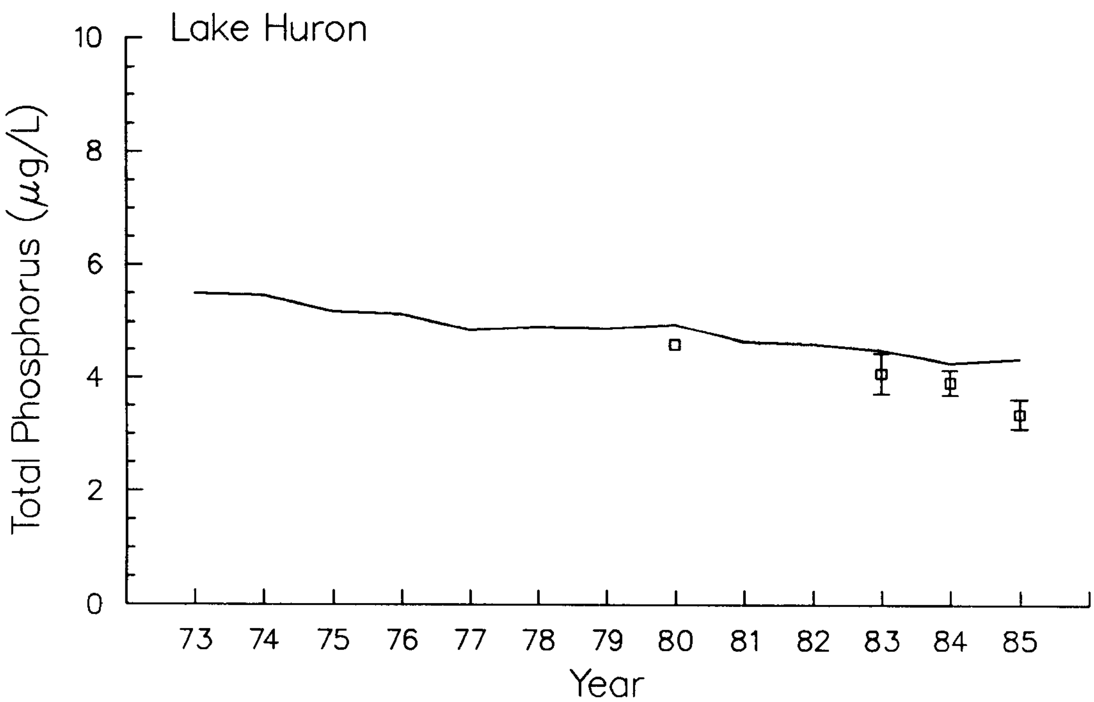


Figure 77. GLMB model simulation of total phosphorus in Lake Huron.

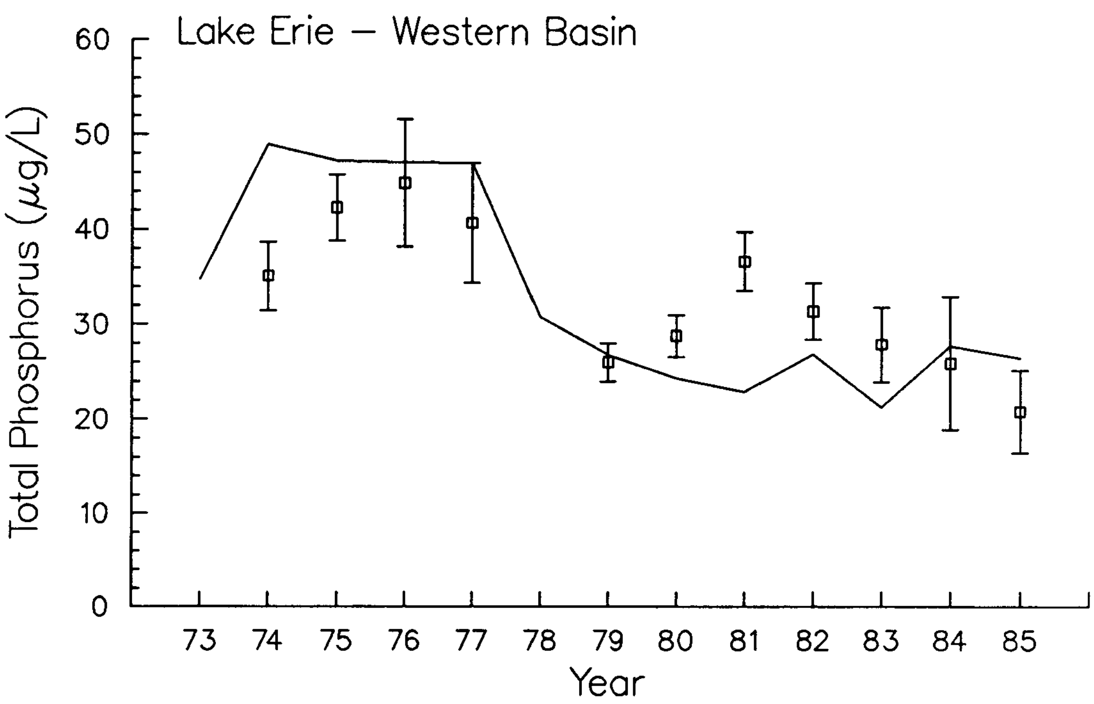


Figure 78. GLMB model simulation of total phosphorus in the western basin of Lake Erie.

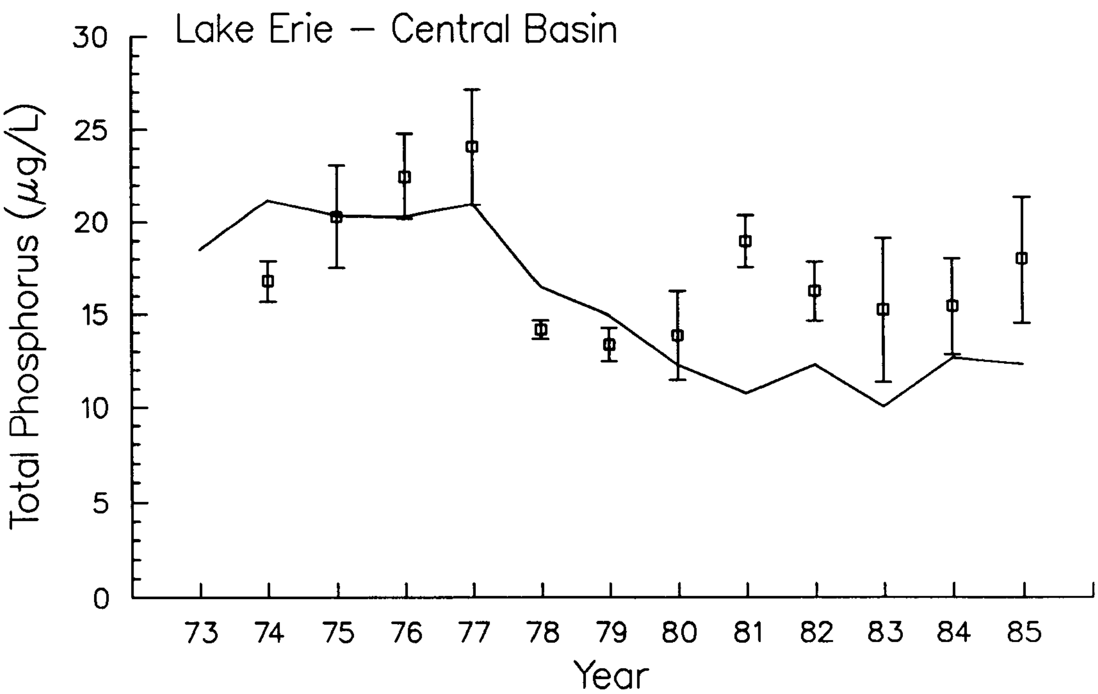


Figure 79. GLMB model simulation of total phosphorus in the central basin of Lake Erie.

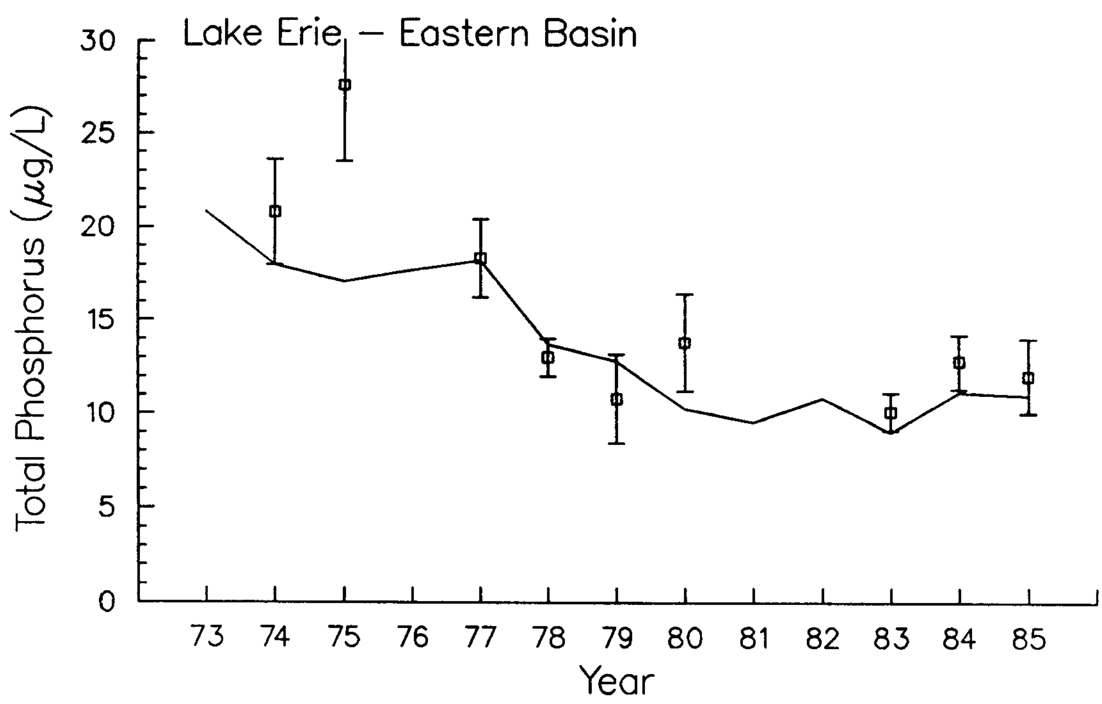


Figure 80. GLMB model simulation of total phosphorus in the eastern basin of Lake Erie.

decrease in total phosphorus between 1976 and 1977 is underestimated by the model by approximately 1 ug/L, a decrease is simulated. In the 1980s the model underestimates the total phosphorus concentration. A better understanding of the effect of winter ice cover on the settling velocity of total phosphorus is needed.

For Lake Huron, a slowly decreasing concentration trend (approximately -0.1 ug/L/yr) is hindcast over the 12-year GLMB model simulation (Figure 77). The observed data suggests that the rate of decrease was about two times greater (approximately -0.2 ug/L/yr). The observed total phosphorus decrease from 1984 to 1985 is not predicted by the model, nor reflected in the increasing load estimate from 1984 to 1985. Perhaps the settling velocity used for this segment has been underestimated or loading estimates are in error.

For the western basin of Lake Erie, the 12-year trend simulated by the GLMB is only grossly in agreement with the surveillance data (Figure

78). Extremely high concentrations are predicted and observed during 1975 through 1977 and a rapid concentration decrease is predicted and observed from 1977 to 1979. However, year-to-year model predictions are not in agreement with corresponding field data. The observed total phosphorus concentration increases from 1979 through 1981 and decreases from 1981 through 1985 are not reflected in the GLMB model hindcast. These disagreements suggest that the total phosphorus loading estimates used do not reflect observed total phosphorus concentrations. The model assumes net deposition of phosphorus into the sediments in the western basin which may not be attained each year due to its shallow nature and storm-induced resuspension (Lesht and Rockwell, 1985).

For the central basin of Lake Erie, the GLMB model hindcasts the high total phosphorus concentrations observed from 1975 through 1977 and the lower concentrations observed from 1978 through 1980 (Figure 79). For the years 1981 through 1985 the model greatly underestimates the surveillance data. This discrepancy is, in part, due to the concentration underestimation in the western basin. Further, the model does not estimate the impact of in-basin phosphorus loading due to anoxic sediment release of phosphorus to the water column.

For the eastern basin of Lake Erie over the 12-year simulation, a decreasing concentration trend is hindcast by the GLMB model and observed in the surveillance data (Figure 80). The predicted concentrations are, for the most part, in very close agreement with the field data. The very high total phosphorus concentrations observed in 1975 appear to be anomalous.

In conclusion, the GLMB model has been used to hindcast the total phosphorus concentrations in the middle Great Lakes. Better agreement between model results and observations are found in Lake Michigan, Huron and eastern Lake Erie where effects from the non-modeled processes of resuspension and anoxic release of phosphorus are less of a factor than in western and central Lake Erie. Further refinement of the GLMB may improve the predictive capability of the model. Refinement possibilities include changes to the model segmentation and to the model coefficients. The segmentation could be refined to separate the southern and northern basins of Lakes Michigan and Huron. The current input data set could be refined to use annually varying parameters to model the net apparent settling velocity as a function of extensive winter ice cover, and storm-induced sediment resuspension or anoxic phosphorus release as internal sources of phosphorus.

Dynamic Nutrient-Phytoplankton WASP Models

The Water Quality Analysis Simulation Program (WASP) (DiToro et al., 1983) is a flexible modeling framework that has been applied individually to eutrophication analyses of the middle Great Lakes. Complex, dynamic, mass-balance models have been developed for Lakes Michigan (Rodgers and Salisbury, 1981a and b), Huron (DiToro and Matystik, 1980) and Erie (DiToro and Connolly, 1980). These models simulate several biological and chemical parameters (Table 54) in multiple segments. WASP treats each segment as a completely mixed reactor connected to adjacent segments via dispersive exchange and advective flow. Biological and chemical parameters interact via empirical kinetics. Parameter concentrations are represented by non-linear partial differential equations. Concentrations are assumed uniform throughout each segment; the WASP models compute average concentrations for each segment. For these model simulations the concentrations of the water quality parameters were calculated on a twelve-hour temporal scale.

The WASP models are driven by external loadings of each of the modeled parameters. For the two phosphorus systems (Table 54), IJC estimates of total phosphorus loading for 1983 to 1985 (Table 49) were divided into non-living organic and soluble reactive phosphorus. For the unknown categories in 1985, 1984 estimates were used. Each total load, including upstream load, was divided into loads for each model segment. The resulting loads used in the WASP model are shown in Table 55.

Table 54. Comparison of biological and nutrient state variables explicitly modeled by the WASP models of Lakes Michigan, Huron and Erie.

State Variable	Lake Michigan Model	Lake Huron Model	Lake Erie Model
Non-diatomaceous chlorophyll-a	X	X	X
Diatomaceous chlorophyll-a			X
Herbivorous zooplankton	X	X	X
Carnivorous zooplankton	X	X	X
Non-living organic carbon			X
Non-living organic nitrogen	X	X	X
Non-living organic phosphorus	X	X	X
Non-living silica	X	X	
Ammonia nitrogen	X	X	X
Nitrite nitrogen			X
Nitrate nitrogen	X	X	X
Dissolved reactive phosphorus	X	X	X
Dissolved reactive silica	X	X	
Dissolved oxygen			X
Total number of state variables	11	8	14

Table 55. Annual total phosphorus loadings (metric ton/year) used for the WASP models.

Model Year	Lake Michigan	Lake Huron	Lake Erie
1983	4531	4206	9677
1984	3532	3568	12887
1985	4016	4833	12195

Source: International Joint Commission, Great Lakes Water Quality Board, Surveillance Subcommittee data.

The WASP models also require data to represent segment volumes, surface areas, flow rates, dispersive exchange rates, water temperatures, photoperiod, solar radiation, initial conditions, net apparent settling velocities, and kinetic rates of the modeled parameters. For most of these model input parameters the values used in the original calibrated versions were used herein. These values represent Great Lakes conditions of the early to mid-1970s.

The selection of initial conditions for the WASP models is extremely important. The results of these models are very sensitive to the initial conditions used (Lesht, 1984b). Initial conditions should be chosen to realistically represent concentrations of the model parameters. Initial 1983 conditions are based on data collected during the winter surveys of 1984 and 1985, and on comparisons between model results and spring 1983 survey data. This iterative "tuning" of initial conditions improves the reliability of the model results by reducing the dependency of model results on the accuracy of individual survey mean concentrations.

Comparison of WASP model results to surveillance data: WASP model results for selected parameters from 1983 through 1985 are compared to data collected for the GLNPO's annual surveillance program begun in the spring of 1983. These data are reported herein and in the earlier surveillance reports (Lesht and Rockwell, 1985 and 1987). Survey means plus/minus one standard error are compared to the WASP model results. The surveillance data are too sparse temporally to perform a rigorous comparison to the results of the WASP models.

The WASP model of Lake Michigan was developed by Rodgers and Salisbury (1981a and 1981b) and was thoroughly investigated by Lesht (1984a and 1984b). Mass balances are calculated by the model for the variables shown in Table 54. The model is divided into four segments representing the epilimnion (upper 20 meters) and the hypolimnion of the southern and the northern basins.

The Lake Michigan WASP model, like the GLMB model, can be used to simulate an accelerated settling of particulates during periods of extensive ice cover. The effect of this hypothetical, ice cover-induced, accelerated particulate settling on chlorophyll-a, ortho phosphorus and total phosphorus concentrations is investigated herein. Lake Michigan was simulated without and with accelerated settling of particulates. For one simulation, the settling velocities of the particulates was increased from 0.2 meters/day to 1.6 m/d for the first 34 days of both 1984 and 1985.

The results of the chlorophyll-a simulations in the epilimnion segments of both basins of Lake Michigan are compared to chlorophyll-a surveillance data in Figures 81 and 82. The dashed line displays model output assuming ice cover-induced accelerated particulate settling. The solid line displays model output assuming a constant particulate settling rate. Typically, spring (April and May) survey data are overpredicted by the model simulations; the model predicts an earlier onset of phytoplankton growth than is supported by the survey data. The model predictions for the other seasons are closer to observed data. Surveillance data are too sparse to support or dispute annual predicted peaks in chlorophyll-a concentration.

The effect of varying the particulate settling rate appears to be insignificant for the first year; there is only a small change in the 1984 model results between the two simulations. However, for 1985 the effect becomes greater. For simulations extending for many years the results would be expected to continue to diverge.

The results of the total phosphorus simulations in the epilimnion segments of both basins of Lake Michigan are compared to total phosphorus surveillance data in Figures 83 and 84. The dashed line displays model output assuming ice cover-induced, accelerated particulate settling. The solid line displays model output assuming a constant settling rate. In the southern basin epilimnion the model output is reasonably close to the 1983 survey data. However, the model predictions for 1984 and 1985 greatly underestimate the survey data. Even by eliminating the accelerated particulate settling the model underestimates the observed concentrations.

In the northern basin epilimnion both simulations track observations better compared to the simulations of the southern basin. In 1984 the ice cover-induced, accelerated particulate settling simulation predicts the survey data best. In 1985 the survey data is predicated best by using the constant settling rate simulation for the entire three years.

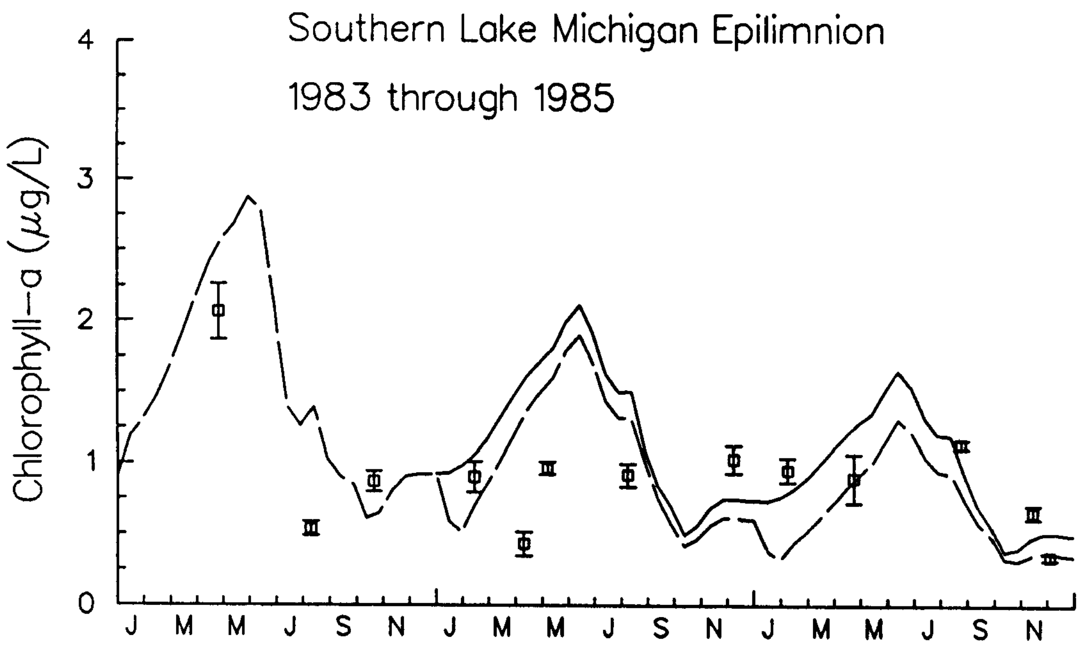


Figure 81. WASP model simulation of chlorophyll-a in the epilimnion of southern Lake Michigan. Model results using a constant settling velocity (solid line) and using ice cover-induced accelerated settling of particulates (dashed line) are compared to surveillance data (mean ± 1 standard error).

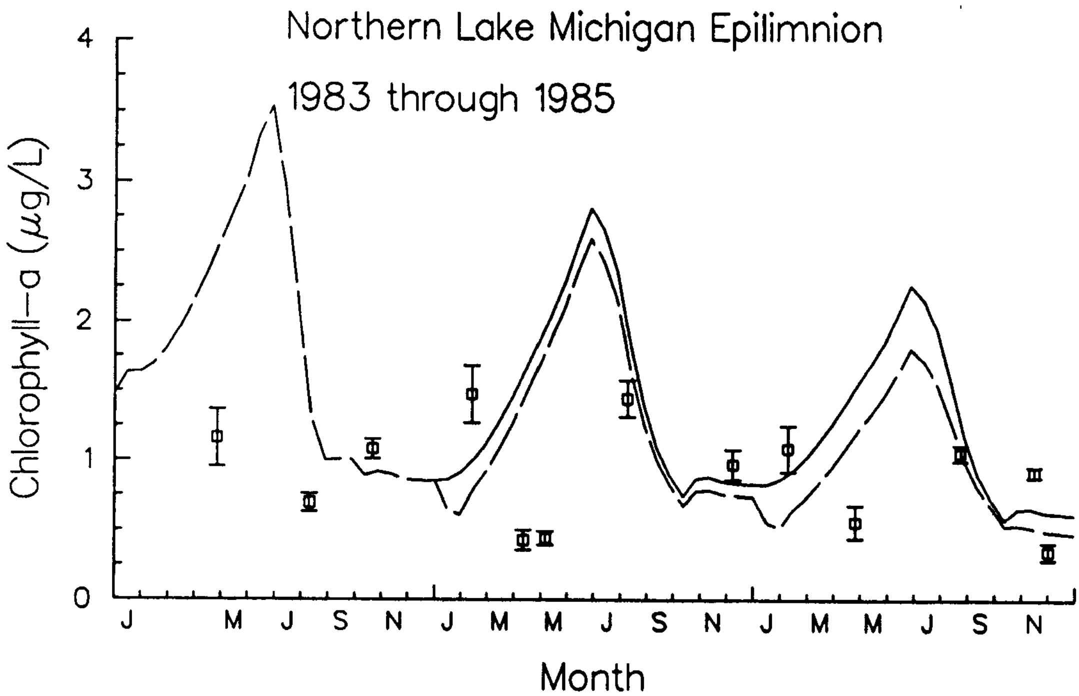


Figure 82. WASP model simulation of chlorophyll-a in the epilimnion of northern Lake Michigan.

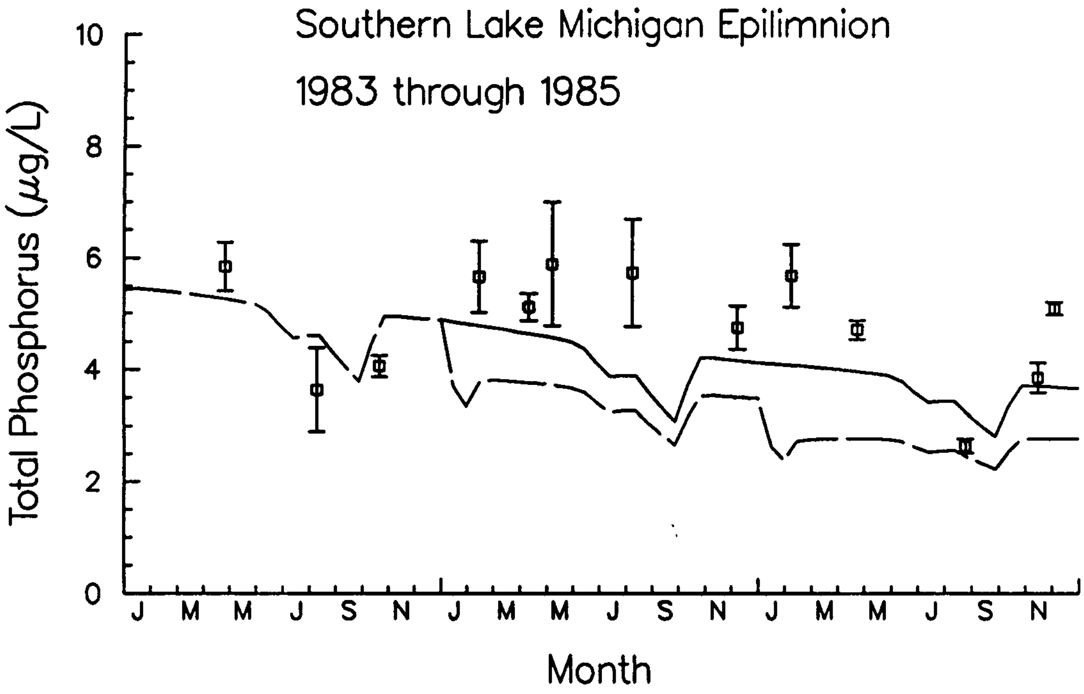


Figure 83. WASP model simulation of total phosphorus in the epilimnion of southern Lake Michigan.

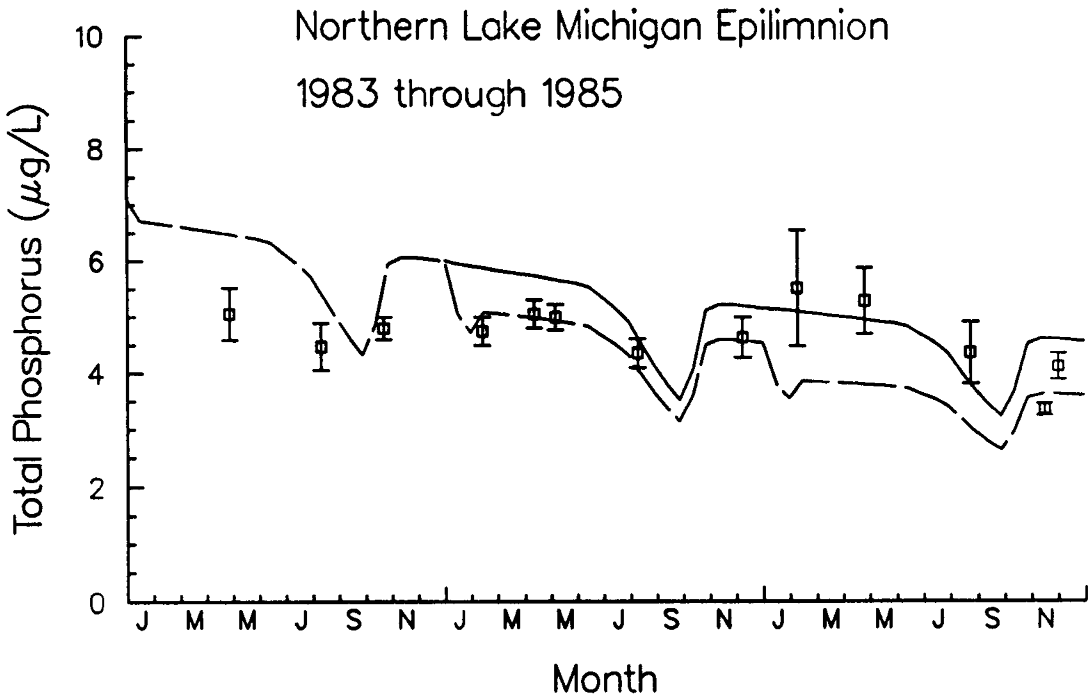


Figure 84. WASP model simulation of total phosphorus in the epilimnion of northern Lake Michigan.

These inconsistent results suggest further refinement is needed in modeling settling rates.

The results of the soluble reactive, ortho phosphorus simulations in the epilimnion segments of both basins of Lake Michigan are compared to ortho phosphorus surveillance data in Figures 85 and 86. The dashed line displays model output assuming ice cover-induced, accelerated particulate settling. The solid line displays model output assuming a constant settling rate. In both basins the model predicts the trend found in the survey data. However, the magnitude is not always predicted. The model overestimates the extent of the summer depletion in both basins during each summer for the extent of the simulations. Typically, the model underestimates the winter peak. There is very little difference in model results whether the particulate settling rate is constant or time-variable as a function of ice cover.

The WASP model of Lake Huron was developed by DiToro and Matystik (1980). Mass balances are calculated by the model for the variables shown in Table 54. The model is divided into four main lake segments representing the epilimnion (upper 15 meters) and the hypolimnion of the northern and southern basins. A fifth segment represents Saginaw Bay.

The Lake Huron WASP model was used to examine the sensitivity of the output to the amount of phosphorus loadings. Water quality was simulated using the annual total phosphorus loadings estimated by the International Joint Commission (Table 55) and, also, using phosphorus loadings at 66.7% of IJC estimates.

The results of the chlorophyll-a simulations in the epilimnion segments of both basins of Lake Huron are compared to chlorophyll-a surveillance data in Figures 87 and 88. The solid line displays model output assuming IJC phosphorus loading estimates. The dashed line shows the output assuming 66.7% of the IJC loading level. In general, the model matches the temporal trend of the survey data, but not the magnitude

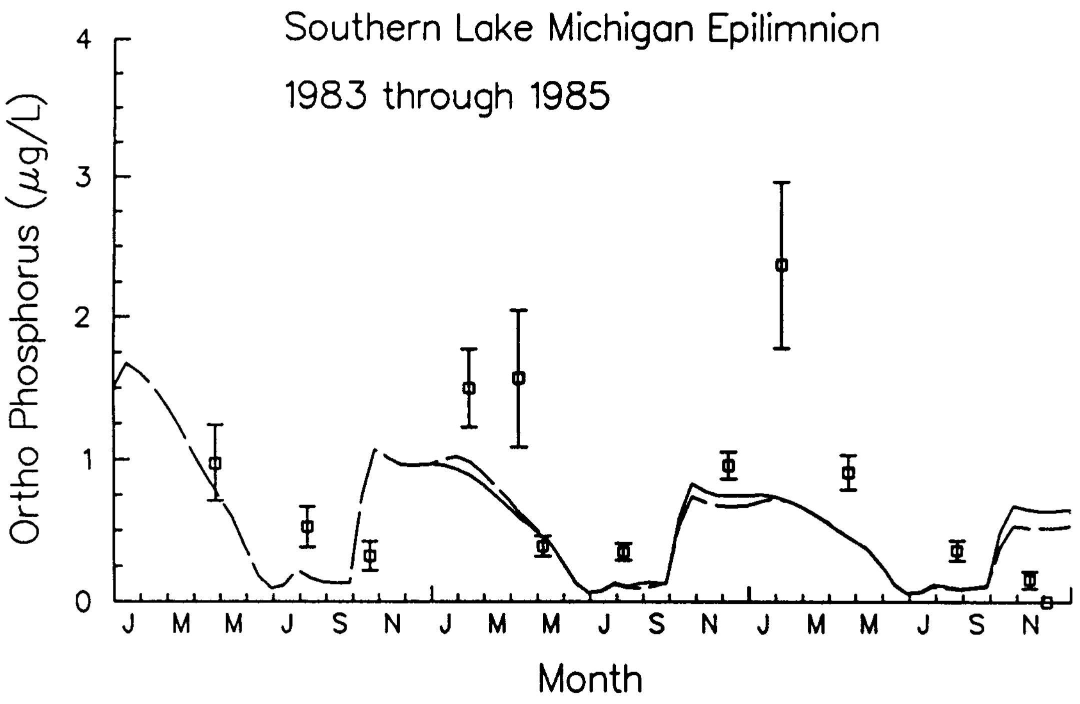


Figure 85. WASP model simulation ortho phosphorus in the epilimnion of southern Lake Michigan.

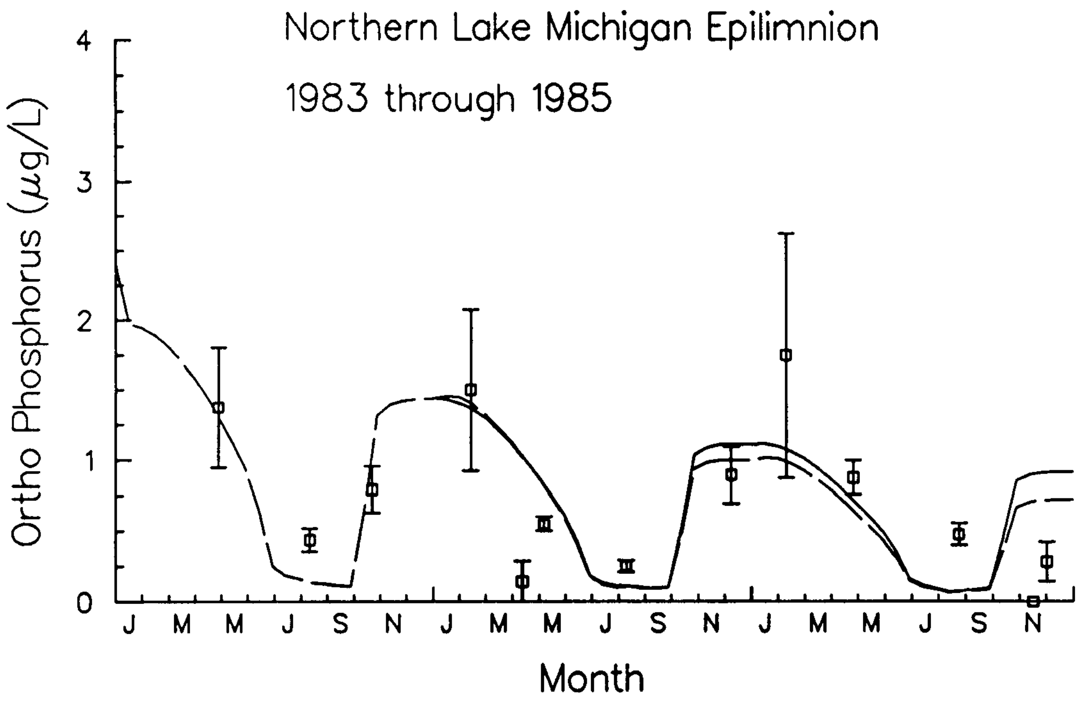


Figure 86. WASP model simulation ortho phosphorus in the epilimnion of northern Lake Michigan.

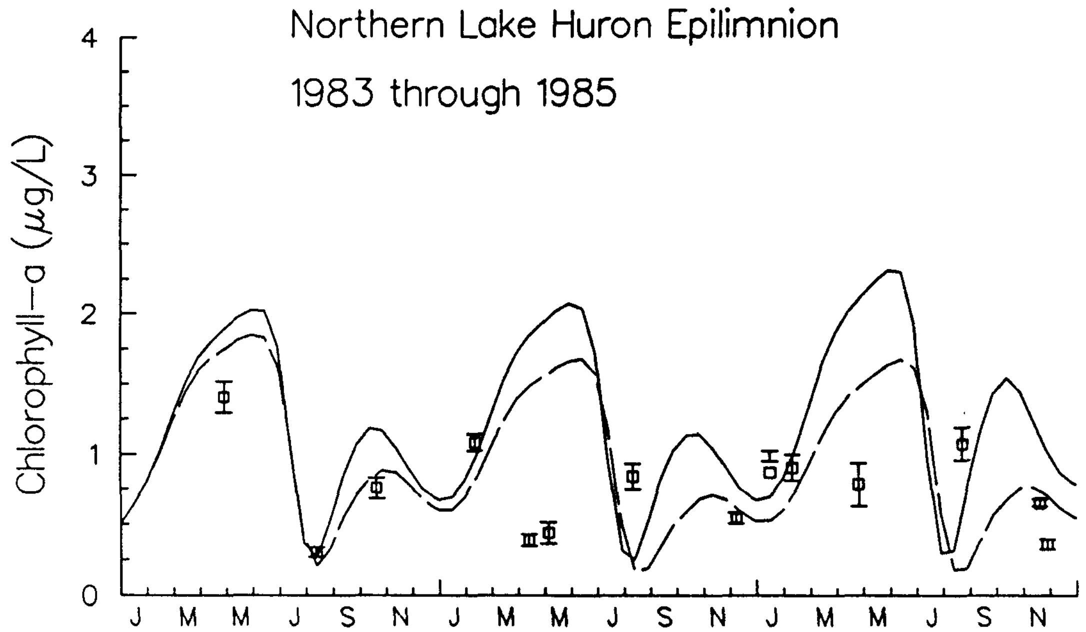


Figure 87. WASP model simulation of chlorophyll-a in the epilimnion of northern Lake Huron. Model results using IJC loading estimates (solid line) and using 66.7% of IJC loading estimates (dashed line) are compared to surveillance data (mean ± 1 standard error).

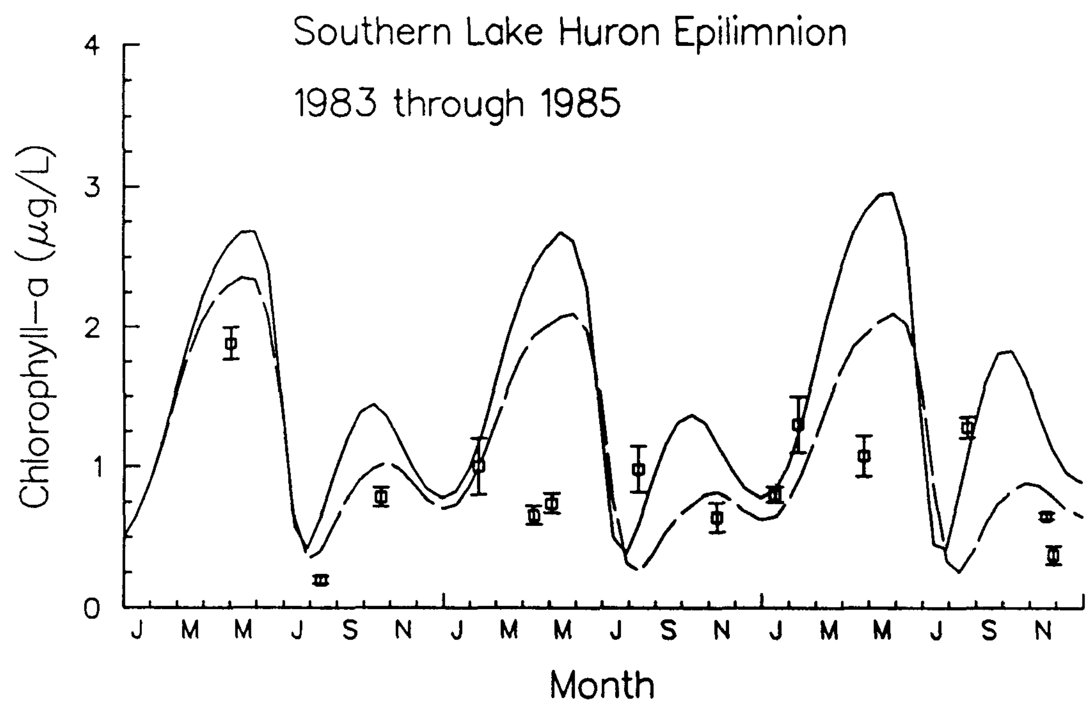


Figure 88. WASP model simulation of chlorophyll-a in the epilimnion of southern Lake Huron.

of the concentrations. The WASP model greatly overpredicts the observed concentrations of chlorophyll-a in the spring (April to May). Lowering phosphorus loads decreased the magnitude of both the spring and fall chlorophyll-a concentration peaks, as expected. The effect becomes greater for each successive peak.

The results of the total phosphorus simulations in the epilimnion segments of both basins of Lake Huron are shown in Figures 89 and 90. The solid line displays the model output assuming IJC phosphorus loading estimates. The dashed line shows the output assuming 66.7% of the IJC loading level. Both scenarios greatly overpredict observed total phosphorus concentrations. Further, the temporal trend of the observed data is not predicted by the model. As observed in the earlier reports of this annual surveillance program, the epilimnetic depletion of total phosphorus observed during the summer is not simulated by the WASP model. The WASP model of Lake Huron apparently does not properly account for the settling of particulate phosphorus.

The results of the ortho phosphorus simulations in the epilimnion segments of both basins of Lake Huron are shown in Figures 91 and 92. The solid line displays the model output assuming IJC phosphorus loading estimates. The dashed line shows the output assuming 66.7% of the IJC loading level. The two scenarios differ little. Both scenarios match the surveillance data in temporal trend and in concentration magnitude. However, as seen in the chlorophyll-a simulation, the difference between the two model scenarios becomes more pronounced with each successive year.

The WASP model of Lake Erie was developed by DiToro and Connolly (1980). Mass balances are calculated by the model for the variables shown in Table 54. The model is divided into six epilimnion and hypolimnion water column segments and four sediment segments. The western basin is represented by a water column and a sediment segment. The central basin is represented by an epilimnion, two hypolimnion, and two sediment segments. The eastern basin is represented by an epilimnion,

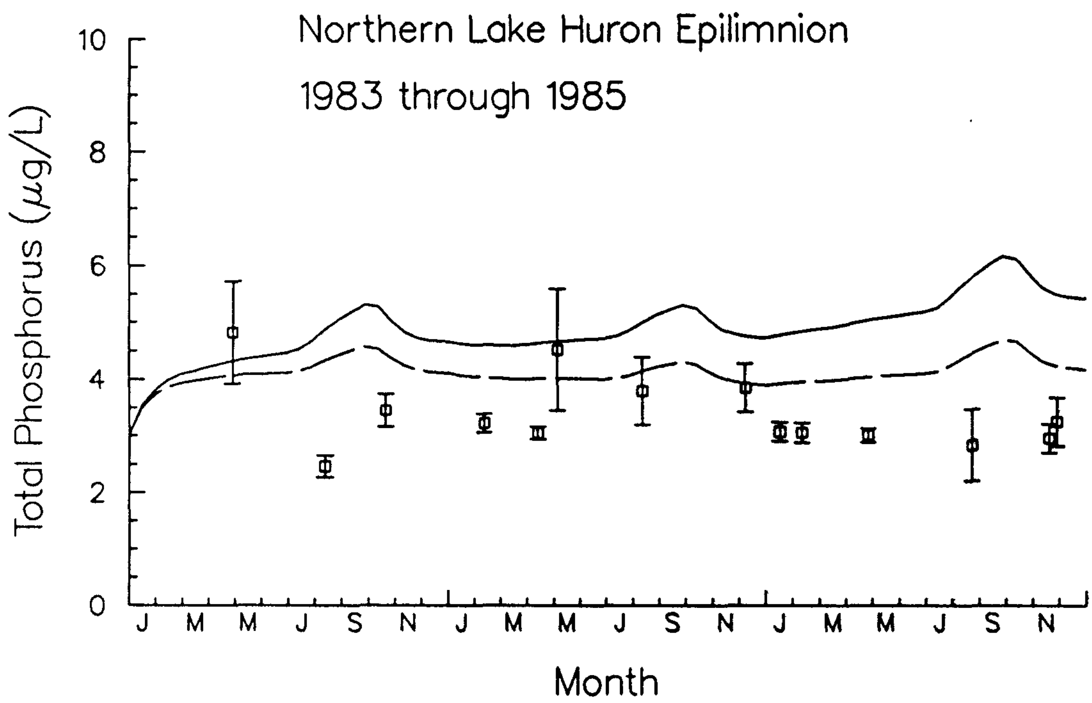


Figure 89. WASP model simulation of total phosphorus in the epilimnion of northern Lake Huron.

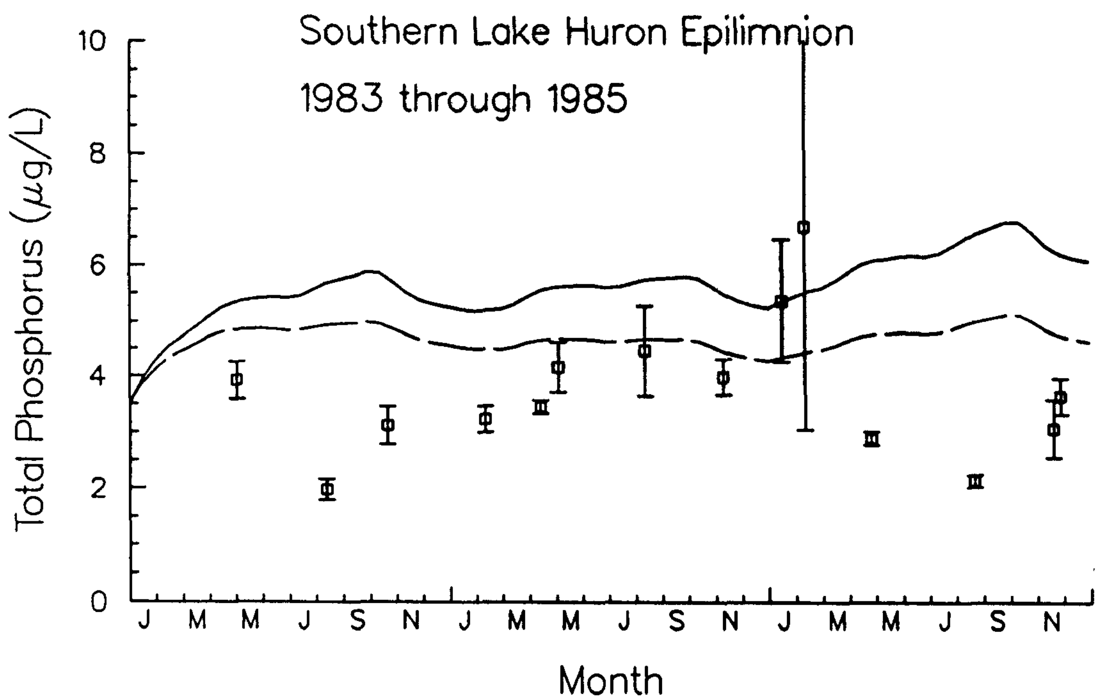


Figure 90. WASP model simulation of total phosphorus in the epilimnion of southern Lake Huron.

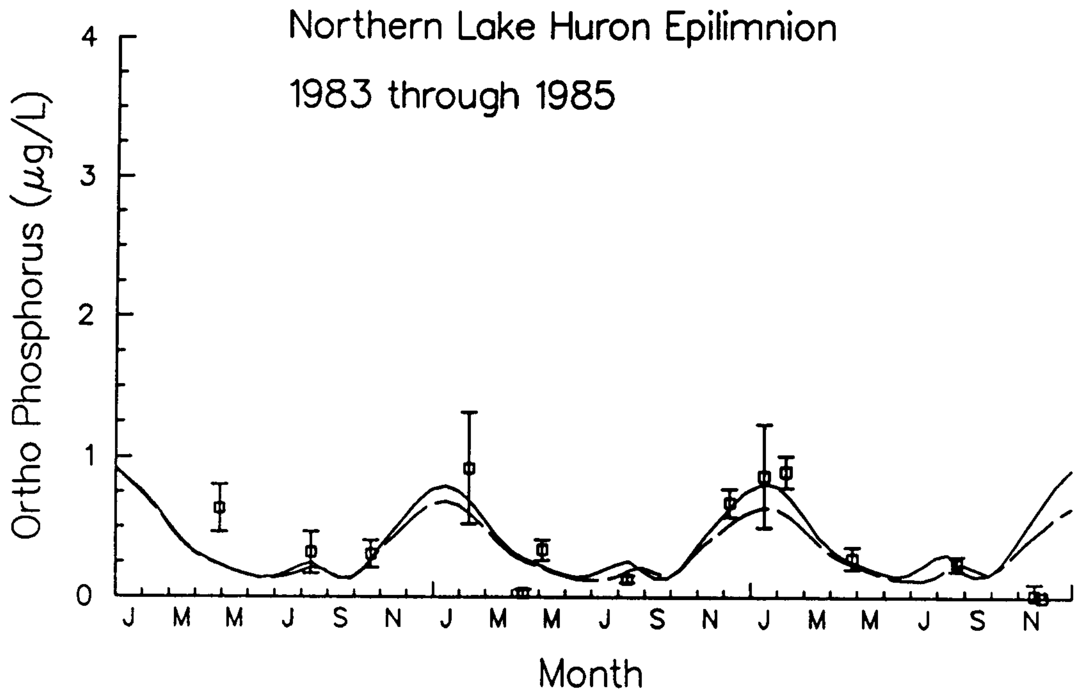


Figure 91. WASP model simulation of ortho phosphorus in the epilimnion of northern Lake Huron.

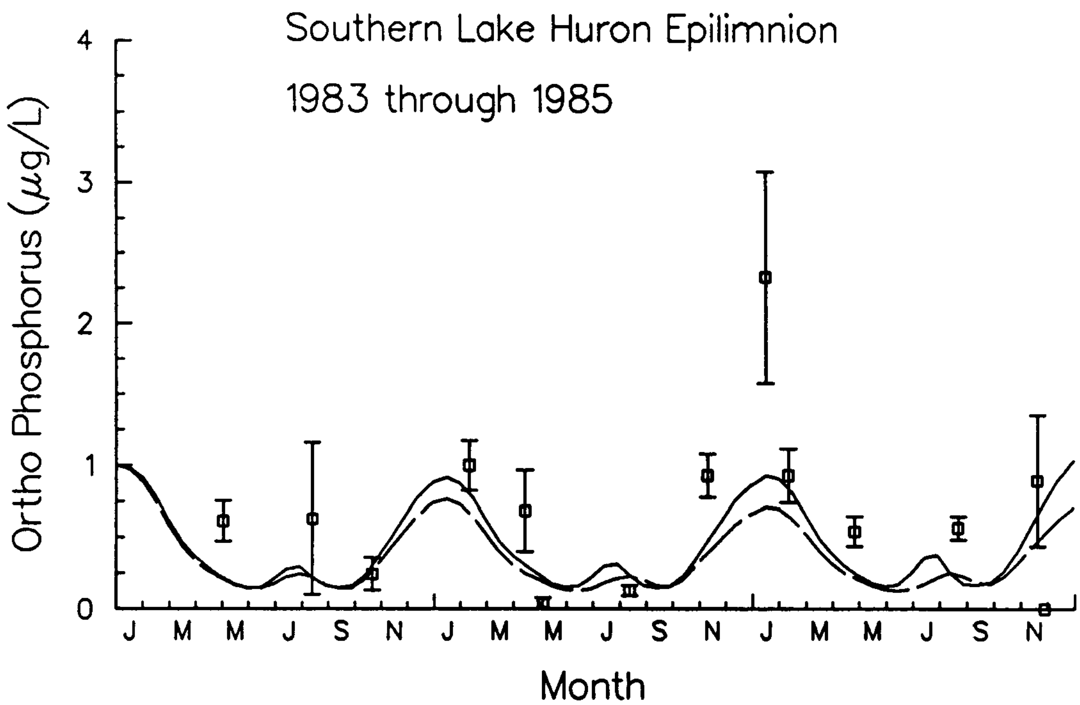


Figure 92. WASP model simulation of ortho phosphorus in the epilimnion of southern Lake Huron.

a hypolimnion, and a sediment segment. Exchanges between the water column and sediment segments are represented in the model.

The Lake Erie WASP model was used to examine the behavior of chlorophyll-a, total phosphorus and ortho phosphorus in the western basin and epilimnion segments of the central and eastern basins. Additionally, dissolved oxygen concentrations in the central basin hypolimnion are examined. Water quality was simulated using the annual total phosphorus loadings estimated by the International Joint Commission (Table 55).

The results of the chlorophyll-a simulations in the western basin and the epilimnion segments of the central and eastern basins of Lake Erie are shown in Figures 93, 94 and 95. In all three basins, typically, the observed spring peak of diatomaceous chlorophyll-a is overpredicted by the model. Further, the model does not simulate a summer peak of non-diatomaceous chlorophyll-a as seen in the surveillance data and demonstrated by DiToro and Connolly (1980) in the mid-1970s. These two inconsistencies are, no doubt, related. Diatomaceous growth is excessive in the spring, resulting in ortho phosphorus depletion to the extent that summer growth of non-diatoms is retarded. Perhaps the diatomaceous growth rate calibrated and verified for the mid-1970s is not appropriate for conditions in Lake Erie in the mid-1980s. Further research on phytoplankton growth rates is needed to resolve this issue.

The results of the total phosphorus simulations in the western basin and the epilimnion segments of the central and eastern basins of Lake Erie are shown in Figures 96, 97 and 98. In the western basin the model underpredicts total phosphorus concentrations during 1983. In contrast, both the magnitude and temporal trend are modeled satisfactorily during 1984 and 1985. The scatter in the surveillance data may be the result of transient processes not explicitly represented in the model.

In the central basin epilimnion the model tracks the lower total phosphorus surveillance data throughout the simulation. However, as seen in the western basin, the variability of the observed data is much greater than the variability simulated by the WASP model. Again this may

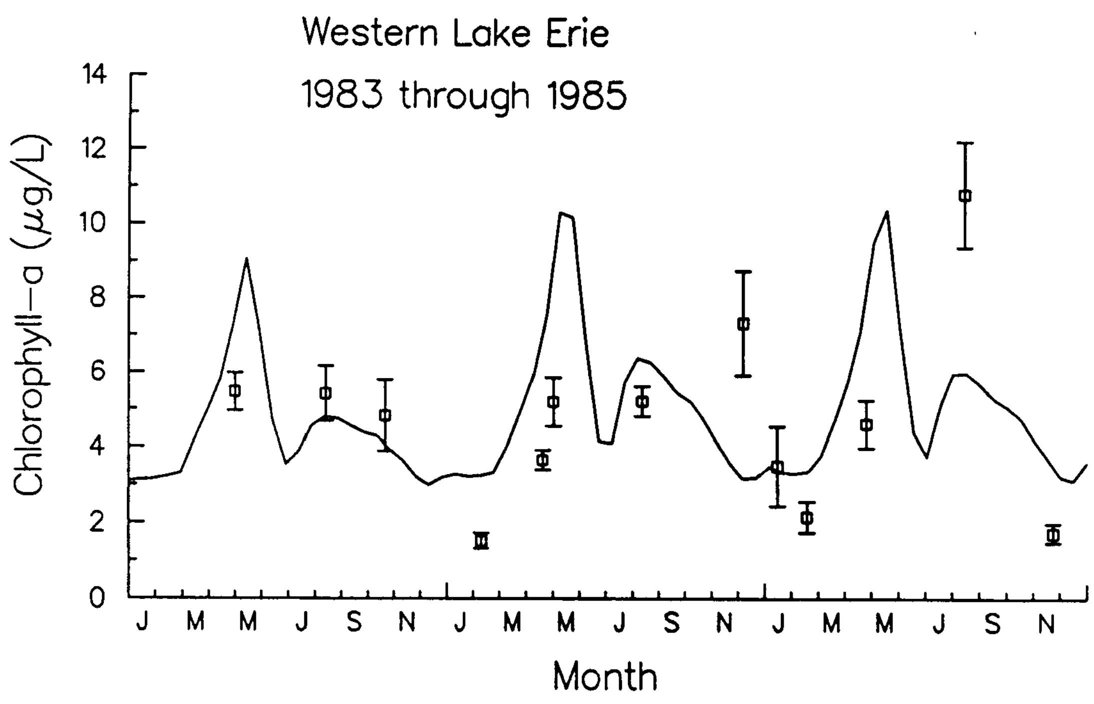


Figure 93. WASP model simulation of chlorophyll-a in western Lake Erie.

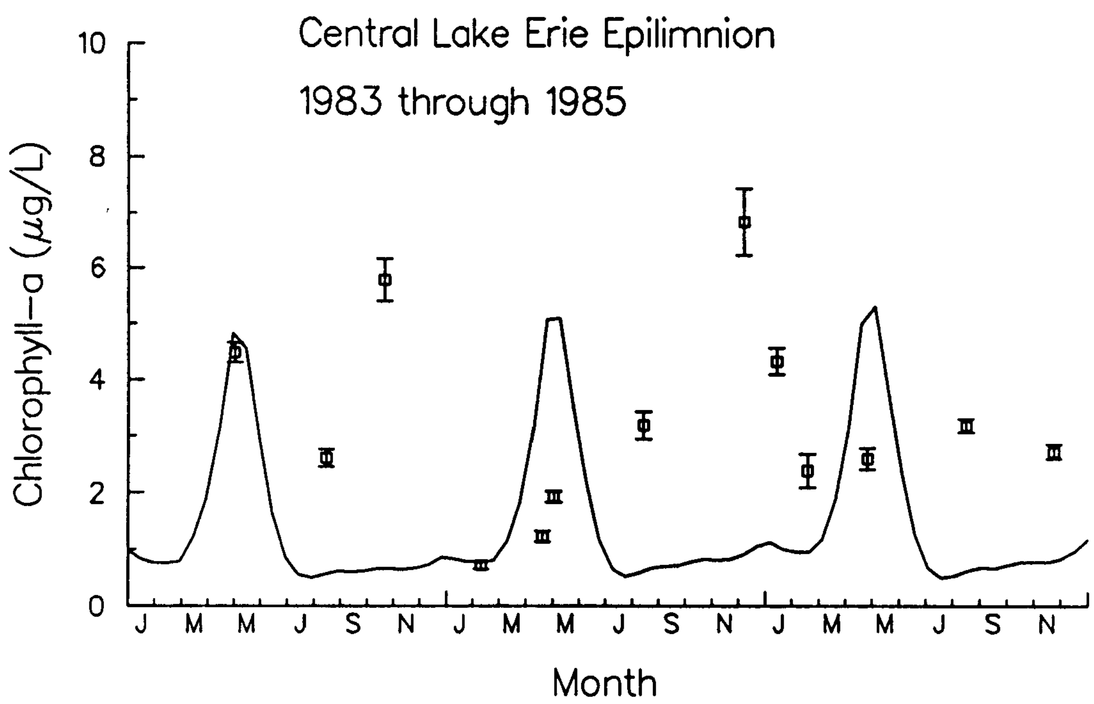


Figure 94. WASP model simulation of chlorophyll-a in the epilimnion of central Lake Erie.

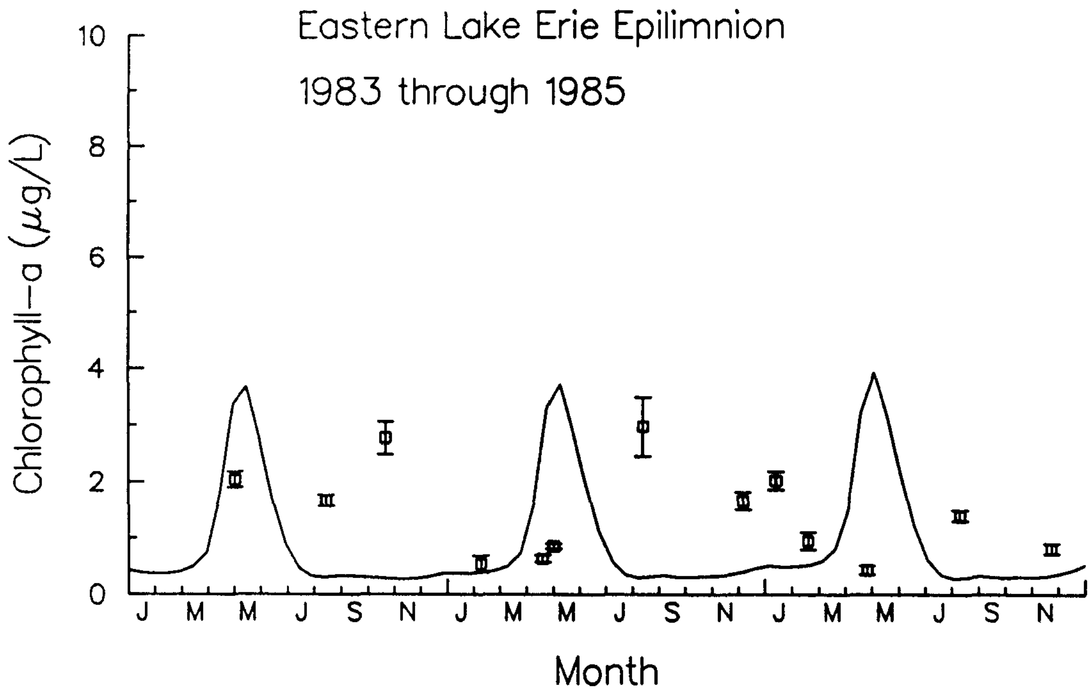


Figure 95. WASP model simulation of chlorophyll-a in the epilimnion of eastern Lake Erie.

be due to the simplified WASP model mathematical structure, which does not track transient processes.

In the eastern basin epilimnion the model generally underpredicts total phosphorus concentrations. However, the temporal trend is roughly simulated. Observed data scatter is much less in the eastern basin than in both of the other basins of Lake Erie, but is still greater than the variability of the model predictions.

The results of the soluble reactive, ortho phosphorus simulations in the western basin and the epilimnion segments of the central and eastern basins of Lake Erie are shown in Figures 99, 100 and 101. In the western basin the model reproduces the observed data in 1984 only. The surveillance data for winter 1984-1985 are extremely low; the model cannot be expected to simulate this anomalous event. Summer concentrations are underpredicted by the model, as expected from the review of problems with the chlorophyll-a simulation.

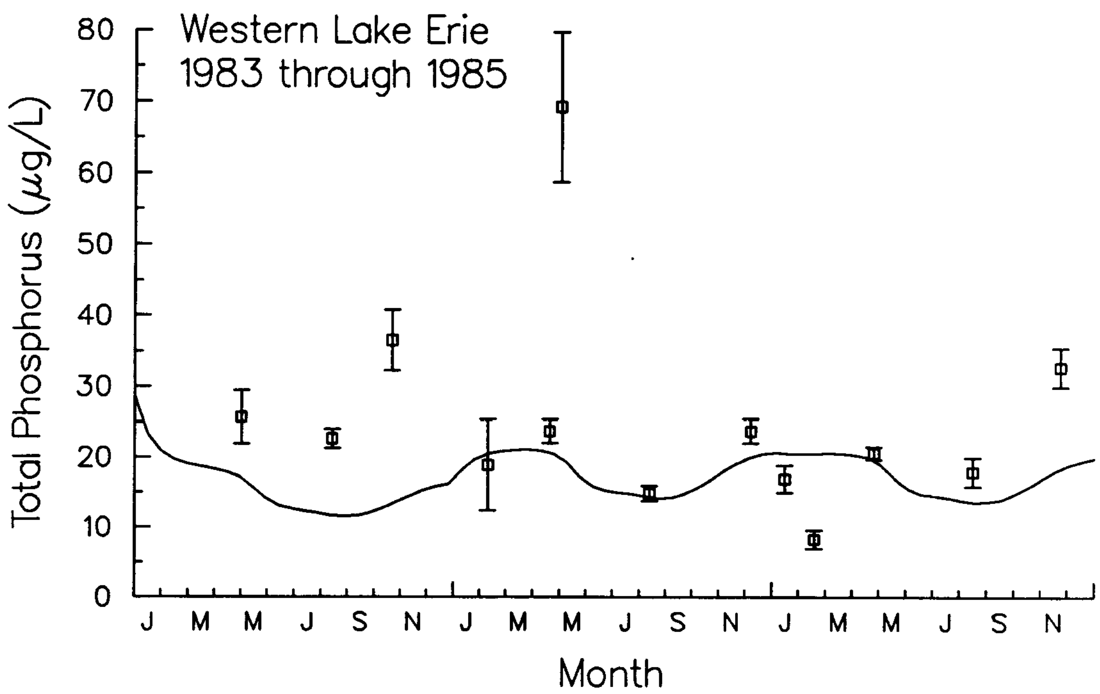


Figure 96. WASP model simulation of total phosphorus in western Lake Erie.

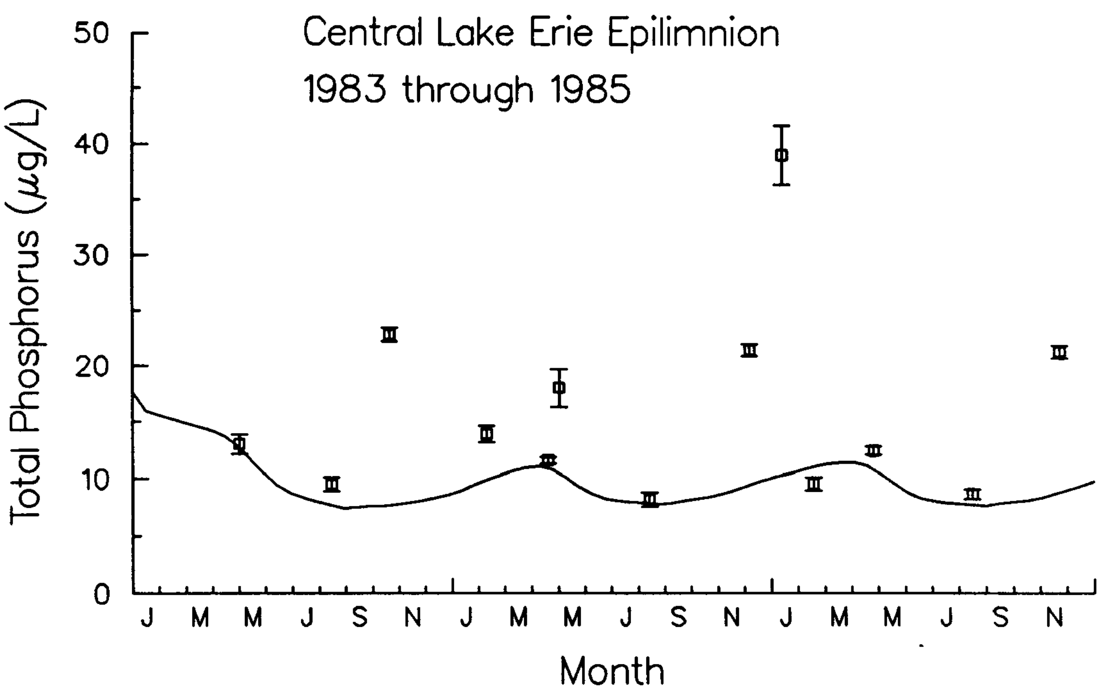


Figure 97. WASP model simulation of total phosphorus in the epilimnion of central Lake Erie.

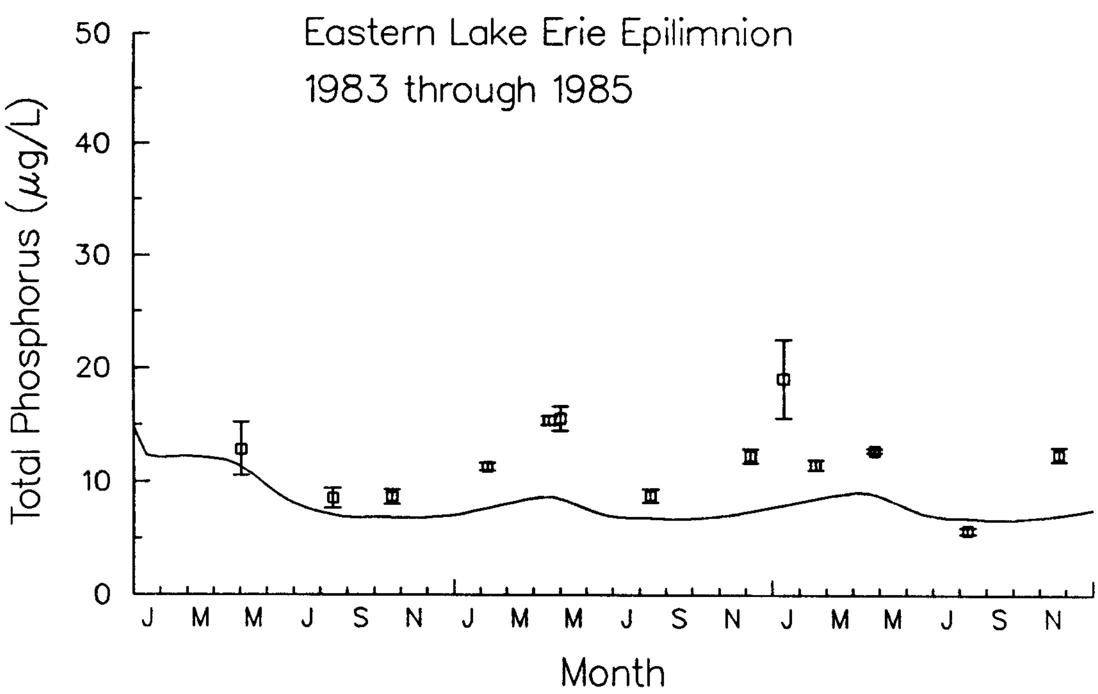


Figure 98. WASP model simulation of total phosphorus in the epilimnion of eastern Lake Erie.

In the central basin epilimnion the model does not predict the temporal trend or magnitudes of ortho phosphorus concentrations. Summer concentrations are underpredicted by the model. As in the western basin, this problem may be related to excessive growth of diatoms in the spring.

In the eastern basin epilimnion the model roughly simulates the temporal trend but not the magnitude of ortho phosphorus concentrations. Maximum and minimum concentrations are both underpredicted. Perhaps these results are related to the problem with the excessive growth of diatoms in the spring.

The results of the dissolved oxygen simulation in the central basin upper hypolimnion of Lake Erie are shown in Figure 102. The observed data statistics shown were calculated from samples collected between 56 and 72 feet (17 to 22 m) to correspond to the layer represented by the WASP model. The model tracks the temporal trend very well throughout the three-year simulation. The magnitude of dissolved oxygen in the fall, winter and spring is simulated accurately. Summer survey dissolved

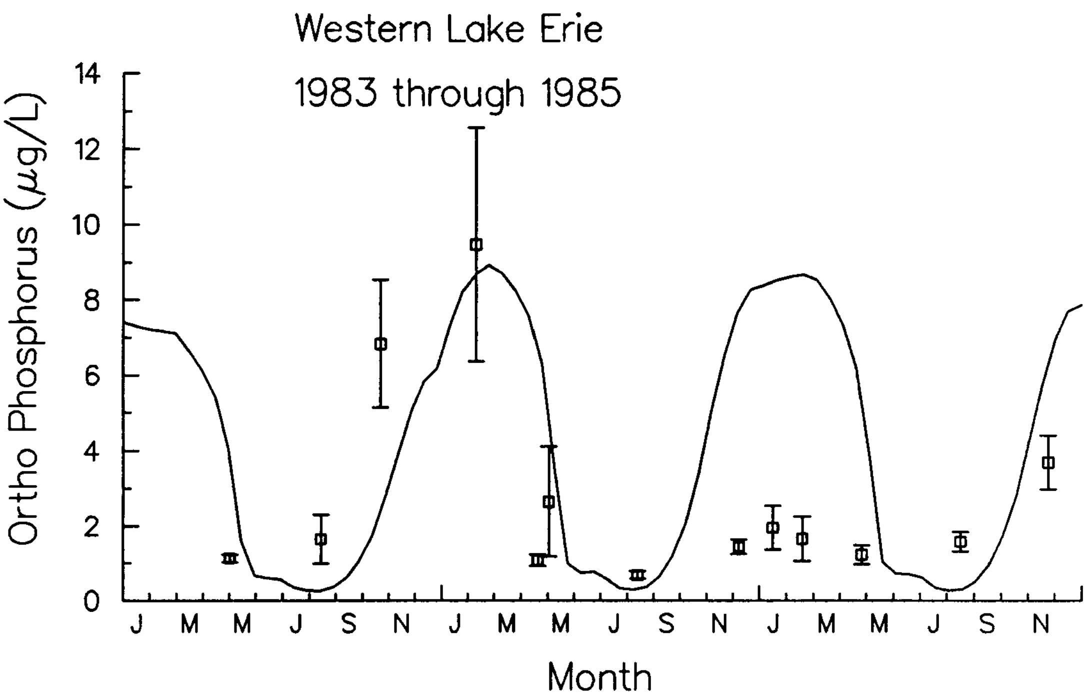


Figure 99. WASP model simulation of ortho phosphorus in western Lake Erie.

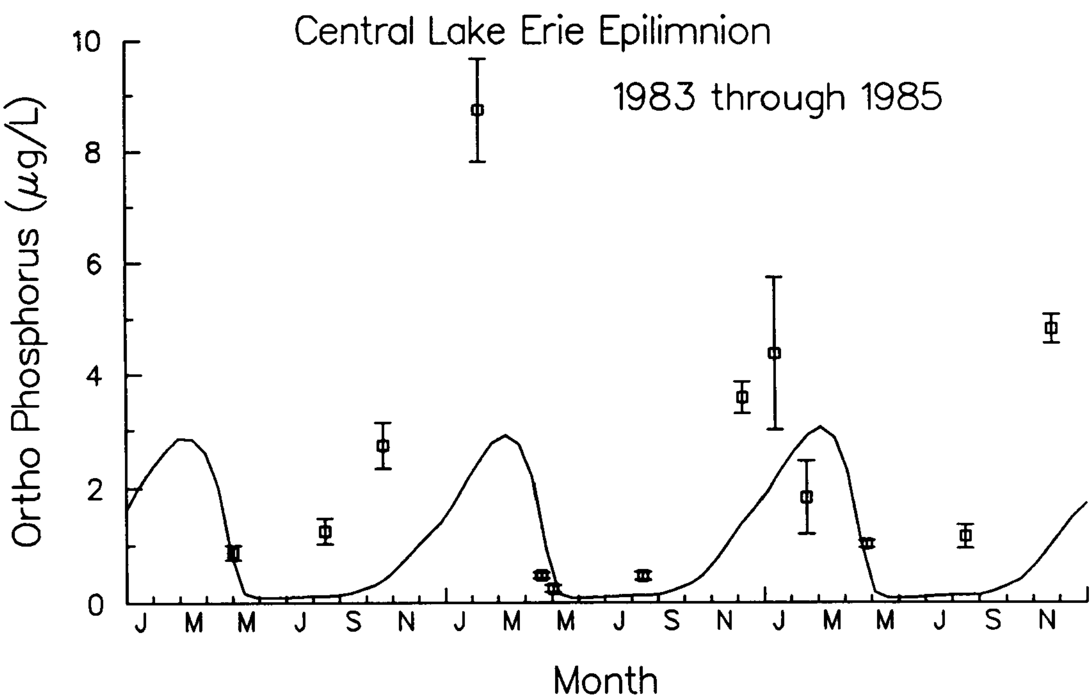


Figure 100. WASP model simulation of ortho phosphorus in the epilimnion of central Lake Erie.

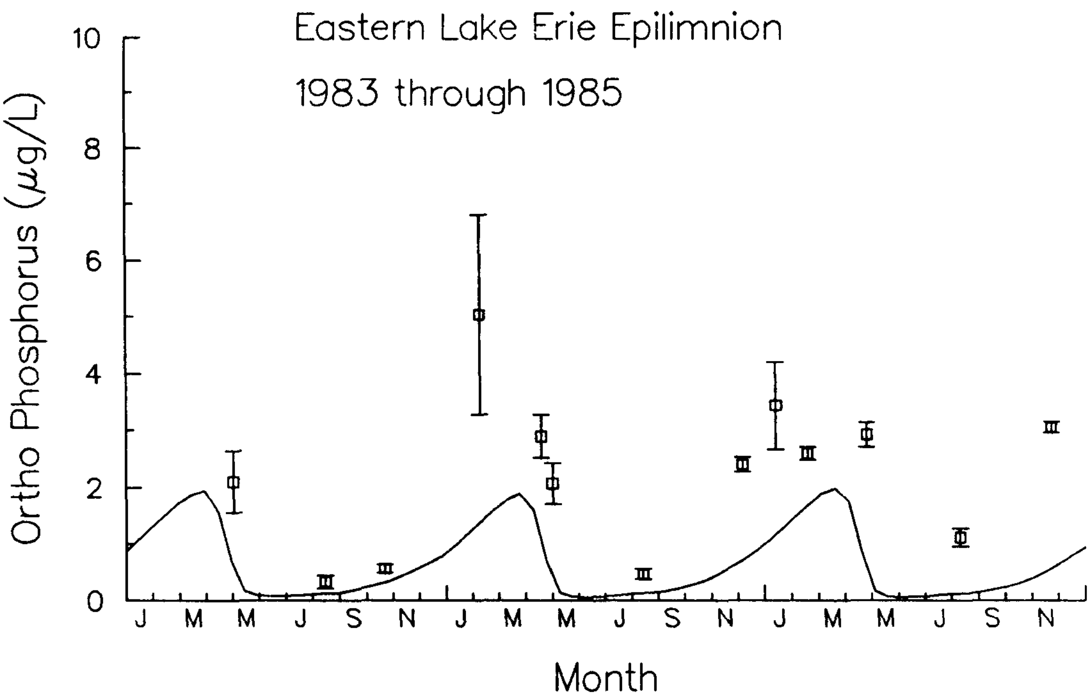


Figure 101. WASP model simulation of ortho phosphorus in the epilimnion of eastern Lake Erie.

oxygen concentrations are overpredicted by the model by about 1 mg/L. These discrepancies are important. However, by updating the environmental variables (i.e., temperature and dispersion) of the model or by resolving issues concerning chlorophyll-a production, these differences may be resolvable.

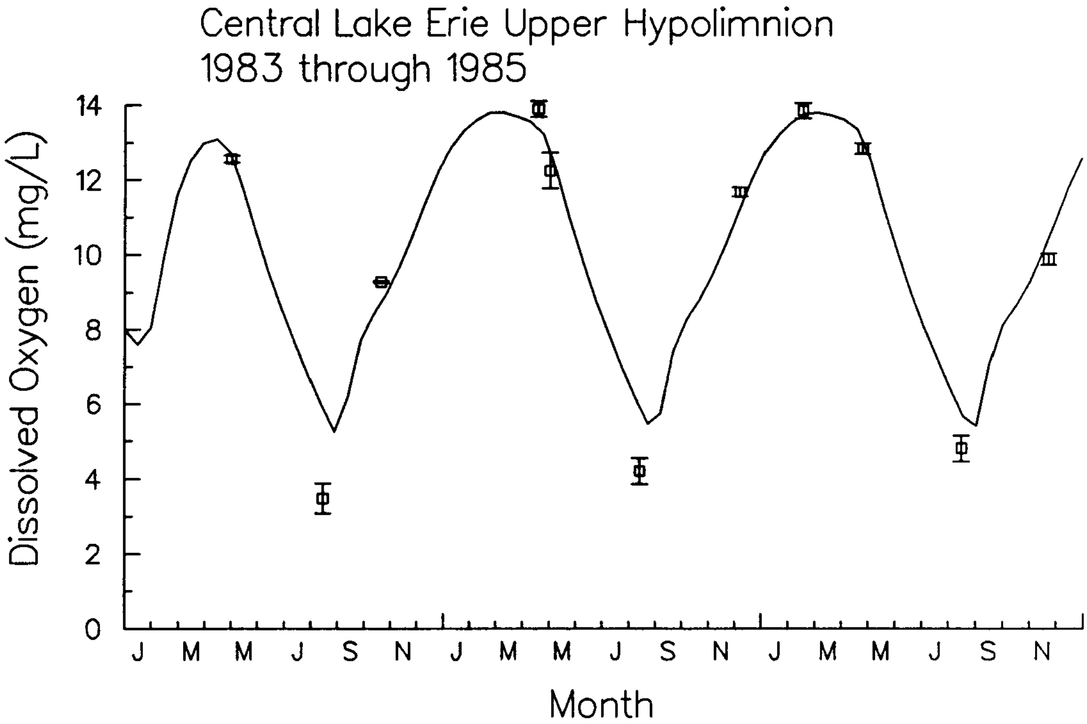


Figure 102. WASP model simulation of dissolved oxygen in the upper hypolimnion (17-22 meters) of central Lake Erie.

CONCLUSIONS AND RECOMMENDATIONS

The limited program of water-quality surveillance conducted by GLNPO in the open waters of Lakes Michigan, Huron, and Erie from 1983 through 1985 provides an alternative surveillance strategy to the five year program described in the original GLISP plan (IJC, 1975). Based on our analysis of the observations made in 1983 and 1984 we concluded that the conditions of three lakes have, in general, improved since the last GLISP intensive surveys. The data collected in 1985 show this trend to be continuing. Reanalysis of the data collected from Lakes Michigan and Huron during previous intensive survey years shows that the sampling scheme used from 1983 through 1985 would have provided representative values of the water-quality parameters measured in the open waters during those previous years. Thus, in terms of monitoring the quality of the open waters of Lakes Michigan, Huron, and Erie, the reduced sampling scheme used in 1983, 1984, and 1985 seems to provide adequate data. The disadvantage of losing the spatial and temporal detail provided by the intensive surveys is offset by the potential advantage of obtaining data annually for the evaluation of natural variances and trends.

Although many measurements of water quality in the lakes were unchanged from 1983 to 1985, the physical conditions, notably temperature, were much different between 1984 and 1985 than in 1983. While 1983 was a mild year, 1984 and 1985 were much colder. This difference had a significant impact on both the annual nutrient cycle and the results of the sampling program since colder spring waters delayed the onset of biological activity, especially in Lakes Huron and Michigan in 1984 and 1985. In addition, during 1985 the stratification for each lake spanned a longer period than in 1983 and 1984. Stratification in Lake Erie lasted 144 days, which is approximately 30% or 33 days longer than normal (Fay and Rathke, 1987).

Concentrations of total phosphorus continue below the IJC target concentrations in Lakes Michigan and Huron, and seem to be declining in Lake Erie. Nitrate + nitrite nitrogen concentrations, are consistently increasing in all three lakes. Chloride concentrations are increasing in

Lake Huron and northern Lake Michigan, but continue to decrease in Lake Erie. The chloride concentration in southern Lake Michigan was unchanged between 1984 and 1985. Chloride concentrations have consistently increased about 0.1 mg/L in prior years between 1963 to 1976 and 1983 to 1984 (Rockwell et al., 1980; Lesht and Rockwell, 1987).

The seasonal sampling program consisting of three ship-borne surveys per year does not provide sufficient temporal resolution within a year to evaluate the dynamics of the eutrophication models of the three lakes. The models are only moderately successful at predicting the 1983, 1984 and 1985 observations.

All three lakes exhibited a pattern of nutrient depletion from the epilimnion and concurrent enrichment of the hypolimnion during summer. However, in 1985 the magnitude of the depletion for some parameters was greater than that observed in 1983 and 1984. After stratification, all of the deeper basins showed evidence of a benthic nepheloid layer, a high turbidity region near the bottom having high concentrations of both dissolved and particulate nutrients.

Nutrient concentrations within the nepheloid layer were consistently higher than within the remainder of the hypolimnion, and the nepheloid layer persisted through the time of the last regular survey in the fall. The persistence of the nepheloid layer may imply active exchange between the surface sediments and the overlying water column.

The Great Lakes water-quality surveillance program represents a collective opportunity for both monitoring and limnological research. On the basis of the data collected so far, we present the following recommendations for future surveillance and surveillance-oriented research activities.

1. The open-lake water quality surveillance program should be continued on an annual basis. Data collected annually will be most valuable for evaluating annual water-quality trends and for establishing the magnitude of natural annual variations.

Furthermore, annual data are required for evaluation of the lake response to changes in loading levels.

2. The evaluation of water quality trends, a major surveillance objective of the Canada-United States Water Quality Agreement, depends critically on estimates of loadings to the lakes. Load estimates for phosphorus are required on a year-to-year basis for 1985-1986 and should be available (updated). Loading estimates should be refined, if possible, and expanded to include other substances in addition to phosphorus. Consistent changes in the amounts of nitrate + nitrate nitrogen, silica, and chloride in Lakes Michigan, Huron, and Erie, while not currently a problem, could be investigated further if an adequate mass balance database were available.

3. The role of the benthic nepheloid layer, and particle removal in general, on the cycling of nutrients in the Great Lakes should be studied. Data from the 1983 through 1985 surveys show that near-bottom waters act as reservoirs of nutrients that may be mixed into overlying waters during turnover.

4. Modeling efforts based both on simplistic mass-balance and dynamic eutrophication models should be continued. Historical simulations that include explicit year-to-year variation in such functions as water temperature and vertical and horizontal mixing should be attempted. Experiments in which the dynamic eutrophication models are restructured to provide a more realistic picture of particle behavior within both the epilimnion and nepheloid layer should be conducted. Field data with greater temporal resolution than the current three surveys per year will be required for any serious attempt to improve model performance.

5. Efforts should be continued to incorporate research activity and methodology into the surveillance program. The goal of both is a better understanding of the entire Great Lakes

system. No doubt, the performance of the models could be improved somewhat through a more vigorous modeling effort than performed herein. However, to improve the confidence and credibility of model results increased temporal resolution in field data is needed. Further, inconsistencies between surveillance data and mathematical model results emphasize the need to perform both types of research.

6. Comparison of the basin mean results of the Great Lakes Intensive Surveillance Program (GLISP) to those of the spatially-reduced GLNPO program reveals that the GLNPO program is as representative of Great Lakes water quality as the GLISP.

7. Comparison of the results of the GLISP to those of the temporally-reduced GLNPO program (three surveys/year vs. eight surveys/year in the GLISP) reveals that the GLNPO program is as representative of central and eastern Lake Erie annual total phosphorus concentrations as the GLISP.

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APPENDIX A

STATISTICAL SUMMARY OF SURVEY DATA[1]

The abbreviations and units used in Appendix A are:

ABBREVIATION	VARIABLE NAME	UNITS
W_TEMP	Water Temperature	Centigrade
TURBTY	Turbidity	Hach FTU
CHLOR_A	Chlorophyll-a	ug/L
PHPHT_A	Pheophytin-a	ug/L
PHOS_T	Total Phosphorus	mg-P/L
PHOS_D	Total Dissolved Phosphorus	mg-P/L
D_ORTH_P	Dissolved ortho Phosphorus	mg-P/L
NO2NO3T	Total Nitrate+Nitrite Nitrogen	mg-N/L
NH3NH4T	Total Ammonia Nitrogen	mg-N/L
KJEL_N	Total Kjeldahl Nitrogen	mg-N/L
DSICON	Dissolved Silicon	ug-Si/L
PH	pH	Standard
LAB_PH	Laboratory pH	Standard
T_ALK	Toatal Alkalinity	mg-$CaCO_3$/L
CNDUCT	Specific Conductance	uSiemen/cm
DO	Dissolved Oxygen	mg/L
CHLORDE	Chloride	mg/L
SULFATE	Total Sulfate	mg-SO_4/L
CA	Total Calcium	mg/L
MG	Total Magnesium	mg/L
NA	Total Sodium	mg/L
K	Total Potassium	mg/L
T_Count	Total Plate Count	#/mL

[1]Sorted by lake, basin, survey, and layer.

L MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---- BASIN=A_SOUTHERN SURVEY=A_WINTER2 LAYER=B_EPILIMNION ----						
W_TEMP	8	1.9500	0.4140	0 1464	1.2000	2.5000
TURBTY	0	.	.	.		.
CHLOR_A	8	0 7875	0 2276	0 0805	0 4800	1.1000
PHPHT_A	8	-0.0700	0 0849	0 0300	-0.2000	0 0500
PHOS_T	8	0 0058	0 0010	0 0004	0.0050	0 0079
PHOS_D	8	0 0047	0 0006	0 0002	0.0036	0 0055
D_ORTH_P	8	0.0026	0 0014	0.0005	0.0008	0 0047
NO2NO3T	8	0 2930	0 0035	0.0012	0 2870	0 2960
NH3NH4T	8	0 0045	0 0038	0 0013	0 0010	0 0110
KJEL_N	8	0.0962	0 0192	0 0068	0.0600	0 1200
DSICON	8	574 3750	29 2034	10 3250	538 0000	616.0000
PH	7	8 0471	0 0509	0 0192	8.0100	8 1600
LAB_PH	8	8 0212	0.0464	0 0164	7 9500	8.1100
T_ALK	8	109 4375	0.4955	0 1752	109.0000	110 5000
CNDUCT	8	281.6250	0 7440	0 2631	280 0000	282 0000
DO	8	12.7875	0.2264	0 0800	12 4000	13 1500
CHLORDE	8	10 0750	1.3414	0 4742	8.7000	11 4000
SULFATE	8	20 1000	2 2071	0 7803	17.7000	22 3000
CA	0	.	.		.	.
MG	0			.	.	
NA	0	.	.		.	.
K	0	.	.	.	.	.
T_COUNT	0	.			.	.
---- BASIN=A_SOUTHERN SURVEY=B_SPRING LAYER=B_EPILIMNION ----						
W_TEMP	62	2 5452	0 2805	0.0356	1.9000	3.1000
TURBTY	58	0 4018	0 1399	0 0184	0 1800	0.9550
CHLOR_A	62	0.9456	0.7268	0 0923	0.0000	2.5000
PHPHT_A	62	0 0495	0.0840	0.0107	-0.2000	0.2000
PHOS_T	62	0 0049	0 0008	0 0001	0 0034	0.0073
PHOS_D	61	0.0023	0 0008	0 0001	0 0015	0.0053
D_ORTH_P	61	0 0009	0 0005	0 0001	0 0000	0 0021
NO2NO3T	61	0 2851	0.0177	0 0023	0 2550	0.3320
NH3NH4T	62	0.0030	0.0033	0.0004	0.0000	0.0200
KJEL_N	62	0.1189	0.0467	0.0059	0.0400	0.3000
DSICON	61	564.9016	17.0506	2 1831	525.0000	594 0000
PH	62	8.1185	0.0754	0.0096	7.9300	8.2500
LAB_PH	0				.	.
T_ALK	62	108.4606	1.5148	0.1924	103.5000	112.0000
CNDUCT	62	279.9231	0 7971	0 1012	278.0000	281.5000
DO	12	12 4425	0 9497	0 2742	10.6000	13.2000
CHLORDE	62	8 6891	0.2454	0.0312	7.8000	9.4000
SULFATE	62	22.0427	0.7245	0.0920	20.9000	23.9000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0		.	.		.
T_COUNT	18	2 0000	1 1376	0.2681	1.0000	5.0000

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
--------- BASIN=A_SOUTHERN SURVEY=C_SUMMER LAYER=B_EPILIMNION ---------						
W_TEMP	43	20 6767	0 6342	0.0967	19.3000	21.9500
TURBTY	42	0.4815	0 1588	0.0245	0 2400	0 7900
CHLOR_A	43	1.1169	0.2173	0.0331	0 7000	1.6000
PHPHT_A	43	0.1907	0 1757	0.0268	-0.1000	0.6000
PHOS_T	43	0.0025	0 0008	0 0001	0.0007	0.0048
PHOS_D	43	0 0014	0.0008	0 0001	0.0005	0.0037
D_ORTH_P	43	0.0004	0 0005	0.0001	-0.0006	0.0019
NO2NO3T	43	0 1591	0.0161	0 0025	0 1340	0 1890
NH3NH4T	43	0.0023	0 0039	0 0006	-0.0010	0.0200
KJEL_N	43	0.2134	0 1047	0.0160	0 0500	0 6400
DSICON	43	97.1395	16 6699	2.5421	52 0000	130 0000
PH	43	8.5827	0.0553	0 0084	8 4300	8 6750
LAB_PH	0	.			.	
T_ALK	43	108.1337	0 8870	0 1353	106.5000	110 0000
CNDUCT	43	277.7151	1 8213	0.2777	274.0000	281.5000
DO	42	9.4530	0.7208	0.1112	8 2000	11 2000
CHLORDE	43	8 8215	0.3555	0 0542	8 0000	9.3000
SULFATE	43	21 7135	0.9364	0.1428	20 0000	23.3000
CA	18	36 0000	0.6860	0 1617	35 0000	37.0000
MG	18	11.1667	0 3835	0.0904	11.0000	12.0000
NA	18	5.4611	0 1290	0.0304	5.2000	5.6000
K	18	1.2283	0 0176	0 0041	1.2000	1 2600
T_COUNT	10	37.1000	21.6151	6 8353	11.0000	71.0000
--------- BASIN=A_SOUTHERN SURVEY=C_SUMMER LAYER=C_MESOLIMNION ---------						
W_TEMP	18	13.9222	1 7121	0.4035	11.3000	17 6000
TURBTY	18	0.4543	0.1457	0.0344	0.2500	0 7500
CHLOR_A	18	1 2306	0 3121	0.0736	0.8000	1 7000
PHPHT_A	18	0 2847	0 2516	0.0593	0.0000	0 9000
PHOS_T	18	0.0035	0 0011	0.0003	0.0008	0.0055
PHOS_D	18	0 0017	0 0010	0 0002	0.0005	0.0045
D_ORTH_P	16	0.0004	0 0003	0 0001	0 0000	0.0010
NO2NO3T	18	0.1936	0.0115	0 0027	0 1740	0.2090
NH3NH4T	18	0.0140	0 0084	0.0020	0.0040	0 0300
KJEL_N	18	0.2057	0 0613	0 0145	0.0900	0.3100
DSICON	18	110.1667	23 2107	5.4708	75 0000	162.0000
PH	18	8 4814	0 0911	0 0215	8.3100	8 6000
LAB_PH	0	.	.	.	.	.
T_ALK	18	108.6250	0.6766	0.1595	107.5000	109.5000
CNDUCT	18	279.4028	1.0611	0.2501	278.0000	281 2500
DO	18	11.8300	1.2257	0.2889	10.1000	14.6000
CHLORDE	18	8.7486	0.2483	0.0585	8.4000	9.2000
SULFATE	18	21.7517	0.9453	0.2228	20.2000	23.3000
CA	0		.	.	.	.
MG	0	.	.	.	.	.
NA	0		.	.	.	.
K	0	.	.	.	.	.
T_COUNT	1	190.0000	.		190.0000	190.0000

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=A_SOUTHERN SURVEY=C_SUMMER LAYER=D_HYPOLIMNION						
W_TEMP	34	4.9088	0.7473	0.1282	3.8000	7.0000
TURBTY	34	0.3167	0.1774	0.0304	0.0900	0.8100
CHLOR_A	34	1.0684	0.5871	0.1007	0.2000	3.2000
PHPHT_A	34	0.3662	0.2920	0.0501	0.0000	1.6000
PHOS_T	34	0.0035	0.0014	0.0002	0.0008	0.0078
PHOS_D	34	0.0016	0.0011	0.0002	0.0000	0.0055
D_ORTH_P	34	0.0006	0.0007	0.0001	-0.0003	0.0036
NO2NO3T	34	0.2742	0.0231	0.0040	0.2190	0.3220
NH3NH4T	34	0.0056	0.0051	0.0009	-0.0020	0.0170
KJEL_N	34	0.1706	0.0520	0.0089	0.0700	0.2900
DSICON	34	431.4706	203.9653	34.9798	135.0000	981.0000
PH	34	8.1612	0.0770	0.0132	8.0200	8.3700
LAB_PH	0	.	.			
T_ALK	34	108.4488	0.5437	0.0932	107.0000	109.5000
CNDUCT	34	281.3676	0.8101	0.1389	279.0000	283.0000
DO	34	12.2571	0.6804	0.1167	11.2000	14.0000
CHLORDE	34	8.6015	0.2739	0.0470	8.1000	9.2000
SULFATE	34	21.6141	0.8962	0.1537	19.6000	22.6000
CA	0	.			.	.
MG	0	.		.		.
NA	0			.	.	.
K	0	.		.	.	.
T_COUNT	4	94.7500	38.1171	19.0586	52.0000	140.0000
BASIN=A_SOUTHERN SURVEY=C_SUMMER LAYER=E_NEPHELOID						
W_TEMP	36	4.1278	0.2742	0.0457	3.8000	4.6000
TURBTY	35	0.8791	0.4536	0.0767	0.1020	2.1000
CHLOR_A	36	0.7056	0.3944	0.0657	0.2000	1.6000
PHPHT_A	36	0.3882	0.1747	0.0291	0.1000	0.8000
PHOS_T	36	0.0060	0.0032	0.0005	0.0028	0.0139
PHOS_D	36	0.0037	0.0027	0.0004	0.0003	0.0089
D_ORTH_P	36	0.0026	0.0022	0.0004	0.0000	0.0067
NO2NO3T	36	0.3160	0.0176	0.0029	0.2890	0.3720
NH3NH4T	35	0.0005	0.0011	0.0002	-0.0020	0.0040
KJEL_N	36	0.1600	0.0670	0.0112	0.0300	0.3500
DSICON	36	906.0556	298.4887	49.7481	509.0000	1530.0000
PH	36	8.0721	0.0622	0.0104	7.9500	8.1800
LAB_PH	0	.	.	.	.	
T_ALK	36	108.8753	0.7001	0.1167	107.5000	110.1300
CNDUCT	36	283.1319	0.9552	0.1592	281.7500	286.0000
DO	35	11.9197	0.8890	0.1503	10.1000	14.3000
CHLORDE	36	8.6174	0.2884	0.0481	8.1000	9.2000
SULFATE	35	21.7457	1.0526	0.1779	19.6000	24.2000
CA	18	36.3889	0.7775	0.1833	35.0000	38.0000
MG	18	11.0556	0.2357	0.0556	11.0000	12.0000
NA	18	5.2833	0.1043	0.0246	5.0000	5.4000
K	18	1.2311	0.0145	0.0034	1.2000	1.2600
T_COUNT	5	95.0000	56.6392	25.3298	34.0000	180.0000

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
--------------------- BASIN=A_SOUTHERN SURVEY=D_FALL1 LAYER=B_EPILIMNION ---------------------						
W_TEMP	20	8.3100	1.0010	0.2238	6.4000	9.3000
TURBTY	20	0.2474	0.1137	0.0254	0.1400	0.6600
CHLOR_A	20	0.5587	0.1776	0.0397	0.2000	0.9000
PHPHT_A	20	0.1637	0.1128	0.0252	-0.1000	0.3000
PHOS_T	20	0.0040	0.0011	0.0003	0.0014	0.0056
PHOS_D	20	0.0024	0.0009	0.0002	0.0010	0.0038
D_ORTH_P	20	0.0002	0.0002	0.0001	0.0000	0.0006
NO2NO3T	20	0.2489	0.0168	0.0038	0.2250	0.2740
NH3NH4T	20	0.0024	0.0011	0.0002	0.0010	0.0041
KJEL_N	20	0.1680	0.0663	0.0148	0.0800	0.2800
DSICON	20	388.9500	45.9983	10.2855	312.0000	506.0000
PH	20	8.3389	0.0363	0.0081	8.2900	8.4100
LAB_PH	0	.	.	.	.	.
T_ALK	20	107.0175	0.7096	0.1587	105.5000	108.5000
CNDUCT	20	281.9815	0.8370	0.1872	280.8799	284.0000
DO	20	9.8612	0.2852	0.0638	9.3000	10.3000
CHLORDE	20	9.0362	0.2767	0.0619	8.4000	9.5000
SULFATE	20	22.0090	0.6005	0.1343	21.1000	23.4000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	13	27.9231	18.8656	5.2324	6.0000	65.0000
--------------------- BASIN=A_SOUTHERN SURVEY=D_FALL1 LAYER=C_MESOLIMNION ---------------------						
W_TEMP	5	6.7400	0.5683	0.2542	6.0000	7.3000
TURBTY	5	0.3195	0.1993	0.0891	0.1775	0.6400
CHLOR_A	5	0.2250	0.0433	0.0194	0.2000	0.3000
PHPHT_A	5	0.1000	0.1225	0.0548	0.0000	0.3000
PHOS_T	5	0.0027	0.0006	0.0003	0.0018	0.0034
PHOS_D	5	0.0015	0.0006	0.0002	0.0009	0.0024
D_ORTH_P	5	0.0006	0.0007	0.0003	0.0000	0.0017
NO2NO3T	5	0.2894	0.0084	0.0037	0.2840	0.3030
NH3NH4T	5	0.0014	0.0008	0.0004	0.0010	0.0029
KJEL_N	5	0.1860	0.0647	0.0289	0.1000	0.2800
DSICON	5	509.2000	83.0855	37.1570	415.0000	644.0000
PH	5	8.1930	0.0396	0.0177	8.1550	8.2600
LAB_PH	0	.	.	.	.	.
T_ALK	5	107.0400	1.3069	0.5845	105.0000	108.5000
CNDUCT	5	283.0500	0.4472	0.2000	282.5000	283.5000
DO	5	10.0700	0.4894	0.2189	9.4000	10.7500
CHLORDE	5	8.9400	0.4037	0.1806	8.4000	9.5000
SULFATE	5	21.5600	1.5710	0.7026	18.8000	22.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=A_SOUTHERN SURVEY=D_FALL1 LAYER=D_HYPOLIMNION						
W_TEMP	7	4.6857	0.5786	0.2187	4.0000	5.6000
TURBTY	7	0.3021	0.1636	0.0618	0.1600	0.5400
CHLOR_A	7	0.1286	0.0488	0.0184	0.1000	0.2000
PHPHT_A	7	0.0643	0.0852	0.0322	-0.1000	0.1500
PHOS_T	7	0.0034	0.0024	0.0009	0.0014	0.0084
PHOS_D	7	0.0021	0.0015	0.0006	0.0007	0.0050
D_ORTH_P	7	0.0008	0.0010	0.0004	0.0000	0.0024
NO2NO3T	7	0.3100	0.0186	0.0070	0.2840	0.3360
NH3NH4T	7	0.0033	0.0050	0.0019	0.0010	0.0145
KJEL_N	7	0.2071	0.1626	0.0614	0.0600	0.5500
DSICON	7	669.2857	150.0330	56.7071	415.0000	809.0000
PH	7	8.1436	0.0293	0.0111	8.1100	8.1850
LAB_PH	0	.	.	.	.	.
T_ALK	7	107.8071	1.0537	0.3983	106.0000	109.0000
CNDUCT	7	283.3214	0.8746	0.3306	281.5000	284.0000
DO	7	10.4143	0.5984	0.2262	9.5000	11.2000
CHLORDE	7	8.9786	0.3510	0.1327	8.4000	9.5000
SULFATE	7	21.8000	1.3952	0.5273	18.8000	22.8000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	5	47.2000	24.6313	11.0154	7.0000	74.0000
BASIN=A_SOUTHERN SURVEY=D_FALL1 LAYER=E_NEPHELOID						
W_TEMP	11	4.3091	0.2663	0.0803	4.0000	4.6000
TURBTY	11	0.8918	0.4622	0.1394	0.4800	2.1100
CHLOR_A	11	0.0886	0.0540	0.0163	0.0000	0.2000
PHPHT_A	11	0.1318	0.0956	0.0288	0.0000	0.3000
PHOS_T	11	0.0049	0.0024	0.0007	0.0016	0.0093
PHOS_D	11	0.0033	0.0015	0.0005	0.0011	0.0052
D_ORTH_P	11	0.0026	0.0021	0.0006	0.0003	0.0060
NO2NO3T	11	0.3314	0.0188	0.0057	0.3080	0.3570
NH3NH4T	11	0.0010	0.0008	0.0002	0.0000	0.0021
KJEL_N	11	0.2230	0.1830	0.0552	0.0700	0.7300
DSICON	11	935.2727	138.0160	41.6134	731.0000	1151.0000
PH	11	8.0891	0.0474	0.0143	8.0100	8.1700
LAB_PH	0	.	.	.	.	.
T_ALK	11	108.2527	0.7591	0.2289	107.0000	109.5000
CNDUCT	11	284.7727	0.5641	0.1701	283.5000	285.5000
DO	11	9.9755	0.3636	0.1096	9.3000	10.3300
CHLORDE	11	9.0818	0.4792	0.1445	8.4000	10.0000
SULFATE	11	21.9091	0.5431	0.1637	21.2000	22.7000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	6	76.8333	73.2186	29.8914	6.0000	210.0000

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

--------------------- BASIN=A_SOUTHERN SURVEY=D_FALL2 LAYER=B_EPILIMNION ---------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	36	5.4361	0.3826	0.0638	4.6000	6.0000
TURBTY	36	0.4493	0.1691	0.0282	0.2800	0.8450
CHLOR_A	35	0.3186	0.0856	0.0145	0.2000	0.4500
PHPHT_A	35	0.0979	0.0573	0.0097	0.0000	0.3000
PHOS_T	36	0.0055	0.0007	0.0001	0.0044	0.0077
PHOS_D	36	0.0028	0.0007	0.0001	0.0019	0.0052
D_ORTH_P	36	-0.0000	0.0001	0.0000	-0.0003	0.0000
NO2NO3T	36	0.2897	0.0197	0.0033	0.2530	0.3190
NH3NH4T	36	0.0012	0.0003	0.0001	0.0008	0.0020
KJEL_N	36	0.0672	0.0524	0.0087	-0.0500	0.1700
DSICON	36	609.5833	85.0282	14.1714	484.0000	803.0000
PH	36	8.1206	0.0536	0.0089	8.0300	8.2300
LAB_PH	0	.	.	.	.	.
T_ALK	36	107.6844	1.1458	0.1910	106.0000	109.1300
CNDUCT	36	279.6100	1.4112	0.2352	277 0000	282.0000
DO	31	11.3739	0.2191	0.0393	11.0000	11.7000
CHLORDE	36	8.6910	0.0930	0.0155	8.5000	8.9000
SULFATE	36	23.1530	0.4650	0.0775	22.3000	24.1000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

--------------------- BASIN=B_NORTHERN SURVEY=A_WINTER2 LAYER=B_EPILIMNION ---------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	6	1.5417	1.3078	0.5339	0.0000	3.0000
TURBTY	0	.	.	.	.	.
CHLOR_A	6	0.8900	0.4402	0.1797	0.3500	1.4900
PHPHT_A	6	-0.1200	0.0447	0.0183	-0.1800	-0.0700
PHOS_T	6	0.0056	0.0015	0.0006	0.0045	0.0086
PHOS_D	6	0.0041	0.0004	0.0002	0.0036	0.0046
D_ORTH_P	6	0.0018	0.0014	0.0006	0.0005	0.0043
NO2NO3T	6	0.2905	0.0260	0.0106	0.2550	0.3190
NH3NH4T	5	0.0044	0.0011	0.0005	0.0030	0.0060
KJEL_N	6	0.2000	0.0982	0.0401	0.1100	0.3200
DSICON	6	545.1667	37.2474	15.2062	492.0000	590.0000
PH	4	8.0275	0.0574	0.0287	7.9500	8.0800
LAB_PH	6	8.0067	0.0520	0.0212	7.9100	8.0600
T_ALK	6	109.5000	1.0000	0.4082	108.5000	111.0000
CNDUCT	6	283.5000	2.8810	1.1762	280.0000	287.0000
DO	6	12.8417	0.7406	0.3023	12.1000	14.0000
CHLORDE	6	8.9667	0.1506	0.0615	8.8000	9.2000
SULFATE	6	22.4167	0.6706	0.2738	21.6000	23.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------- BASIN=B_NORTHERN SURVEY=B_SPRING LAYER=B_EPILIMNION ----------						
W_TEMP	62	2.5202	0.2417	0.0307	2.1000	3.0000
TURBTY	62	0.3396	0.2873	0.0365	0.1200	2.3700
CHLOR_A	62	0.7474	0.9373	0.1190	0.0000	5.5000
PHPHT_A	62	-0.0088	0.2548	0.0324	-1.5000	0.2000
PHOS_T	62	0.0052	0.0022	0.0003	0.0031	0.0161
PHOS_D	62	0.0028	0.0011	0.0001	0.0014	0.0054
D_ORTH_P	62	0.0009	0.0006	0.0001	0.0000	0.0028
NO2NO3T	62	0.2863	0.0152	0.0019	0.2610	0.3190
NH3NH4T	62	0.0016	0.0009	0.0001	0.0000	0.0040
KJEL_N	62	0.0805	0.0493	0.0063	0.0100	0.2400
DSICON	62	562.8387	49.9637	6.3454	494.0000	752.0000
PH	62	8.1691	0.0632	0.0080	8.0100	8.2800
LAB_PH	0	.	.			
T_ALK	62	107.9210	1.4409	0.1830	105.0000	111.0000
CNDUCT	62	279.7790	0.8799	0.1117	278.0000	281.5000
DO	10	12.7370	0.4822	0.1525	11.9000	13.7400
CHLORDE	62	8.8363	0.3100	0.0394	8.4000	9.8000
SULFATE	62	22.3456	0.3625	0.0460	21.4000	23.1000
CA	0	.	.	.	.	.
MG	0		.	.	.	.
NA	0	.	.		.	.
K	0	.	.	.	.	.
T_COUNT	19	1.4211	0.6070	0.1393	1.0000	3.0000
---------- BASIN=B_NORTHERN SURVEY=C_SUMMER LAYER=B_EPILIMNION ----------						
W_TEMP	33	18.4848	1.1603	0.2020	15.2000	19.7000
TURBTY	33	0.3588	0.1742	0.0303	0.1600	0.8400
CHLOR_A	33	0.9955	0.2879	0.0501	0.6000	1.6000
PHPHT_A	33	0.1227	0.1587	0.0276	-0.1000	0.5000
PHOS_T	33	0.0045	0.0036	0.0006	0.0020	0.0191
PHOS_D	32	0.0012	0.0006	0.0001	-0.0003	0.0026
D_ORTH_P	31	0.0004	0.0005	0.0001	-0.0003	0.0016
NO2NO3T	33	0.1556	0.0166	0.0029	0.1340	0.1895
NH3NH4T	33	0.0036	0.0027	0.0005	0.0010	0.0120
KJEL_N	33	0.1837	0.0617	0.0107	0.0200	0.3800
DSICON	33	92.8788	22.1638	3.8582	57.0000	163.0000
PH	33	8.5444	0.0580	0.0101	8.4500	8.6700
LAB_PH	0	.	.	.	.	.
T_ALK	32	108.0353	0.7330	0.1296	107.0000	109.5000
CNDUCT	33	276.5606	1.3521	0.2354	274.0000	279.0000
DO	33	9.9202	0.6913	0.1203	9.1000	11.8000
CHLORDE	33	8.5561	0.3132	0.0545	7.9000	9.0000
SULFATE	33	21.5751	0.4922	0.0857	20.7000	23.2000
CA	15	35.2000	0.7746	0.2000	34.0000	36.0000
MG	15	11.0000	0.0000	0.0000	11.0000	11.0000
NA	15	5.3733	0.0961	0.0748	5.2000	5.5000
K	15	1.2073	0.0139	0.0036	1.1900	1.2300
T_COUNT	10	101.5000	56.3979	17.8346	26.0000	200.0000

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=B_NORTHERN SURVEY=C_SUMMER LAYER=C_MESOLIMNION						
W_TEMP	15	12.3067	2.0748	0.5357	6.6000	14.6000
TURBTY	15	0.2850	0.1354	0.0350	0.1600	0.7000
CHLOR_A	15	1.3200	0.3707	0.0957	0.7000	2.1000
PHPHT_A	15	0.3000	0.1852	0.0478	0.1000	0.7000
PHOS_T	15	0.0056	0.0047	0.0012	0.0018	0.0221
PHOS_D	15	0.0013	0.0007	0.0002	0.0005	0 0027
D_ORTH_P	15	0.0006	0.0005	0.0001	-0.0003	0.0013
NO2NO3T	15	0.1958	0 0130	0.0034	0.1770	0.2240
NH3NH4T	15	0.0099	0.0073	0.0019	0.0000	0.0270
KJEL_N	15	0.1773	0.0597	0.0154	0.1200	0.3500
DSICON	15	144.9333	69.2732	17.8863	47.0000	275.0000
PH	15	8.4510	0.0771	0.0199	8.3300	8.5800
LAB_PH	0	.	.	.	.	.
T_ALK	15	108.4167	0.7420	0.1916	107 0000	109 7500
CNDUCT	15	279.0000	1.0177	0.2628	277.0000	281 0000
DO	14	12.2929	0.6810	0.1820	11.3000	13.5000
CHLORDE	15	8.5300	0.3116	0.0804	7.9000	8.9000
SULFATE	15	21.8333	0 5551	0.1433	20.7000	23.2000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.
BASIN=B_NORTHERN SURVEY=C_SUMMER LAYER=D_HYPOLIMNION						
W_TEMP	37	4.4892	0.5577	0.0917	3.8000	5.7000
TURBTY	37	0.2002	0.0992	0.0163	0.1000	0.5700
CHLOR_A	37	0.7365	0.7260	0.1193	0.1000	3.2000
PHPHT_A	37	0.2378	0.2073	0.0341	0.0000	1.0000
PHOS_T	37	0.0034	0.0016	0.0003	0.0015	0.0096
PHOS_D	36	0.0016	0.0010	0.0002	0.0000	0.0050
D_ORTH_P	37	0.0009	0.0007	0.0001	-0.0003	0.0022
NO2NO3T	37	0.2827	0.0155	0.0025	0.2480	0.3210
NH3NH4T	37	0.0035	0.0049	0.0008	-0.0010	0.0200
KJEL_N	37	0.1274	0.0441	0.0072	0.0300	0.2200
DSICON	37	420.1892	97.1559	15.9723	249.0000	592.0000
PH	37	8.1802	0.0378	0.0062	8.0900	8.2700
LAB_PH	0	.	.	.	.	.
T_ALK	37	108.3378	0.7822	0.1286	107.0000	110.0000
CNDUCT	37	281.4324	0.7920	0.1302	279.0000	283.0000
DO	37	12.5730	0.5146	0.0846	11.4000	13.4000
CHLORDE	37	8.5304	0.3174	0.0522	7.9000	8.9000
SULFATE	37	21.9973	0.4356	0.0716	20.9000	23.2000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	5	129 4000	85.2690	38.1334	48.0000	240.0000

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=B_NORTHERN SURVEY=C_SUMMER LAYER=E_NEPHELOID						
W_TEMP	30	3.8367	0.1351	0.0247	3.7000	4.2000
TURBTY	30	0.7544	0.2676	0.0489	0.1200	1.4400
CHLOR_A	30	0.4397	0.2641	0.0482	0.2000	1.3000
PHPHT_A	30	0.2847	0.1182	0.0216	0.1000	0.6500
PHOS_T	30	0.0080	0.0023	0.0004	0.0017	0.0139
PHOS_D	30	0.0058	0.0023	0.0004	0.0012	0.0104
D_ORTH_P	30	0.0040	0.0026	0.0005	-0.0019	0.0099
NO2NO3T	30	0.3137	0.0146	0.0027	0.2797	0.3460
NH3NH4T	30	0.0010	0.0017	0.0003	-0.0005	0.0070
KJEL_N	30	0.1322	0 0560	0.0102	0.0200	0.2800
DSICON	30	1003.6000	198.7535	36.2873	723.0000	1476.0000
PH	30	8.0770	0.0585	0.0107	7.8900	8.1700
LAB_PH	0	.	.	.	.	.
T_ALK	30	108.9673	0.7019	0 1281	108.0000	110.0000
CNDUCT	30	283.0753	1.1051	0.2018	280.0000	285.0000
DO	30	11.9483	0.6355	0.1160	10.3000	12.9000
CHLORDE	30	8.4992	0.3291	0.0601	7.9000	8.9000
SULFATE	30	22.0483	0.5051	0.0922	20.9000	23.0000
CA	15	35 9333	0.7037	0.1817	35.0000	37 0000
MG	15	11.0220	0.0852	0.0220	11.0000	11.3300
NA	15	5.3933	0.1163	0.0300	5.2000	5.6000
K	15	1.2278	0.0197	0.0051	1.2100	1.2800
T_COUNT	5	99.8000	83.0193	37.1273	19.0000	230.0000
BASIN=B_NORTHERN SURVEY=D_FALL1 LAYER=B_EPILIMNION						
W_TEMP	14	8.1357	0.9716	0.2597	7.3000	9.9000
TURBTY	14	0.2295	0 0400	0.0107	0.1800	0.3400
CHLOR_A	14	0.7804	0.2333	0.0624	0 3000	1.1000
PHPHT_A	14	0.2304	0.0810	0.0216	0.1000	0.3000
PHOS_T	14	0.0032	0.0005	0.0001	0.0019	0.0039
PHOS_D	14	0.0021	0.0007	0.0002	0.0007	0.0032
D_ORTH_P	14	-0.0003	0.0005	0.0001	-0.0011	0 0005
NO2NO3T	14	0.2321	0.0158	0.0042	0.2000	0.2530
NH3NH4T	14	0.0014	0.0009	0.0002	0.0000	0.0030
KJEL_N	14	0.1025	0.0346	0.0092	0.0400	0.1700
DSICON	14	337.5714	40.6991	10.8773	258.0000	378.0000
PH	14	8.3587	0.0266	0.0071	8.3100	8.4200
LAB_PH	0	.	.	.	.	.
T_ALK	14	107.2364	0.3550	0.0949	106.8800	108.0000
CNDUCT	14	281.0536	1.1015	0.2944	279.2500	283.0000
DO	14	10 8275	0.6945	0.1856	9.5000	11.5000
CHLORDE	14	8.5857	0.0641	0.0171	8.5000	8.7000
SULFATE	14	21.7143	0.3207	0.0857	21.1000	22.3000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	10	16.9000	19.3129	6.1073	3.0000	64.0000

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
-------------------- BASIN=B_NORTHERN SURVEY=D_FALL1 LAYER=C_MESOLIMNION --------------------						
W_TEMP	5	6.6400	0.5899	0.2638	6.1000	7.5000
TURBTY	5	0.1940	0.0182	0.0081	0.1700	0.2100
CHLOR_A	5	0.1400	0.0548	0.0245	0.1000	0.2000
PHPHT_A	5	0.1200	0.0447	0.0200	0.1000	0.2000
PHOS_T	5	0.0022	0.0010	0.0004	0.0006	0.0033
PHOS_D	5	0.0018	0.0006	0.0003	0.0009	0.0026
D_ORTH_P	5	-0.0003	0.0005	0.0002	-0.0011	0.0000
NO2NO3T	5	0.2790	0.0095	0.0042	0.2720	0.2950
NH3NH4T	5	0.0008	0.0004	0.0002	0.0000	0.0010
KJEL_N	5	0.1120	0.0277	0.0124	0.0800	0.1500
DSICON	5	409.2000	50.5094	22.5885	337.0000	460.0000
PH	5	8.2040	0.0329	0.0147	8.1500	8.2400
LAB_PH	0	.	.	.	.	.
T_ALK	5	107.4400	0.4929	0.2205	107.0000	108.2000
CNDUCT	5	282.8000	0.7583	0.3391	282.0000	284.0000
DO	5	11.0100	0.8806	0.3938	9.8500	11.8000
CHLORDE	5	8.5800	0.1095	0.0490	8.5000	8.7000
SULFATE	5	21.8400	0.1817	0.0812	21.6000	22.0000
CA	0	.	.		.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.
-------------------- BASIN=B_NORTHERN SURVEY=D_FALL1 LAYER=D_HYPOLIMNION --------------------						
W_TEMP	10	4.3300	0.3974	0.1257	3.8000	5.0000
TURBTY	10	0.1975	0.0544	0.0172	0.1500	0.3325
CHLOR_A	10	0.0500	0.0486	0.0154	0.0000	0.1000
PHPHT_A	10	0.1050	0.0919	0.0291	0.0000	0.3000
PHOS_T	10	0.0033	0.0010	0.0003	0.0019	0.0047
PHOS_D	10	0.0032	0.0013	0.0004	0.0016	0.0061
D_ORTH_P	10	0.0014	0.0010	0.0003	0.0003	0.0033
NO2NO3T	10	0.2931	0.0074	0.0023	0.2847	0.3022
NH3NH4T	10	0.0006	0.0008	0.0003	0.0000	0.0020
KJEL_N	10	0.0737	0.0557	0.0176	-0.0600	0.1300
DSICON	10	588.5000	158.9530	50.2654	409.0000	938.0000
PH	10	8.1780	0.0346	0.0109	8.0900	8.2100
LAB_PH	0	.	.	.	.	.
T_ALK	10	107.7930	0.6773	0.2142	106.5000	109.0000
CNDUCT	10	283.0630	1.1039	0.3491	281.0000	284.5000
DO	10	11.4410	0.7921	0.2505	10.4000	12.3000
CHLORDE	10	8.5825	0.0817	0.0258	8.4500	8.7000
SULFATE	10	21.9800	0.1398	0.0442	21.8000	22.2000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	1	20.0000	.	.	20.0000	20.0000

L MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------- BASIN=B_NORTHERN SURVEY=D_FALL1 LAYER=E_NEPHELOID ----------						
W_TEMP	10	3.9400	0.1430	0.0452	3.8000	4.1000
TURBTY	10	0.8380	0.3517	0.1112	0.4500	1.6500
CHLOR_A	10	0.0800	0.0632	0.0200	0.0000	0 2000
PHPHT_A	10	0.2700	0.2163	0.0684	0.1000	0.8000
PHOS_T	10	0 0090	0.0017	0 0005	0.0072	0.0130
PHOS_D	10	0.0069	0.0015	0.0005	0.0048	0.0092
D_ORTH_P	10	0.0042	0 0009	0.0003	0.0031	0.0061
NO2NO3T	10	0.3109	0.0128	0.0040	0.2900	0.3310
NH3NH4T	10	0 0010	0.0008	0 0003	0.0000	0.0020
KJEL_N	10	0.1070	0.1431	0.0452	0.0200	0.5000
DSICON	10	1162 5000	188.2824	59.5401	771.0000	1384.0000
PH	10	8.1030	0.0365	0.0116	8.0400	8.1600
LAB_PH	0		.	.	.	.
T_ALK	10	108.5100	0.7767	0.2456	107.8000	110 0000
CNDUCT	10	284 9500	0.7619	0.2409	284.0000	286.5000
DO	10	10 8150	0.8124	0 2569	9.6000	11.8000
CHLORDE	10	8 5750	0.0425	0.0134	8 5000	8.6000
SULFATE	10	21 7400	0.5562	0.1759	20.6000	22.5000
CA	0	.	.	.	.	.
MG	0	.	.	.		.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	9	16.4444	18.7424	6.2475	3.0000	60.0000
---------- BASIN=B_NORTHERN SURVEY=D_FALL2 LAYER=B_EPILIMNION ----------						
W_TEMP	15	6.5000	0.5182	0 1338	5 8000	7.2000
TURBTY	15	0.2567	0.0966	0.0249	0.1500	0.4800
CHLOR_A	15	0 3200	0.1373	0 0355	0.2000	0.6000
PHPHT A	15	0 1067	0.0704	0.0182	0.0000	0 2000
PHOS_T	15	0.0043	0 0009	0 0002	0.0032	0.0064
PHOS_D	15	0.0030	0.0004	0 0001	0.0024	0.0036
D_ORTH_P	15	0 0004	0.0004	0.0001	-0.0003	0.0013
NO2NO3T	15	0.2464	0.0322	0.0083	0.1500	0.2800
NH3NH4T	15	0.0015	0.0004	0.0001	0.0007	0.0021
KJEL_N	15	0.0467	0.0763	0 0197	-0.0600	0.2700
DSICON	15	410 4000	63.7246	16 4536	353.0000	541.0000
PH	15	8.1867	0.0516	0.0133	8.1200	8.2900
LAB_PH	0	.	.	.	.	.
T_ALK	15	107.0833	0.7260	0.1874	105.8000	108.0000
CNDUCT	15	278 7266	1.7056	0.4404	275.5000	280.5000
DO	10	12.0180	0.5074	0.1605	11.5000	12.8000
CHLORDE	15	8.8667	0.1397	0.0361	8.5000	9 1000
SULFATE	15	21.7767	0.4460	0.1151	21.0000	22.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

---------------------- BASIN=B_NORTHERN SURVEY=D_FALL2 LAYER=C_MESOLIMNION ----------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	5	5.2000	0.3317	0.1483	4.9000	5.6000
TURBTY	5	0.3230	0.1789	0.0800	0.1600	0.6200
CHLOR_A	5	0.1300	0.0975	0.0436	0.0000	0.2500
PHPHT_A	5	0.0900	0.0742	0.0332	0.0000	0.2000
PHOS_T	5	0.0044	0.0011	0.0005	0.0029	0.0057
PHOS_D	5	0.0040	0.0006	0.0003	0.0033	0.0048
D_ORTH_P	5	0.0010	0.0004	0.0002	0.0008	0.0018
NO2NO3T	5	0.2763	0.0139	0.0062	0.2590	0.2960
NH3NH4T	5	0.0015	0.0004	0.0002	0.0007	0.0018
KJEL_N	5	0.0730	0.0455	0.0203	0.0100	0.1300
DSICON	5	623 8000	219.7150	98.2596	457.0000	1008.0000
PH	5	8.1620	0.1425	0.0637	8.0200	8.4000
LAB_PH	0	.	.	.	.	.
T_ALK	5	107.0360	1.3283	0.5941	105.3800	108.0000
CNDUCT	5	279.6260	1.4831	0.6632	278.0000	281.0000
DO	4	12.2450	0.6471	0.3236	11.5800	12.8000
CHLORDE	5	8.8800	0.1304	0.0583	8.8000	9.1000
SULFATE	5	21.9060	0.6436	0.2878	21.1000	22.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

---------------------- BASIN=B_NORTHERN SURVEY=D_FALL2 LAYER=D_HYPOLIMNION ----------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	7	4.1571	0.4036	0.1525	3.8000	5.0000
TURBTY	7	0.3411	0.1924	0.0727	0.1100	0.7100
CHLOR_A	7	0.0429	0.0535	0.0202	0.0000	0.1000
PHPHT_A	7	0.0643	0.0476	0.0180	0.0000	0.1000
PHOS_T	7	0.0064	0.0013	0.0005	0.0038	0.0082
PHOS_D	7	0.0056	0.0009	0.0003	0.0043	0.0071
D_ORTH_P	7	0.0026	0.0010	0.0004	0.0014	0.0039
NO2NO3T	7	0.2886	0.0149	0.0056	0.2620	0.3050
NH3NH4T	7	0.0012	0.0002	0.0001	0.0010	0.0016
KJEL_N	7	0.0461	0.0196	0.0074	0.0200	0 0800
DSICON	7	765.8571	164.9843	62.3582	499.0000	982.0000
PH	7	8.1636	0.1907	0.0721	7.9800	8.5250
LAB_PH	0	.	.	.	.	.
T_ALK	7	107.6614	1.2427	0.4697	105.0000	109.0000
CNDUCT	7	281.2828	1.5627	0.5907	279.0000	283.0000
DO	5	12.1760	0.5717	0.2557	11.6000	12.8000
CHLORDE	7	8.8929	0.1018	0.0385	8.8000	9.1000
SULFATE	7	21.8686	0.3876	0.1465	21.5000	22.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. MICHIGAN DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------- BASIN=B_NORTHERN SURVEY=D_FALL2 LAYER=E_NEPHELOID ----------						
W_TEMP	10	4.1500	0.3951	0.1249	3 8000	4 9000
TURBTY	10	0.7390	0.4158	0.1315	0.2800	1.8000
CHLOR_A	10	0.0650	0.0459	0.0145	0.0000	0.1000
PHPHT_A	10	0.1000	0.0635	0.0201	0.0000	0.2000
PHOS_T	10	0.0083	0.0012	0.0004	0.0071	0 0117
PHOS_D	10	0.0069	0.0012	0.0004	0.0047	0.0084
D_ORTH_P	10	0.0035	0.0012	0.0004	0.0016	0.0055
NO2NO3T	10	0.2948	0.0130	0.0041	0.2720	0.3075
NH3NH4T	10	0.0014	0 0004	0.0001	0.0008	0.0021
KJEL_N	10	0.0262	0.0403	0.0127	-0.0300	0.0700
DSICON	10	922.7000	105.6746	33.4172	723.0000	1003.0000
PH	10	8.0395	0.0345	0.0109	8.0000	8.1000
LAB_PH	0	.	.	.	.	.
T_ALK	10	107.6130	1.0744	0.3398	105.0000	109.0000
CNDUCT	10	281.5810	1 4603	0.4618	279.0000	283.0000
DO	10	12.0950	0.4487	0 1419	11.5000	12.7000
CHLORDE	10	8.8600	0.1776	0.0562	8.5000	9.1000
SULFATE	10	22 0310	0.4832	0.1528	21 4300	22.7000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=A_NORTHERN SURVEY=A_WINTER1 LAYER=B_EPILIMNION						
W_TEMP	6	1.7500	0.2739	0.1118	1.5000	2.0000
TURBTY	0	.	.	.	.	.
CHLOR_A	6	0.8883	0.1288	0.0526	0.7000	1.1000
PHPHT_A	6	-0.0167	0.0582	0.0238	-0.1200	0.0500
PHOS_T	6	0.0030	0.0003	0.0001	0.0026	0.0034
PHOS_D	6	0.0021	0.0006	0.0003	0.0015	0.0033
D_ORTH_P	6	0.0008	0.0004	0.0002	0.0005	0.0016
NO2NO3T	6	0.3355	0.0060	0.0024	0.3290	0.3430
NH3NH4T	6	0.0008	0.0004	0.0002	0.0000	0.0010
KJEL_N	6	0.0133	0.0082	0.0033	0.0100	0.0300
DSICON	6	768.8333	4.0208	1.6415	762.0000	772.0000
PH	5	8.0280	0.0148	0.0066	8.0100	8.0500
LAB_PH	6	7.9533	0.0662	0.0270	7.8800	8.0400
T_ALK	6	78.5833	0.4916	0.2007	78.0000	79.0000
CNDUCT	6	206.5000	1.9748	0.8062	204.0000	208.0000
DO	3	13.2333	0.1528	0.0882	13 1000	13.4000
CHLORDE	6	5.3333	0.0816	0.0333	5.2000	5.4000
SULFATE	6	16.0500	0.1225	0.0500	15.9000	16.2000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.
BASIN=A_NORTHERN SURVEY=A_WINTER2 LAYER=B_EPILIMNION						
W_TEMP	11	0.7500	0.5916	0.1784	0.0000	2.0000
TURBTY	0	.	.	.	.	.
CHLOR_A	12	0.7975	0.2411	0.0696	0.3500	1.2300
PHPHT_A	12	-0.0992	0.0896	0.0259	-0.3000	0.0000
PHOS_T	12	0.0037	0.0021	0.0006	0.0028	0.0103
PHOS_D	12	0.0023	0.0004	0.0001	0.0018	0.0032
D_ORTH_P	12	0.0008	0.0002	0.0001	0.0005	0.0013
NO2NO3T	12	0.3038	0.0492	0.0142	0.2000	0.3360
NH3NH4T	12	0.0032	0.0026	0.0007	0.0010	0.0100
KJEL_N	12	0.1483	0.0422	0.0122	0.1000	0.2500
DSICON	12	801.3333	26.6538	7.6943	748.0000	837.0000
PH	9	7.9611	0.0732	0.0244	7.8300	8.0400
LAB_PH	12	7.9008	0.0329	0.0095	7.8600	7.9800
T_ALK	11	77.2273	0.9045	0.2727	75.5000	78.0000
CNDUCT	12	202.5833	2.3533	0.6793	198.0000	205.0000
DO	11	13.2818	0.3783	0.1141	12.6500	13.8500
CHLORDE	12	5.5833	0.2250	0.0649	5.3000	6.2000
SULFATE	12	16.1167	0.4407	0.1272	15.5000	16.7000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------- BASIN=A_NORTHERN SURVEY=B_SPRING LAYER=B_EPILIMNION ----------						
W_TEMP	58	1.4560	0.2616	0.0343	0.9000	1.8000
TURBTY	56	0.3873	0.1426	0.0190	0.2100	1.1400
CHLOR_A	58	0.7814	0.5878	0.0772	0.2000	1.8000
PHPHT_A	58	0.0172	0.1539	0.0202	-0.2000	0.9000
PHOS_T	57	0.0033	0.0018	0.0002	0.0022	0.0146
PHOS_D	57	0.0013	0.0005	0.0001	0.0000	0.0032
D_ORTH_P	58	0.0003	0.0003	0.0000	-0 0002	0.0009
NO2NO3T	58	0.3021	0.0265	0.0035	0.2440	0.3310
NH3NH4T	33	0 0022	0.0009	0 0001	0.0010	0.0050
KJEL_N	57	0 0763	0.0546	0.0072	0.0100	0.2700
DSICON	58	772 8448	19.9638	2 6214	740 0000	806.0000
PH	57	8.0000	0.0986	0 0131	7.8000	8.2700
LAB_PH	0	.	.		.	.
T_ALK	58	76.4983	1 0501	0 1379	74.5000	79.0000
CNDUCT	58	202 6534	1.1442	0 1502	200.0000	204.0000
DO	11	13 3718	0.3759	0 1133	12.8500	13 8800
CHLORDE	53	5 4057	0.3805	0 0523	5.2000	8.0000
SULFATE	58	15.8897	0.4081	0 0536	15.2000	17.0000
CA	0		.		.	.
MG	0	.	.		.	.
NA	0	.			.	.
K	0	.			.	.
T_COUNT	23	1.4348	0.8435	0 1759	1.0000	4.0000
---------- BASIN=A_NORTHERN SURVEY=C_SUMMER LAYER=B_EPILIMNION ----------						
W_TEMP	36	17 6500	0 7458	0.1243	15.7000	18.8000
TURBTY	36	0 2082	0 0807	0 0134	0 1200	0.5700
CHLOR_A	36	0.9986	0 6407	0 1068	0 4000	4.2000
PHPHT_A	36	0.1687	0 1770	0 0295	-0.1000	0.6000
PHOS_T	36	0.0028	0.0038	0.0006	0 0008	0.0182
PHOS_D	36	0.0019	0.0035	0.0006	0 0000	0.0169
D_ORTH_P	36	0.0003	0 0003	0.0001	-0 0001	0.0011
NO2NO3T	36	0.2668	0.0266	0.0044	0 2100	0.3050
NH3NH4T	36	0.0018	0.0012	0 0002	0 0000	0.0040
KJEL_N	36	0 1590	0.0583	0.0097	0 0500	0.3500
DSICON	36	421.6667	86.0764	14 3461	242.0000	536.0000
PH	36	8.4247	0.0538	0.0090	8.3100	8.5100
LAB_PH	0	.	.	.	.	.
T_ALK	36	75.0869	2.9268	0 4878	66.0000	79.0000
CNDUCT	36	198 9028	6.8812	1.1469	180.0000	205.0000
DO	36	9.8362	0.6583	0.1097	9.0000	11.3000
CHLORDE	35	5.2264	0.2533	0 0428	4.6000	5.6000
SULFATE	36	15.7383	0.6524	0.1087	13.5000	16.7000
CA	16	26.2500	1.1255	0.2814	24.0000	28.0000
MG	16	7.1000	0.2658	0.0665	6.6000	7.5000
NA	16	3.3437	0.1153	0.0288	3.1000	3.5000
K	16	0.8681	0.0229	0.0057	0.8200	0.9000
T_COUNT	11	12.6273	23.1017	6.9654	0.9000	81.0000

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

-------------------- BASIN=A_NORTHERN SURVEY=C_SUMMER LAYER=C_MESOLIMNION --------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	17	12.0647	1.0805	0 2621	9.1000	13.7000
TURBTY	17	0.2384	0.0528	0.0128	0.1600	0.3300
CHLOR_A	17	1.6074	0.7079	0.1717	0.5000	3.2000
PHPHT_A	17	0.2059	0.3015	0.0731	-0.7000	0.7000
PHOS_T	17	0.0029	0.0013	0.0003	0.0011	0.0058
PHOS_D	17	0.0011	0.0006	0.0002	0.0000	0.0028
D_ORTH_P	17	0.0003	0.0005	0.0001	-0.0001	0.0017
NO2NO3T	17	0.2840	0.0227	0.0055	0.2530	0.3270
NH3NH4T	17	0.0023	0.0013	0.0003	0.0010	0.0060
KJEL_N	17	0.1888	0.0766	0.0186	0.0700	0 4000
DSICON	17	495.9412	78.1573	18.9559	346.0000	627.0000
PH	17	8.4188	0.0834	0.0202	8.2200	8.5900
LAB_PH	0	.	.	.	.	.
T_ALK	17	75.5812	1.7438	0.4229	71.0000	77.5000
CNDUCT	17	201.0147	4.0625	0.9853	194.0000	206.0000
DO	17	12.2959	0.9846	0.2388	10.8000	14.1000
CHLORDE	17	5.2471	0.2239	0.0543	4.8000	5.5000
SULFATE	17	15.9265	0.4402	0.1068	15.0000	16.4000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

-------------------- BASIN=A_NORTHERN SURVEY=C_SUMMER LAYER=D_HYPOLIMNION --------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	29	5.0862	0.7958	0.1478	4.0000	6.6000
TURBTY	29	0.2866	0.0880	0.0163	0.1400	0.6100
CHLOR_A	29	1.4741	0.8129	0.1510	0.4000	3.6000
PHPHT_A	29	0.3629	0.2040	0.0379	0.1000	0.9000
PHOS_T	29	0.0028	0.0011	0.0002	0.0003	0.0055
PHOS_D	29	0.0015	0.0008	0.0002	0.0003	0.0040
D_ORTH_P	29	0.0004	0.0004	0.0001	0.0000	0.0015
NO2NO3T	29	0.3232	0.0209	0.0039	0.2770	0.3580
NH3NH4T	29	0.0033	0.0021	0.0004	0.0000	0.0090
KJEL_N	29	0.1291	0.0474	0.0088	0.0400	0.2400
DSICON	29	684.6552	90.2707	16.7629	535.0000	855.0000
PH	29	8.1269	0.0953	0.0177	7.9200	8.2700
LAB_PH	0	.	.	.	.	.
T_ALK	29	76.2241	0.9410	0.1747	74.0000	77.5000
CNDUCT	29	204.4097	1.2105	0.2248	201.0000	206.0000
DO	29	12.5597	0.5529	0.1027	11.4000	13.9000
CHLORDE	29	5.3224	0.1544	0.0287	5.0000	5.5000
SULFATE	29	16.0500	0.2928	0.0544	15.3000	16.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	5	9.8000	5.4037	2.4166	3.0000	16.0000

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=A_NORTHERN SURVEY=C_SUMMER LAYER=E_NEPHELOID						
W_TEMP	34	4.1412	0.2285	0.0392	3.9000	4.8000
TURBTY	34	0.9161	0.5474	0.0939	0.4125	3.4000
CHLOR_A	34	0.6625	0.3350	0.0575	0.2000	1.4000
PHPHT_A	34	0.4221	0.3877	0.0665	0.0750	2.4000
PHOS_T	34	0.0033	0.0016	0.0003	0.0013	0.0088
PHOS_D	34	0.0013	0.0005	0.0001	0.0003	0.0024
D_ORTH_P	34	0.0006	0.0005	0.0001	0.0000	0.0017
NO2NO3T	34	0.3538	0.0139	0.0024	0.3275	0.3770
NH3NH4T	34	0.0022	0.0016	0.0003	0.0000	0.0060
KJEL_N	34	0.1242	0.0524	0.0090	0.0300	0.2500
DSICON	34	976.6471	126.5749	21.7074	759.0000	1344.0000
PH	34	7.9794	0.0827	0.0142	7.8200	8.1200
LAB_PH	0				.	
T_ALK	34	76.5824	1.0689	0.1833	74.0000	78.0000
CNDUCT	34	204.8444	0.9184	0.1575	203.0000	207.0000
DO	34	11.9318	0.4749	0.0814	10.8000	12.6000
CHLORDE	34	5.3757	0.1439	0.0247	5.0000	5.5250
SULFATE	34	16.1250	0.2711	0.0465	15.3500	16.6000
CA	17	26.9412	0.8269	0.2006	26.0000	28.0000
MG	17	7.2706	0.1263	0.0306	7.1000	7.4000
NA	17	3.3882	0.0928	0.0225	3.2000	3.5000
K	17	0.8935	0.0262	0.0064	0.8500	0.9600
T_COUNT	6	8.1667	5.8793	2.4002	3.0000	17.0000
BASIN=A_NORTHERN SURVEY=D_FALL1 LAYER=B_EPILIMNION						
W_TEMP	15	7.9400	0.2131	0.0550	7.6000	8.2000
TURBTY	15	0.2078	0.0302	0.0078	0.1700	0.2600
CHLOR_A	15	0.5800	0.1612	0.0416	0.1000	0.7000
PHPHT_A	15	0.0917	0.0890	0.0230	0.0000	0.2250
PHOS_T	14	0.0029	0.0007	0.0002	0.0018	0.0039
PHOS_D	15	0.0011	0.0003	0.0001	0.0005	0.0017
D_ORTH_P	14	0.0000	0.0004	0.0001	-0.0003	0.0009
NO2NO3T	15	0.3080	0.0122	0.0031	0.2922	0.3280
NH3NH4T	15	0.0025	0.0013	0.0003	0.0010	0.0060
KJEL_N	15	0.0883	0.0535	0.0138	0.0000	0.1800
DSICON	15	631.7333	30.5929	7.8990	599.0000	687.0000
PH	15	8.0875	0.0713	0.0184	7.9400	8.1700
LAB_PH	0		.	.	.	.
T_ALK	15	76.1007	0.4163	0.1075	75.0000	76.7000
CNDUCT	15	204.9673	2.1767	0.5620	199.8800	207.0000
DO	15	11.3187	0.2298	0.0593	11.0900	12.0000
CHLORDE	15	5.1983	0.1255	0.0324	5.0000	5.4000
SULFATE	15	15.7560	0.4366	0.1127	14.8800	16.3000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.		.	.
T_COUNT	13	5.1538	4.4130	1.2239	2.0000	19.0000

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------------------- BASIN=A_NORTHERN SURVEY=D_FALL1 LAYER=C_MESOLIMNION ----------------------						
W_TEMP	6	6.3000	0.7823	0.3194	5.3000	7.3000
TURBTY	6	0.2417	0.0585	0.0239	0.1800	0.3400
CHLOR_A	6	0.2333	0.1211	0.0494	0.1000	0.4000
PHPHT_A	6	0.1333	0.0816	0.0333	0.0000	0.2000
PHOS_T	6	0.0023	0.0005	0.0002	0.0016	0.0027
PHOS_D	6	0.0011	0.0002	0.0001	0.0007	0.0013
D_ORTH_P	6	0.0003	0.0005	0.0002	-0.0003	0.0011
NO2NO3T	6	0.3380	0.0221	0.0090	0.3050	0.3630
NH3NH4T	6	0.0020	0.0015	0.0006	0.0010	0.0050
KJEL_N	6	0.0567	0.0742	0.0303	-0.0700	0.1300
DSICON	6	800.3333	81.7476	33.3733	707.0000	924.0000
PH	6	7.9650	0.0596	0.0243	7.8800	8.0300
LAB_PH	0	.	.	.	.	.
T_ALK	6	76.3500	0.7477	0.3052	75.0000	77.0000
CNDUCT	6	205.7500	1.3323	0.5439	203.5000	207.0000
DO	6	11.6833	0.1169	0.0477	11 5000	11.8000
CHLORDE	6	5.2167	0 1329	0.0543	5.0000	5.4000
SULFATE	6	15.8167	0.3764	0.1537	15.4000	16.3000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.
---------------------- BASIN=A_NORTHERN SURVEY=D_FALL1 LAYER=D_HYPOLIMNION ----------------------						
W_TEMP	10	4.5800	0.4849	0.1533	4.1000	5 7000
TURBTY	10	0.3550	0.1227	0.0388	0.1800	0.5600
CHLOR_A	10	0.1400	0.0699	0.0221	0.1000	0.3000
PHPHT_A	10	0.0400	0.0843	0.0267	-0.1000	0.1000
PHOS_T	9	0.0022	0.0006	0.0002	0.0012	0.0032
PHOS_D	9	0.0014	0.0006	0.0002	0.0007	0.0026
D_ORTH_P	10	0.0003	0.0004	0.0001	-0.0003	0.0008
NO2NO3T	10	0.3556	0.0149	0.0047	0.3310	0.3780
NH3NH4T	10	0.0014	0.0010	0.0003	0.0010	0.0040
KJEL_N	10	0.0620	0.0459	0.0145	-0.0300	0.1100
DSICON	10	958.1000	73.5866	23.2701	795.0000	1033.0000
PH	10	7.9000	0.0359	0.0114	7.8600	7.9700
LAB_PH	0	.	.	.	.	.
T_ALK	10	76.0700	0.7258	0.2295	75.0000	77.0000
CNDUCT	10	205.8000	1.1353	0.3590	203.5000	207.0000
DO	10	11.9400	0.1265	0.0400	11.8000	12.2000
CHLORDE	10	5.2000	0.1155	0.0365	5.0000	5.3000
SULFATE	10	15.8400	0.3748	0.1185	15.4000	16.5000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	5	25.4000	41.2953	18.4678	4.0000	99.0000

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=A_NORTHERN SURVEY=D_FALL1 LAYER=E_NEPHELOID						
W_TEMP	12	4.2583	0.1881	0.0543	4.1000	4.7000
TURBTY	11	0.5736	0.0881	0.0266	0.4000	0.6800
CHLOR_A	12	0.0729	0.0445	0.0129	0.0000	0.1000
PHPHT_A	12	0.1146	0.0588	0.0170	0.0000	0.2000
PHOS_T	12	0.0031	0.0006	0.0002	0.0023	0.0045
PHOS_D	12	0.0014	0.0004	0.0001	0.0009	0.0021
D_ORTH_P	12	0.0007	0.0003	0.0001	0.0003	0.0011
NO2NO3T	12	0.3628	0.0163	0.0047	0.3372	0.3890
NH3NH4T	12	0.0019	0.0016	0.0005	0.0000	0.0050
KJEL_N	12	0.0646	0.0652	0.0188	-0.0400	0.1400
DSICON	12	1032.0000	25.8668	7.4671	991.0000	1074.0000
PH	12	7.8508	0.0446	0.0129	7.7700	7.9100
LAB_PH	0		.			.
T_ALK	12	76.1542	0.7266	0.2097	74.7500	77.0000
CNDUCT	12	205.4775	0.8585	0.2478	204.2300	207.0000
DO	12	11.9833	0.1801	0.0520	11.8000	12.4000
CHLORDE	12	5.2250	0.1138	0.0329	5.0000	5.3000
SULFATE	12	15.6792	0.4186	0.1208	15.0000	16.3500
CA	0					.
MG	0				.	.
NA	0	.				.
K	0	.	.	.	.	.
T_COUNT	6	9.6667	10.5767	4.3179	3.0000	31.0000
BASIN=A_NORTHERN SURVEY=D_FALL2 LAYER=B_EPILIMNION						
W_TEMP	26	6.1808	0.6609	0.1296	4.7000	6.9000
TURBTY	26	0.4310	0.1774	0.0348	0.2700	0.9875
CHLOR_A	26	0.2962	0.1417	0.0278	0.1000	0.5000
PHPHT_A	26	0.0827	0.0710	0.0139	0.0000	0.2250
PHOS_T	26	0.0038	0.0012	0.0002	0.0017	0.0066
PHOS_D	26	0.0009	0.0008	0.0002	0.0000	0.0027
D_ORTH_P	26	-0.0000	0.0010	0.0002	-0.0009	0.0044
NO2NO3T	26	0.3007	0.0130	0.0025	0.2790	0.3330
NH3NH4T	26	0.0020	0.0008	0.0002	0.0003	0.0040
KJEL_N	25	0.1199	0.0567	0.0113	0.0400	0.3200
DSICON	26	746.9615	86.9025	17.0430	643.0000	928.0000
PH	26	7.9535	0.0752	0.0148	7.7800	8.0300
LAB_PH	0	.	.	.	.	
T_ALK	26	76.3992	0.8193	0.1607	75.0000	78.2000
CNDUCT	26	201.9042	2.0807	0.4081	197.5000	205.3500
DO	26	12.4704	0.4221	0.0828	11.8000	13.5000
CHLORDE	26	5.3702	0.1667	0.0327	5.1500	5.7000
SULFATE	26	16.6792	0.8311	0.1630	15.5000	17.9000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

-------------------- BASIN=B_SOUTHERN SURVEY=A_WINTER1 LAYER=B_EPILIMNION --------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	6	2.0000	0.7746	0.3162	1.0000	2.5000
TURBTY	0	.	.	.	.	.
CHLOR_A	6	0.8550	0.1005	0.0410	0.7000	1.0100
PHPHT_A	6	0.0233	0.0948	0.0387	-0.1000	0.1600
PHOS_T	6	0.0048	0.0014	0.0006	0.0038	0.0075
PHOS_D	6	0.0030	0.0013	0.0005	0.0022	0.0056
D_ORTH_P	6	0.0019	0.0010	0.0004	0.0008	0.0038
NO2NO3T	6	0.3313	0.0027	0.0011	0.3270	0.3330
NH3NH4T	6	0.0015	0.0005	0.0002	0.0010	0.0020
KJEL_N	6	0.1167	0.1277	0.0521	0.0100	0.2800
DSICON	6	712.8333	7.3598	3.0046	707.0000	722.0000
PH	5	8.0840	0.0792	0.0354	7.9600	8.1500
LAB_PH	6	8.0567	0.0216	0.0088	8.0300	8.0900
T_ALK	6	78.5833	0.3764	0.1537	78.0000	79.0000
CNDUCT	6	206.0000	0.0000	0.0000	206.0000	206.0000
DO	3	12.4000	0.2000	0.1155	12.2000	12.6000
CHLORDE	6	5.3333	0.1033	0.0422	5.2000	5.5000
SULFATE	6	15.9000	0.2280	0.0931	15.5000	16.1000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

-------------------- BASIN=B_SOUTHERN SURVEY=A_WINTER2 LAYER=B_EPILIMNION --------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	6	0.1667	0.2582	0.1054	0.0000	0.5000
TURBTY	0	.	.	.	.	.
CHLOR_A	6	1.3017	0.3225	0.1316	0.8800	1.5800
PHPHT_A	6	-0.2150	0.1115	0.0455	-0.4000	-0.1000
PHOS_T	6	0.0050	0.0044	0.0018	0.0028	0.0140
PHOS_D	6	0.0020	0.0004	0.0002	0.0014	0.0024
D_ORTH_P	6	0.0009	0.0004	0.0002	0.0003	0.0015
NO2NO3T	6	0.3293	0.0060	0.0025	0.3200	0.3360
NH3NH4T	6	0.0067	0.0031	0.0013	0.0020	0.0110
KJEL_N	6	0.1383	0.0286	0.0117	0.1200	0.1800
DSICON	6	798.6667	9.6885	3.9553	788.0000	812.0000
PH	5	7.9080	0.0130	0.0058	7.8900	7.9200
LAB_PH	6	7.9517	0.0360	0.0147	7.9200	8.0200
T_ALK	6	78.4167	0.5845	0.2386	77.5000	79.0000
CNDUCT	6	205.1667	1.4720	0.6009	203.0000	207.0000
DO	6	13.5583	0.3338	0.1363	12.9500	13.8500
CHLORDE	6	5.6833	0.0408	0.0167	5.6000	5.7000
SULFATE	6	16.5167	0.2787	0.1138	16.2000	16.9000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------- BASIN=B_SOUTHERN SURVEY=B_SPRING LAYER=B_EPILIMNION ----------						
W_TEMP	45	1.7867	0.4578	0.0682	1.2000	2.7000
TURBTY	45	0.5280	0.3277	0.0489	0.2900	2.2900
CHLOR_A	45	1.0949	0.5353	0.0798	0.3000	1.9000
PHPHT_A	45	-0.0414	0.0973	0.0145	-0.2000	0.1000
PHOS_T	45	0.0036	0.0017	0.0003	0.0022	0.0125
PHOS_D	45	0.0013	0.0006	0.0001	0.0005	0.0035
D_ORTH_P	45	0 0005	0.0004	0.0001	0.0000	0.0015
NO2NO3T	45	0.3009	0.0205	0.0030	0 2660	0.3420
NH3NH4T	20	0.0025	0.0006	0.0001	0.0020	0.0040
KJEL_N	45	0 1124	0.0571	0.0085	0.0100	0.2300
DSICON	45	782 4222	13 3714	1 9933	743.0000	803.0000
PH	45	8 0276	0.0754	0.0112	7.8800	8.2000
LAB_PH	0	.	.	.	.	
T_ALK	45	77.5556	1 1083	0.1652	75 0000	79.5000
CNDUCT	45	203.3956	1.3186	0 1966	201.0000	207.8000
DO	8	13 4512	0 2002	0.0708	13 0200	13 6500
CHLORDE	45	5 3800	0 1342	0.0200	5.2000	5 6000
SULFATE	45	15.6867	0 4751	0.0708	14.3000	16 4000
CA	0	.				.
MG	0		.	.		.
NA	0		.		.	
K	0	.	.			.
T_COUNT	16	3 0625	1.8786	0 4697	1.0000	8.0000
---------- BASIN=B_SOUTHERN SURVEY=C_SUMMER LAYER=B_EPILIMNION ----------						
W_TEMP	29	19 6724	0 3854	0.0716	18.7000	20 2000
TURBTY	29	0.2498	0 0873	0 0162	0 1600	0 6000
CHLOR_A	29	1 3560	0 4173	0 0775	0 8000	2 3000
PHPHT_A	29	0 1276	0.5346	0.0993	-0.5000	2.6000
PHOS_T	28	0 0023	0.0006	0.0001	0.0015	0.0035
PHOS_D	29	0 0013	0.0006	0.0001	0 0005	0 0037
D_ORTH_P	29	0 0005	0.0004	0 0001	0.0000	0.0012
NO2NO3T	29	0.2764	0.0177	0 0033	0 2510	0.3340
NH3NH4T	29	0.0014	0.0011	0 0002	0.0000	0.0040
KJEL_N	29	0.1984	0.0895	0 0166	0.1000	0.4600
DSICON	29	338.2069	69 5672	12.9183	255.0000	588.0000
PH	29	8.4403	0.1098	0.0204	8.0400	8.6800
LAB_PH	0	.	.	.	.	.
T_ALK	29	77.5821	1.0980	0.2039	75.0000	79.0000
CNDUCT	29	206.5390	6.5558	1.2174	173.6300	211.0000
DO	28	9.4085	0.7135	0.1348	8.6000	11.7000
CHLORDE	29	5.6336	0.2400	0.0446	5.2000	6.1000
SULFATE	29	16.0769	0.4583	0.0851	15.2000	16.7000
CA	13	27.7692	0.7250	0 2011	27.0000	29.0000
MG	13	7.3769	0.1363	0.0378	7.2000	7.6000
NA	13	3.5744	0.0829	0.0230	3.4000	3 7000
K	13	0.8995	0.0251	0.0070	0.8600	0.9300
T_COUNT	8	29.5000	22.2133	7.8536	4.0000	63.0000

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

-------------------- BASIN=B_SOUTHERN SURVEY=C_SUMMER LAYER=C_MESOLIMNION --------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	13	13.7538	1.3270	0.3681	10.8000	15.2000
TURBTY	13	0.2769	0.0788	0.0219	0.2100	0.5150
CHLOR_A	12	2.7708	3.0562	0.8822	0.9000	11.4000
PHPHT_A	12	0 2458	0.3665	0.1058	-0.4000	0.8000
PHOS_T	13	0.0030	0.0006	0.0002	0.0020	0.0042
PHOS_D	13	0.0012	0.0004	0.0001	0.0008	0.0019
D_ORTH_P	13	0.0006	0.0003	0.0001	0.0000	0.0012
NO2NO3T	13	0.2972	0.0189	0.0052	0.2670	0.3325
NH3NH4T	13	0.0036	0.0018	0.0005	0.0010	0 0080
KJEL_N	13	0 1958	0 0969	0.0269	0.0700	0.3800
DSICON	13	479.3846	69.3380	19.2309	358.0000	610.0000
PH	13	8.2998	0.1185	0 0329	8.0700	8.4600
LAB_PH	0	.	.	.	.	.
T_ALK	13	77.1931	1.1344	0.3146	75.0000	78.3800
CNDUCT	13	206.9908	1 9498	0.5408	204.0000	211 0000
DO	13	11.4150	0.7886	0.2187	9.6250	12 4300
CHLORDE	13	5.5615	0.2190	0.0608	5.0000	5.8000
SULFATE	13	16.0369	0.3992	0.1107	15.4000	16.6000
CA	0	.	.	.	.	
MG	0	.	.	.	.	.
NA	0	.	.	.		.
K	0	.	.	.	.	
T_COUNT	0	.	.	.	.	.

-------------------- BASIN=B_SOUTHERN SURVEY=C_SUMMER LAYER=D_HYPOLIMNION --------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	19	5.7474	0 8065	0.1850	4.4000	6.7000
TURBTY	19	0.3391	0.1253	0.0287	0.1800	0 5850
CHLOR_A	19	0.9434	0.3571	0.0819	0.4000	1.9000
PHPHT_A	19	0.2934	0.6267	0.1438	-0.3000	2.6000
PHOS_T	19	0.0029	0.0008	0.0002	0.0015	0.0050
PHOS_D	19	0.0012	0.0005	0.0001	0.0005	0.0021
D_ORTH_P	19	0.0005	0 0003	0.0001	0.0000	0.0011
NO2NO3T	19	0.3342	0.0211	0.0048	0.3090	0 3870
NH3NH4T	19	0.0021	0.0030	0.0007	0.0000	0.0080
KJEL_N	19	0.1716	0.0874	0.0200	0.0700	0.3900
DSICON	19	766.7368	133.2065	30.5597	574.0000	1027.0000
PH	19	8.0118	0.1512	0.0347	7.7600	8.4100
LAB_PH	0	.	.	.	.	.
T_ALK	19	76.6447	0.9476	0.2174	75.0000	78.0000
CNDUCT	19	205.9474	1.8401	0.4221	204.0000	211.0000
DO	19	11.7884	0.6601	0.1514	10.1000	12.7000
CHLORDE	19	5.5145	0.1571	0.0360	5.2000	5.8000
SULFATE	19	15.7789	0.5808	0.1332	15.0000	16.8000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	4	27.5000	11.1505	5.5752	18.0000	43.0000

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=B_SOUTHERN SURVEY=C_SUMMER LAYER=E_NEPHELOID						
W_TEMP	25	4.8120	0.5869	0.1174	4.0000	6.2000
TURBTY	25	1.1407	0.6712	0.1342	0.4475	3.3400
CHLOR_A	25	0.8760	0.2962	0.0592	0.3000	1.5000
PHPHT_A	25	0.3050	0.5739	0.1148	-0.5000	2.6000
PHOS_T	25	0.0041	0.0014	0.0003	0.0009	0.0073
PHOS_D	25	0.0011	0.0003	0.0001	0.0008	0.0016
D_ORTH_P	25	0.0007	0.0003	0.0001	0.0003	0.0014
NO2NO3T	25	0.3621	0.0184	0.0037	0.3160	0.3910
NH3NH4T	25	0.0010	0.0015	0.0003	0.0000	0.0070
KJEL_N	25	0.1817	0.1170	0.0234	0.0700	0.5100
DSICON	25	1061.8800	164.2235	32.8447	735.0000	1394.0000
PH	25	7.8470	0.0760	0.0152	7.7200	8.0600
LAB_PH	0		.			.
T_ALK	25	76.5600	0.8578	0.1716	75.0000	77.5000
CNDUCT	25	206.7552	1.6457	0.3291	204.8800	211.0000
DO	25	10.9120	0.5659	0.1132	9.9000	12.1000
CHLORDE	25	5.5060	0.1781	0.0356	5.2000	5.8000
SULFATE	25	15.9920	0.4020	0.0804	15.2000	16.9000
CA	13	27.3846	0.7679	0.2130	26.0000	28.0000
MG	13	7.3692	0.1251	0.0347	7.2000	7.6000
NA	13	3.4615	0.0870	0.0241	3.3000	3.6000
K	13	0.8962	0.0299	0.0083	0.8600	0.9400
T_COUNT	4	27.0000	8.2462	4.1231	18.0000	38.0000

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=B_SOUTHERN SURVEY=D_FALL1 LAYER=B_EPILIMNION						
W_TEMP	17	8.2529	0.1772	0.0430	7.8000	8.4000
TURBTY	17	0.3140	0.0724	0.0176	0.2400	0.4600
CHLOR_A	17	0.5956	0.1160	0.0281	0.3000	0.8000
PHPHT_A	17	0.1515	0.1483	0.0360	-0.1000	0.4000
PHOS_T	17	0.0030	0.0008	0.0002	0.0023	0.0055
PHOS_D	17	0.0008	0.0004	0.0001	0.0003	0.0017
D_ORTH_P	17	0.0005	0.0007	0.0002	0.0000	0.0028
NO2NO3T	17	0.3275	0.0379	0.0092	0.2820	0.4030
NH3NH4T	17	0.0031	0.0011	0.0003	0.0010	0.0050
KJEL_N	17	0.0981	0.0301	0.0073	0.0400	0.1500
DSICON	17	716.2353	75.8556	18.3977	645.0000	947.0000
PH	17	8.0722	0.1055	0.0256	7.8600	8.4000
LAB_PH	0	.		.		.
T_ALK	17	76.4588	0.6890	0.1671	75.5000	78.0000
CNDUCT	17	207.0259	0.7973	0.1934	205.0000	208.0000
DO	17	11.2076	0.1628	0.0395	10.9300	11.6000
CHLORDE	17	5.3824	0.1334	0.0324	5.2000	5.6000
SULFATE	17	16.3059	0.7903	0.1917	15.4500	17.3000
CA	0	.		.	.	
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	11	9.8182	10.1076	3.0476	2.0000	38.0000

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

--------------------- BASIN=B_SOUTHERN SURVEY=D_FALL1 LAYER=C_MESOLIMNION ---------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	3	6.9333	0.2309	0.1333	6.8000	7.2000
TURBTY	3	0.4533	0.2157	0.1245	0 3000	0.7000
CHLOR_A	3	0.2667	0.1155	0.0667	0.2000	0.4000
PHPHT_A	3	0.1333	0.2517	0.1453	-0.1000	0.4000
PHOS_T	3	0.0025	0.0002	0.0001	0.0023	0.0027
PHOS_D	3	0.0006	0.0003	0.0002	0.0003	0.0008
D_ORTH_P	3	0.0003	0.0003	0.0001	0.0000	0.0005
NO2NO3T	3	0.3393	0.0727	0.0420	0 2920	0.4230
NH3NH4T	3	0.0017	0.0006	0.0003	0.0010	0.0020
KJEL_N	3	0.0800	0.0529	0.0306	0.0200	0.1200
DSICON	3	971.6667	130.8485	75.5454	869 0000	1119.0000
PH	3	7.8333	0.0666	0.0384	7.7600	7.8900
LAB_PH	0	.	.	.	.	.
T_ALK	3	76.5000	0.0000	0.0000	76.5000	76.5000
CNDUCT	3	207.0000	0.8660	0.5000	206.0000	207.5000
DO	3	11.0333	0.2082	0.1202	10.8000	11.2000
CHLORDE	3	5.3333	0 1528	0.0882	5 2000	5.5000
SULFATE	3	16.0667	1.0786	0.6227	15.3000	17.3000
CA	0	.	.	.	.	.
MG	0	.		.	.	.
NA	0	.	.	.		.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

--------------------- BASIN=B_SOUTHERN SURVEY=D_FALL1 LAYER=D_HYPOLIMNION ---------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	3	5.6000	0.4359	0.2517	5.3000	6.1000
TURBTY	3	0.5700	0.1609	0.0929	0.4400	0.7500
CHLOR_A	3	0.2000	0.1000	0 0577	0.1000	0.3000
PHPHT_A	3	0.1667	0.1155	0.0667	0.1000	0.3000
PHOS_T	3	0.0032	0.0004	0.0002	0.0027	0.0035
PHOS_D	3	0 0018	0.0012	0 0007	0.0009	0.0032
D_ORTH_P	3	0.0006	0.0003	0 0002	0.0003	0.0008
NO2NO3T	3	0.3483	0.0711	0.0410	0.2950	0.4290
NH3NH4T	3	0.0013	0.0006	0.0003	0.0010	0.0020
KJEL_N	3	0.0467	0.0306	0.0176	0.0200	0.0800
DSICON	3	1074.0000	80.7217	46.6047	984.0000	1140.0000
PH	3	7.7667	0.0289	0.0167	7.7500	7.8000
LAB_PH	0	.	.	.	.	.
T_ALK	3	76.0000	0.0000	0.0000	76 0000	76.0000
CNDUCT	3	207.3333	0.5774	0.3333	207.0000	208.0000
DO	3	10.9333	0.1528	0.0882	10 8000	11.1000
CHLORDE	3	5.3333	0.1528	0.0882	5.2000	5.5000
SULFATE	3	16.0667	1.0786	0.6227	15.3000	17.3000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0		.	.		.
K	0	.		.	.	.
T_COUNT	2	4.5000	0.7071	0.5000	4.0000	5.0000

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=B_SOUTHERN SURVEY=D_FALL1 LAYER=E_NEPHELOID						
W_TEMP	4	5.3000	0.4761	0.2380	5.0000	6.0000
TURBTY	4	0 7100	0.1344	0.0672	0.6200	0.9100
CHLOR_A	4	0.1500	0.0577	0.0289	0.1000	0.2000
PHPHT_A	4	0.1750	0.0957	0.0479	0.1000	0.3000
PHOS_T	4	0.0039	0.0003	0.0001	0.0035	0.0042
PHOS_D	4	0.0015	0.0006	0.0003	0.0010	0.0024
D_ORTH_P	4	0.0005	0.0002	0.0001	0.0003	0.0008
NO2NO3T	4	0.3532	0.0472	0.0236	0.3210	0.4230
NH3NH4T	4	0.0015	0.0010	0.0005	0.0010	0.0030
KJEL_N	4	0.0875	0.0171	0.0085	0.0700	0.1100
DSICON	4	1110.0000	78.4049	39.2025	994.0000	1166.0000
PH	4	7 7600	0.0346	0.0173	7 7300	7.7900
LAB_PH	0		.	.		.
T_ALK	4	76 2250	0 2062	0 1031	76 0000	76.5000
CNDUCT	4	207.6250	0.4787	0.2394	207.0000	208.0000
DO	4	10.9500	0.1291	0.0645	10.8000	11.1000
CHLORDE	4	5 2500	0.0577	0.0289	5.2000	5.3000
SULFATE	4	15 8000	1.0132	0.5066	15.1000	17.3000
CA	0		.	.	.	.
MG	0	.		.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	3	7.6667	2 5166	1.4530	5.0000	10.0000
BASIN=B_SOUTHERN SURVEY=D_FALL2 LAYER=B_EPILIMNION						
W_TEMP	23	6 9000	0.1679	0.0350	6.7000	7.3000
TURBTY	22	0 4153	0.0959	0 0204	0.2900	0.6475
CHLOR A	23	0 4022	0 1601	0 0334	0.2000	0.7000
PHPHT_A	23	0.0511	0.0827	0 0173	-0.1000	0.2000
PHOS_T	23	0.0037	0.0008	0.0002	0 0028	0.0059
PHOS_D	23	0.0021	0.0010	0.0002	0.0011	0.0061
D_ORTH_P	23	-0.0005	0.0005	0.0001	-0.0009	0.0004
NO2NO3T	23	0.2969	0.0213	0.0044	0.2570	0.3282
NH3NH4T	23	0 0025	0.0008	0.0002	0.0017	0.0040
KJEL_N	23	0.1324	0.0344	0.0072	0.0700	0.1800
DSICON	23	740.6522	40.1142	8.3644	684.0000	819.0000
PH	21	8.0142	0.0458	0.0100	7.9200	8.0800
LAB_PH	0	.	.	.	.	.
T_ALK	22	77.2814	0.9947	0.2121	75.0000	79.0000
CNDUCT	22	204.4050	1.1202	0.2388	201.5000	206.0000
DO	23	10.8309	0.6465	0.1348	10.2000	12.2000
CHLORDE	23	5.4413	0.0973	0.0203	5.3000	5.6000
SULFATE	23	16.6070	1.1623	0.2424	14.8000	17.9000
CA	0	.	.	.	.	.
MG	0	.	.		.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=B_SOUTHERN SURVEY=D_FALL2 LAYER=C_MESOLIMNION						
W_TEMP	1	6.5000	.	.	6.5000	6.5000
TURBTY	1	0.4200	.	.	0.4200	0.4200
CHLOR_A	1	0.2000	.	.	0.2000	0.2000
PHPHT_A	1	0.0000	.	.	0.0000	0.0000
PHOS_T	1	0.0030	.	.	0.0030	0.0030
PHOS_D	1	0.0021	.	.	0.0021	0.0021
D_ORTH_P	1	-0.0009	.	.	-0.0009	-0.0009
NO2NO3T	1	0.3410	.	.	0.3410	0.3410
NH3NH4T	1	0.0010	.	.	0.0010	0.0010
KJEL_N	1	0.1300	.	.	0.1300	0.1300
DSICON	1	944.0000	.	.	944.0000	944.0000
PH	1	7.8900	.	.	7.8900	7.8900
LAB_PH	0	.	.	.	.	.
T_ALK	1	78.0000	.	.	78.0000	78.0000
CNDUCT	1	200.0000	.	.	200.0000	200.0000
DO	1	10.2000	.	.	10.2000	10.2000
CHLORDE	1	5.5000	.	.	5.5000	5.5000
SULFATE	1	15.6000	.	.	15.6000	15.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.
BASIN=B_SOUTHERN SURVEY=D_FALL2 LAYER=D_HYPOLIMNION						
W_TEMP	1	5.2000	.	.	5.2000	5.2000
TURBTY	1	0.6300	.	.	0.6300	0.6300
CHLOR_A	1	0.0000	.	.	0.0000	0.0000
PHPHT_A	1	0.2000	.	.	0.2000	0.2000
PHOS_T	1	0.0033	.	.	0.0033	0.0033
PHOS_D	1	0.0017	.	.	0.0017	0.0017
D_ORTH_P	1	-0.0003	.	.	-0.0003	-0.0003
NO2NO3T	1	0.3600	.	.	0.3600	0.3600
NH3NH4T	1	0.0010	.	.	0.0010	0.0010
KJEL_N	1	0.2400	.	.	0.2400	0.2400
DSICON	1	1104.0000	.	.	1104.0000	1104.0000
PH	1	7.7500	.	.	7.7500	7.7500
LAB_PH	0	.	.	.	.	.
T_ALK	1	78.8000	.	.	78.8000	78.8000
CNDUCT	1	206.5000	.	.	206.5000	206.5000
DO	1	11.0000	.	.	11.0000	11.0000
CHLORDE	1	5.4000	.	.	5.4000	5.4000
SULFATE	1	15.9000	.	.	15.9000	15.9000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. HURON DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------------------- BASIN=B_SOUTHERN SURVEY=D_FALL2 LAYER=E_NEPHELOID ----------------------						
W_TEMP	2	5.1000	0.0000	0.0000	5.1000	5.1000
TURBTY	2	0.7150	0.0636	0.0450	0.6700	0.7600
CHLOR_A	2	0.1000	0.0000	0.0000	0.1000	0.1000
PHPHT_A	2	0.0500	0.0707	0.0500	0.0000	0.1000
PHOS_T	2	0 0037	0.0006	0.0004	0.0033	0.0041
PHOS_D	2	0.0033	0.0017	0.0012	0.0021	0.0045
D_ORTH_P	2	0.0000	0.0000	0.0000	0.0000	0.0000
NO2NO3T	2	0.3610	0.0057	0.0040	0.3570	0.3650
NH3NH4T	2	0.0010	0 0000	0.0000	0.0010	0.0010
KJEL_N	2	0.0800	0 0141	0.0100	0.0700	0 0900
DSICON	2	1138.0000	18 3848	13.0000	1125.0000	1151.0000
PH	2	7.7400	0 0283	0.0200	7.7200	7.7600
LAB_PH	0	.		.	.	.
T_ALK	2	78.0000	0 0000	0.0000	78.0000	78.0000
CNDUCT	2	205.3500	1.6263	1.1500	204.2000	206.5000
DO	2	9 8500	0.0707	0.0500	9.8000	9.9000
CHLORDE	2	5.5000	0.0000	0.0000	5.5000	5.5000
SULFATE	2	15.6500	0 0707	0.0500	15.6000	15 7000
CA	0			.	.	.
MG	0	.	.	.	.	.
NA	0		.	.	.	.
K	0			.	.	.
T_COUNT	0			.	.	.

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

BASIN=A_WESTERN SURVEY=A_WINTER1 LAYER=B_EPILIMNION

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	6	0.0000	0.0000	0.0000	0.0000	0.0000
TURBTY	0	.	.	.	.	.
CHLOR_A	6	3.4883	2.5852	1.0554	1.3200	7.0000
PHPHT_A	6	0.8117	0.8377	0.3420	0.0300	2.2000
PHOS_T	6	0.0168	0.0049	0.0020	0.0098	0.0223
PHOS_D	6	0.0039	0.0014	0.0006	0.0026	0.0064
D_ORTH_P	6	0.0019	0.0014	0.0006	0.0008	0.0038
NO2NO3T	6	0.5115	0.0315	0.0128	0.4720	0.5430
NH3NH4T	6	0.0645	0.0683	0.0279	0.0160	0.1640
KJEL_N	6	0.0717	0.0631	0.0257	0.0100	0.1600
DSICON	6	710.3333	248.0755	101.2764	413.0000	969.0000
PH	5	7.9480	0.1293	0.0578	7.7900	8.0700
LAB_PH	6	7.9667	0.0468	0.0191	7.9000	8.0200
T_ALK	6	87.0000	1.7889	0.7303	84.5000	88.5000
CNDUCT	6	260.1667	12.2706	5.0094	252.0000	276.0000
DO	3	13.6000	0.3123	0.1803	13.3500	13.9500
CHLORDE	6	14.0000	2.3707	0.9678	11.3000	16.7000
SULFATE	6	21.0167	2.0459	0.8352	18.5000	23.3000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

BASIN=A_WESTERN SURVEY=A_WINTER2 LAYER=B_EPILIMNION

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	6	0.0000	0.0000	0.0000	0.0000	0.0000
TURBTY	0	.	.	.	.	.
CHLOR_A	6	2.1433	0.9983	0.4076	0.5300	3.3600
PHPHT_A	6	0.1183	0.0643	0.0263	0.0500	0.2200
PHOS_T	6	0.0082	0.0033	0.0013	0.0036	0.0120
PHOS_D	0	.	.	.	.	.
D_ORTH_P	6	0.0016	0.0015	0.0006	0.0005	0.0042
NO2NO3T	6	0.4575	0.0762	0.0311	0.3600	0.5510
NH3NH4T	4	0.0145	0.0130	0.0065	0.0010	0.0280
KJEL_N	6	0.2033	0.0931	0.0380	0.1100	0.3200
DSICON	6	637.6667	59.0886	24.1228	566.0000	703.0000
PH	5	8.2080	0.0887	0.0397	8.0900	8.2900
LAB_PH	6	7.8883	0.0714	0.0291	7.8000	7.9700
T_ALK	6	85.8333	2.3805	0.9718	83.0000	89.0000
CNDUCT	6	263.8333	20.8654	8.5183	244.0000	299.0000
DO	6	14.2633	0.4683	0.1912	13.4300	14.6500
CHLORDE	6	11.3500	1.7237	0.7037	9.1000	12.8000
SULFATE	6	18.9833	1.2156	0.4963	17.9000	20.9000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

------------------- BASIN=A_WESTERN SURVEY=B_SPRING2 LAYER=B_EPILIMNION -------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	14	11.9857	1.1883	0.3176	10.7000	13.9000
TURBTY	14	6.3929	1.4498	0.3875	2.8200	8.6000
CHLOR_A	14	5.8482	3.3532	0.8962	1.0000	13.3000
PHPHT_A	14	0.3100	0.3666	0.0980	-0.3000	1.0000
PHOS_T	14	0 0207	0.0039	0.0010	0.0160	0 0305
PHOS_D	14	0.0039	0.0020	0.0005	0.0021	0.0106
D_ORTH_P	14	0 0010	0.0010	0.0003	0.0002	0.0044
NO2NO3T	14	0.6987	0.1638	0.0438	0.4090	1.0750
NH3NH4T	12	0.0205	0.0319	0.0092	0.0060	0.1200
KJEL_N	14	0.1836	0.0673	0.0180	0.1000	0.3300
DSICON	14	633.0714	166.8682	44.5974	461.0000	1035.0000
PH	14	8.2984	0.2148	0.0574	7 9800	8.6300
LAB_PH	0	.	.	.	.	.
T_ALK	14	86 4321	3.3644	0.8992	82.5000	96.0000
CNDUCT	14	256.1500	15 0897	4.0329	241.5000	301.0000
DO	14	11 7500	0 7198	0.1924	10.6000	12.9000
CHLORDE	14	13.1089	2 4060	0.6430	10.4000	17.9000
SULFATE	14	20.3893	1.8793	0.5023	19.2000	25.0000
CA	0	.			.	
MG	0	.	.	.	.	.
NA	0		.	.	.	.
K	0	.	.	.	.	.
T_COUNT	3	3666 0000	3138.5455	1812.0401	98.0000	6000.0000

------------------- BASIN=A_WESTERN SURVEY=B_SPRING2 LAYER=C_MESOLIMNION -------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	4	11.0000	1.7263	0.8631	9.3000	12.9000
TURBTY	4	6 8125	1 7609	0.8804	4.7000	8.5000
CHLOR_A	4	2.9500	1 9227	0 9613	1 6000	5.8000
PHPHT_A	4	0.2500	0.2380	0 1190	0.1000	0.6000
PHOS_T	4	0.0198	0 0059	0.0030	0.0133	0.0276
PHOS_D	4	0.0034	0.0010	0 0005	0.0021	0.0043
D_ORTH_P	4	0.0010	0.0005	0.0002	0.0005	0.0015
NO2NO3T	4	0.7080	0.1480	0.0740	0.4920	0.8210
NH3NH4T	4	0.0225	0.0192	0.0096	0 0110	0.0510
KJEL_N	4	0 1425	0.0818	0.0409	0.0400	0.2300
DSICON	4	679.2500	150.0208	75.0104	469.0000	802.0000
PH	4	8.1950	0.1047	0.0524	8.0600	8.3100
LAB_PH	0	.	.	.	.	.
T_ALK	4	85.5000	3.9370	1 9685	81.5000	90.0000
CNDUCT	4	250.8750	14.9687	7.4844	232.5000	268.0000
DO	4	11 5625	0.6343	0.3171	10.7000	12.1500
CHLORDE	4	12.0500	3.1544	1.5772	8.9000	16.2000
SULFATE	4	19.5000	1.2832	0.6416	18.6000	21.4000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	2	699.5000	849.2352	600.5000	99.0000	1300.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

-------------------- BASIN=A_WESTERN SURVEY=B_SPRING2 LAYER=D_HYPOLIMNION --------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	5	8.4200	1.4237	0.6367	6.8000	10.1000
TURBTY	5	6.5080	1.6220	0.7254	4.0000	8.0000
CHLOR_A	5	4.2600	3.3702	1.5072	1.0000	8.5000
PHPHT_A	5	0.3500	0.3708	0.1658	0.0000	0.9500
PHOS_T	5	0.0194	0.0043	0.0019	0.0130	0.0250
PHOS_D	5	0.0039	0.0024	0.0011	0.0023	0.0082
D_ORTH_P	5	0.0015	0.0017	0.0007	0.0005	0.0044
NO2NO3T	5	0.7671	0.1444	0.0646	0.6417	1.0080
NH3NH4T	5	0.0543	0.0928	0.0415	0.0065	0.2200
KJEL_N	5	0.2140	0.1905	0.0852	0.0500	0.5400
DSICON	5	688.2000	196.2695	87.7744	499.0000	974.0000
PH	5	8.1305	0.0557	0.0249	8.0600	8.1725
LAB_PH	0	.	.	.	.	.
T_ALK	5	85.4000	5.7271	2.5612	80.0000	94.0000
CNDUCT	5	254.2500	24.8357	11.1069	222.0000	291.0000
DO	5	11.4300	0.5473	0.2447	10.7000	12.1000
CHLORDE	5	13.0800	3.9638	1.7727	7.6000	17.0000
SULFATE	5	19.7400	2.3104	1.0332	17.4000	23.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

-------------------- BASIN=A_WESTERN SURVEY=B_SPRING2 LAYER=E_NEPHELOID --------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	3	7.1667	1.4224	0.8212	6.2000	8.8000
TURBTY	3	6.9167	2.9079	1.6789	4.4000	10.1000
CHLOR_A	3	1.7333	0.8622	0.4978	0.8000	2.5000
PHPHT_A	3	0.0667	0.0577	0.0333	0.0000	0.1000
PHOS_T	3	0.0223	0.0085	0.0049	0.0159	0.0319
PHOS_D	3	0.0051	0.0052	0.0030	0.0017	0.0111
D_ORTH_P	3	0.0021	0.0024	0.0014	0.0005	0.0048
NO2NO3T	3	0.7667	0.3405	0.1966	0.4370	1.1170
NH3NH4T	3	0.0437	0.0575	0.0332	0.0080	0.1100
KJEL_N	3	0.1500	0.1082	0.0624	0.0600	0.2700
DSICON	3	744.0000	283.5930	163.7325	509.0000	1059.0000
PH	3	8.1033	0.1290	0.0745	7.9600	8.2100
LAB_PH	0	.	.	.	.	.
T_ALK	3	86.3333	7.9425	4.5856	81.5000	95.5000
CNDUCT	3	258.1667	36.5046	21.0759	222.0000	295.0000
DO	3	11.6667	0.5795	0.3346	11.0000	12.0500
CHLORDE	3	13.4333	5.2310	3.0201	7.4000	16.7000
SULFATE	3	19.8000	2.8844	1.6653	17.4000	23.0000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	3	613.3333	546.0159	315.2424	120.0000	1200.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

---- BASIN=A_WESTERN SURVEY=C_SUMMER LAYER=B_EPILIMNION ----

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	21	22.4762	0.7389	0.1612	21.2000	23.7000
TURBTY	21	4.1712	1.2869	0.2808	1.9667	6.2400
CHLOR_A	21	10.8357	6.5627	1.4321	2.1000	23.5000
PHPHT_A	21	2.9476	2.8282	0.6172	-5.4000	7.1750
PHOS_T	21	0.0179	0.0093	0.0020	0.0048	0.0344
PHOS_D	21	0.0042	0.0018	0.0004	0.0019	0.0086
D_ORTH_P	21	0.0016	0.0012	0.0003	0.0004	0.0059
NO2NO3T	21	0.1814	0.1115	0.0243	0.0320	0.3340
NH3NH4T	21	0.0274	0.0216	0.0047	0.0055	0.0910
KJEL_N	19	0.3501	0.1309	0.0300	0.1700	0.7050
DSICON	21	329.4286	166.6759	36.3717	76.0000	571.0000
PH	21	8.5360	0.2018	0.0440	8.1100	8.7500
LAB_PH	0		.			
T_ALK	21	82.7800	3.3920	0.7402	78.0000	90.0000
CNDUCT	21	233.9524	10.1006	2.2041	219.0000	255.0000
DO	16	7.9577	0.3658	0.0914	7.3000	8.6000
CHLORDE	21	9.5286	1.1975	0.2613	7.5000	11.5000
SULFATE	21	18.8821	1.4332	0.3127	16.9000	21.5000
CA	16	29.9375	1.7308	0.4327	28.0000	34.0000
MG	16	8.0562	0.2828	0.0707	7.5000	8.5000
NA	16	6.0437	0.7780	0.1945	4.9000	7.3000
K	16	1.1781	0.1055	0.0264	0.9700	1.3500
T_COUNT	3	453.3333	350.1904	202.1825	110.0000	810.0000

---- BASIN=A_WESTERN SURVEY=D_FALL LAYER=B_EPILIMNION ----

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	15	7.0400	0.9295	0.2400	5.7000	8.4000
TURBTY	14	12.0182	6.1928	1.6551	6.8100	23.2000
CHLOR_A	14	1.7214	0.9305	0.2487	0.7000	3.6750
PHPHT_A	14	0.8357	0.5077	0.1357	0.2000	1.9000
PHOS_T	14	0.0326	0.0102	0.0027	0.0176	0.0442
PHOS_D	14	0.0069	0.0037	0.0010	0.0021	0.0147
D_ORTH_P	14	0.0037	0.0027	0.0007	0.0006	0.0098
NO2NO3T	14	0.4327	0.1040	0.0278	0.2910	0.5960
NH3NH4T	14	0.0379	0.0442	0.0118	0.0062	0.1500
KJEL_N	14	0.2539	0.0901	0.0241	0.1000	0.4250
DSICON	14	743.3571	212.4685	56.7846	390.0000	1126.0000
PH	14	8.0946	0.0521	0.0139	7.9875	8.1700
LAB_PH	0	.	.			.
T_ALK	14	83.5900	4.4463	1.1883	78.5000	92.8000
CNDUCT	14	244.6329	20.1825	5.3940	224.5000	291.5000
DO	15	10.8640	0.4975	0.1285	10.1300	11.9000
CHLORDE	14	10.7932	2.7452	0.7337	7.8000	16.9000
SULFATE	14	18.4921	2.2947	0.6133	16.0000	23.0000
CA	0	.	.	.		.
MG	0	.	.	.	.	.
NA	0		.	.	.	.
K	0	.	.	.	.	.
T_COUNT	6	10148.3333	11759.9599	4800.9835	220.0000	27200.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------- BASIN=B_CENTRAL SURVEY=A_WINTER1 LAYER=B_EPILIMNION ----------						
W_TEMP	4	2.0000	0.0000	0.0000	2.0000	2.0000
TURBTY	0	.	.	.	.	.
CHLOR_A	4	4.5700	0.5811	0.2905	3.9500	5.2300
PHPHT_A	4	2.5650	0.7964	0.3982	1.7300	3.6200
PHOS_T	4	0.0429	0.0027	0.0013	0.0391	0.0452
PHOS_D	4	0.0075	0.0010	0.0005	0.0064	0.0085
D_ORTH_P	4	0.0055	0.0036	0.0018	0.0030	0.0109
NO2NO3T	4	0.2172	0.0097	0.0049	0.2080	0.2310
NH3NH4T	4	0.0057	0.0057	0.0029	0.0010	0.0140
KJEL_N	4	0.1500	0.0183	0.0091	0.1300	0.1700
DSICON	4	75.2500	14.1510	7.0755	63.0000	88.0000
PH	3	8.1500	0.0100	0.0058	8.1400	8.1600
LAB_PH	4	8.0675	0.0263	0.0131	8.0300	8.0900
T_ALK	4	97 0000	0.0000	0.0000	97.0000	97.0000
CNDUCT	4	290.7500	0 9574	0.4787	290.0000	292.0000
DO	2	12.8500	0.0707	0.0500	12.8000	12.9000
CHLORDE	4	17.5000	0.0816	0.0408	17.4000	17.6000
SULFATE	4	25.4250	0.2217	0.1109	25.1000	25.6000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0		.	.		.
T_COUNT	0	.	.	.	.	.
---------- BASIN=B_CENTRAL SURVEY=A_WINTER2 LAYER=B_EPILIMNION ----------						
W_TEMP	4	0.0000	0.0000	0.0000	0.0000	0.0000
TURBTY	0	.	.	.	.	.
CHLOR_A	4	2.4750	0.3979	0.1989	2.0000	2.9300
PHPHT_A	4	0.0750	0.2127	0.1063	-0.1600	0.3400
PHOS_T	4	0.0095	0.0006	0.0003	0.0087	0.0102
PHOS_D	0	.	.	.	.	.
D_ORTH_P	4	0.0014	0.0005	0.0002	0.0010	0.0021
NO2NO3T	4	0.2212	0.0078	0.0039	0.2110	0.2300
NH3NH4T	4	0.0010	0.0012	0.0006	0.0000	0.0020
KJEL_N	4	0.1475	0.0126	0.0063	0.1300	0.1600
DSICON	4	36.0000	13.8564	6.9282	24.0000	48.0000
PH	0	.	.	.	.	.
LAB_PH	4	8.0025	0.0330	0.0165	7.9700	8.0400
T_ALK	4	96.6250	0.2500	0.1250	96.5000	97.0000
CNDUCT	4	283.7500	0.9574	0.4787	283.0000	285.0000
DO	4	14.0200	0.4226	0.2113	13.4500	14.4500
CHLORDE	4	13.4000	1.6753	0.8377	11.9000	14.9000
SULFATE	4	23.7000	0.1826	0.0913	23.5000	23.9000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=B_CENTRAL SURVEY=B_SPRING1 LAYER=B_EPILIMNION						
W_TEMP	13	6.6000	0.8803	0.2442	5.5000	8.2000
TURBTY	13	1.4615	0.2163	0.0600	1.0700	1.8100
CHLOR_A	13	2.5231	1.1656	0.3233	1.3000	4.9000
PHPHT_A	13	0.0231	0.1472	0.0408	-0.1000	0.3000
PHOS_T	13	0.0118	0.0019	0.0005	0 0098	0.0159
PHOS_D	13	0.0037	0.0007	0.0002	0.0030	0.0048
D_ORTH_P	13	0.0009	0.0002	0.0001	0.0006	0.0013
NO2NO3T	13	0.1977	0.0270	0.0075	0.1420	0.2280
NH3NH4T	13	0.0035	0.0021	0.0006	0.0010	0.0070
KJEL_N	13	0.1154	0.0431	0.0120	0.0300	0.1800
DSICON	13	12.0000	7.3144	2.0286	4.0000	34.0000
PH	13	8.3127	0.0676	0.0187	8.2000	8.4300
LAB_PH	0	.	.	.	.	.
T_ALK	13	93.1023	1.0352	0.2871	91 0000	94.1300
CNDUCT	13	277.5292	3.3598	0.9318	274.0000	283.0000
DO	12	12.6883	0.8867	0.2560	10.3500	13.4000
CHLORDE	13	14.8423	0 7772	0.2156	14.0000	16.3000
SULFATE	13	22.7000	0 6312	0.1751	21.7000	23.9750
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	4	7 5000	1.0000	0.5000	7.0000	9.0000
BASIN=B_CENTRAL SURVEY=B_SPRING1 LAYER=C_MESOLIMNION						
W_TEMP	5	5.8200	0 6419	0.2871	5 0000	6.5000
TURBTY	4	1.5375	0.1795	0.0898	1.2700	1.6500
CHLOR_A	4	2.9250	2 7909	1.3955	1.3000	7.1000
PHPHT_A	4	0.1500	0 5686	0.2843	-0.2000	1.0000
PHOS_T	4	0.0150	0.0068	0 0034	0.0098	0.0250
PHOS_D	4	0.0037	0.0009	0.0005	0.0028	0.0046
D_ORTH_P	4	0.0019	0.0008	0.0004	0.0010	0.0030
NO2NO3T	4	0.2205	0.0177	0.0089	0.1980	0.2370
NH3NH4T	4	0.0027	0.0005	0.0002	0.0020	0.0030
KJEL_N	5	0.1000	0.0524	0.0235	0.0400	0.1800
DSICON	4	12.5000	12.2610	6.1305	4.0000	30.0000
PH	4	8.2000	0 0716	0.0358	8.1000	8.2700
LAB_PH	0	.			.	.
T_ALK	4	93.1250	0.7500	0.3750	92.5000	94.0000
CNDUCT	4	277.6250	4.0492	2 0246	274.5000	283.5000
DO	5	12.2600	1.0825	0.4841	10.5000	13.4500
CHLORDE	4	14.9000	0.8124	0.4062	14.3000	16.1000
SULFATE	4	22.7250	0.7274	0.3637	22.2000	23.8000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	2	19.0000	16.9706	12.0000	7.0000	31.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
-------------------- BASIN=B_CENTRAL SURVEY=B_SPRING1 LAYER=D_HYPOLIMNION --------------------						
W_TEMP	6	4.1667	0.3983	0.1626	3.8000	4.8000
TURBTY	5	1.5460	0.2360	0.1055	1.2700	1.8300
CHLOR_A	5	1.3200	0 1095	0.0490	1.2000	1.5000
PHPHT_A	5	0.0600	0.0548	0.0245	0.0000	0 1000
PHOS_T	5	0.0132	0.0050	0.0023	0.0103	0.0222
PHOS_D	5	0.0030	0.0007	0.0003	0.0021	0.0037
D_ORTH_P	5	0.0008	0.0003	0.0001	0.0004	0.0012
NO2NO3T	5	0.2300	0.0306	0.0137	0.1920	0.2580
NH3NH4T	5	0.0050	0.0025	0.0011	0.0030	0.0090
KJEL_N	6	0.1350	0.0459	0.0188	0.0600	0 1800
DSICON	5	9.6000	3.5777	1.6000	4.0000	12.0000
PH	5	8.1480	0.0650	0.0291	8 0600	8.2300
LAB_PH	0	.	.			.
T_ALK	5	92.6000	0.5477	0 2449	92.0000	93.0000
CNDUCT	5	276.8600	3 0246	1.3526	274.5000	282 0000
DO	6	12.0317	1.0787	0.4404	10 0400	13.0000
CHLORDE	5	14.6000	0.5050	0.2258	14 3000	15 5000
SULFATE	5	22.4600	0.4980	0.2227	22.0000	23.3000
CA	0	.		.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.		.
T_COUNT	2	13.5000	4.9497	3.5000	10.0000	17.0000
-------------------- BASIN=B_CENTRAL SURVEY=B_SPRING1 LAYER=E_NEPHELOID --------------------						
W_TEMP	6	3.9667	0.2733	0.1116	3.7000	4.4000
TURBTY	6	2.4350	0.7845	0.3203	1 6700	3.7500
CHLOR_A	6	2.9633	1.4582	0 5953	1.7000	5.1000
PHPHT_A	6	0.3417	0.5907	0.2412	-0.1000	1.5000
PHOS_T	6	0.0170	0.0030	0.0012	0 0137	0.0215
PHOS_D	6	0.0034	0.0007	0.0003	0.0028	0.0047
D_ORTH_P	6	0.0012	0.0004	0.0002	0.0008	0.0018
NO2NO3T	6	0.2225	0.0239	0 0097	0.1940	0 2580
NH3NH4T	6	0.0073	0.0038	0.0015	0.0020	0.0120
KJEL_N	6	0 1350	0.0302	0.0123	0.0900	0.1800
DSICON	6	30.5000	13.9821	5.7082	12.0000	51.0000
PH	6	8.0517	0.0902	0.0368	7.9000	8.1500
LAB_PH	0	.	.	.	.	.
T_ALK	6	93.0333	0.9893	0.4039	92 4000	95.0000
CNDUCT	6	278.2666	3.5092	1.4326	275.0000	283.5000
DO	6	12.0300	0.6461	0.2638	11.1800	12.9500
CHLORDE	6	14.9500	0.9006	0.3676	14.3000	16.3000
SULFATE	6	22.7667	0.7448	0.3040	22.0000	23.8000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	3	13.6667	4.1633	2.4037	9.0000	17.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------------------- BASIN=B_CENTRAL SURVEY=B_SPRING2 LAYER=B_EPILIMNION ----------------------						
W_TEMP	47	4.6317	0.6268	0.0914	3.6000	6.0000
TURBTY	47	1.8534	0.7818	0.1140	0.9700	5.0400
CHLOR_A	47	2.8191	1.3289	0.1938	0.4000	5.9000
PHPHT_A	47	0.0448	0.2917	0.0425	-0.4000	1.3000
PHOS_T	47	0.0130	0.0023	0.0003	0.0098	0.0227
PHOS_D	47	0.0038	0.0006	0.0001	0.0025	0.0054
D_ORTH_P	47	0.0009	0.0003	0.0000	0.0002	0.0016
NO2NO3T	47	0.2064	0.0191	0.0028	0.1630	0.2430
NH3NH4T	47	0.0032	0.0013	0.0002	0.0015	0.0080
KJEL_N	47	0.1436	0.0684	0.0100	0.0400	0.3800
DSICON	47	9.0426	5.2542	0.7664	4.0000	31.0000
PH	47	8.2107	0.1059	0.0155	7.9300	8.4050
LAB_PH	0		.		.	.
T_ALK	47	93.3898	1.2138	0.1771	91.0000	95.5000
CNDUCT	47	276.1619	2.0980	0.3060	270.0000	280.0000
DO	47	13.1923	0.3665	0.0535	12.3500	14.1500
CHLORDE	47	14.5931	0.2939	0.0429	14.0000	15.2000
SULFATE	47	23.5574	1.4176	0.2068	20.5000	29.6000
CA	0	.		.	.	.
MG	0			.	.	.
NA	0	.		.		
K	0	.	.	.	.	.
T_COUNT	15	9.1333	4.0860	1.0550	5.0000	21.0000
---------------------- BASIN=B_CENTRAL SURVEY=C_SUMMER LAYER=B_EPILIMNION ----------------------						
W_TEMP	83	22.1904	0.2423	0.0266	21.7000	22.9000
TURBTY	81	0.4167	0.0787	0.0087	0.2800	0.6500
CHLOR_A	82	3.1555	1.0818	0.1195	1.3000	7.1000
PHPHT_A	82	0.9311	0.4601	0.0508	0.1000	2.4000
PHOS_T	83	0.0088	0.0037	0.0004	0.0050	0.0279
PHOS_D	82	0.0037	0.0021	0.0002	0.0007	0.0170
D_ORTH_P	80	0.0011	0.0016	0.0002	-0.0002	0.0126
NO2NO3T	83	0.1923	0.0295	0.0032	0.1240	0.2480
NH3NH4T	82	0.0140	0.0097	0.0011	0.0020	0.0540
KJEL_N	77	0.2997	0.0987	0.0112	0.1700	0.8100
DSICON	83	139.8072	71.0183	7.7953	54.0000	451.0000
PH	82	8.5466	0.2412	0.0266	6.5900	8.7600
LAB_PH	0	.		.		.
T_ALK	82	92.2365	0.8930	0.0986	90.0000	94.0000
CNDUCT	82	275.4223	2.8950	0.3197	270.0000	284.0000
DO	82	8.2819	0.5624	0.0621	6.2000	9.4000
CHLORDE	83	14.6736	0.4467	0.0490	13.0000	15.4000
SULFATE	83	22.6758	1.3417	0.1473	19.0000	26.0000
CA	29	34.9655	0.7311	0.1358	34.0000	36.0000
MG	29	8.3598	0.1310	0.0243	8.1000	8.6000
NA	29	8.6379	0.2901	0.0539	8.2000	9.4000
K	29	1.3254	0.0232	0.0043	1.2800	1.3700
T_COUNT	16	105.8125	60.0313	15.0078	37.0000	210.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------- BASIN=B_CENTRAL SURVEY=C_SUMMER LAYER=C_MESOLIMNION ----------						
W_TEMP	28	18.6964	1.3054	0.2467	15.0000	21 0000
TURBTY	28	0.7202	0.3308	0.0625	0.3100	1 5300
CHLOR_A	28	3.5634	1.7326	0.3274	1.2000	8.7000
PHPHT_A	28	1.1482	0.7182	0.1357	-0.3000	2 9000
PHOS_T	28	0.0157	0.0145	0.0027	0.0059	0 0746
PHOS_D	26	0.0067	0.0085	0.0017	0.0007	0.0419
D_ORTH_P	27	0 0038	0.0080	0 0015	-0.0001	0.0396
NO2NO3T	28	0.2080	0.0759	0 0143	0.0860	0.4645
NH3NH4T	28	0.0309	0.0277	0.0052	0.0040	0 1080
KJEL_N	25	0.3137	0 0887	0 0177	0.2000	0.5500
DSICON	28	601.2143	343.2596	64.8700	67.0000	1312.0000
PH	28	8.1106	0.2971	0.0562	7.6500	8.6500
LAB_PH	0	.	.	.	.	
T_ALK	28	93.1836	1.6731	0.3162	89.5000	96.3800
CNDUCT	28	279.1696	3.7614	0.7108	271.5000	284.0000
DO	28	5.3031	1.7810	0.3366	2 0500	8.3000
CHLORDE	28	14.6091	0.3742	0.0707	13.7000	15.4000
SULFATE	28	22.5670	1.1414	0 2157	20.3000	24.4500
CA	1	34.0000	.	.	34.0000	34.0000
MG	1	8.4000	.	.	8.4000	8.4000
NA	1	8.6000	.	.	8.6000	8.6000
K	1	1.3500	.	.	1.3500	1.3500
T_COUNT	0	.	.		.	.
---------- BASIN=B_CENTRAL SURVEY=C_SUMMER LAYER=D_HYPOLIMNION ----------						
W_TEMP	27	15.2667	1.4036	0.2701	13.3000	19.7000
TURBTY	27	1.7682	0.8609	0.1657	0 7000	4.2500
CHLOR_A	27	2.6991	2 8260	0 5439	0.1000	12 6000
PHPHT_A	27	1.0213	0.6738	0.1297	-0.6000	2.6000
PHOS_T	26	0.0422	0.0531	0 0104	0.0103	0 2552
PHOS_D	26	0.0215	0.0316	0.0062	0.0022	0.1544
D_ORTH_P	24	0.0237	0 0391	0.0080	0.0004	0.1735
NO2NO3T	26	0.2031	0.1181	0.0232	0.0050	0.4500
NH3NH4T	27	0.0467	0.0403	0.0078	0.0040	0.1430
KJEL_N	25	0.3446	0.1325	0.0265	0.2000	0.7300
DSICON	26	1572.0769	395.4946	77.5629	836.0000	2400.0000
PH	27	7.6166	0.1511	0.0291	7.4300	8.0600
LAB_PH	0	.	.	.	.	.
T_ALK	27	96.4309	2.5922	0.4989	93.0000	102.0000
CNDUCT	27	284.5926	2.2211	0.4275	279.2500	288.0000
DO	26	1.3835	1.2917	0.2533	0.2500	6.0000
CHLORDE	27	14.5250	0.3616	0.0696	13.9000	15.2000
SULFATE	27	22.4891	1.4244	0.2741	20.3000	24.7000
CA	26	35.8462	0.8806	0.1727	34.0000	37.0000
MG	26	8.4397	0.1347	0.0264	8.2000	8.7000
NA	26	8.5077	0.2314	0.0454	7.9000	8.9000
K	26	1.3747	0.0228	0.0045	1.3000	1.4100
T_COUNT	7	119.5714	44.5865	16 8521	61.0000	180.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=B_CENTRAL SURVEY=C_SUMMER LAYER=E_NEPHELOID						
W_TEMP	1	14.1000	.	.	14.1000	14.1000
TURBTY	1	1.5800		.	1.5800	1.5800
CHLOR_A	1	0.5000		.	0.5000	0.5000
PHPHT_A	1	0.5000			0.5000	0.5000
PHOS_T	1	0.0551	.		0.0551	0.0551
PHOS_D	1	0.0330	.		0.0330	0.0330
D_ORTH_P	1	0.0295	.		0.0295	0.0295
NO2NO3T	1	0.0970		.	0.0970	0.0970
NH3NH4T	1	0.1070			0.1070	0.1070
KJEL_N	1	0.3200		.	0.3200	0.3200
DSICON	1	1360.0000	.		1360.0000	1360.0000
PH	1	7.5300	.		7.5300	7.5300
LAB_PH	0			.		.
T_ALK	1	100.0000			100.0000	100.0000
CNDUCT	1	290.0000	.		290.0000	290.0000
DO	1	0.2500	.		0.2500	0.2500
CHLORDE	1	14.6000	.		14.6000	14.6000
SULFATE	1	23.7000	.		23.7000	23.7000
CA	1	37.0000	.		37.0000	37.0000
MG	1	8.4000	.	.	8.4000	8.4000
NA	1	8.5000	.		8.5000	8.5000
K	1	1.3800	.		1.3800	1.3800
T_COUNT	0		.			.
BASIN=B_CENTRAL SURVEY=D_FALL LAYER=B_EPILIMNION						
W_TEMP	67	10.5910	0.4673	0.0571	9.7000	11.4000
TURBTY	67	2.3744	0.5581	0.0682	1.3400	4.0600
CHLOR_A	68	2.6200	0.8316	0.1008	1.2000	4.9000
PHPHT_A	68	0.5656	0.2858	0.0347	-0.5000	1.2000
PHOS_T	68	0.0214	0.0039	0.0005	0.0121	0.0281
PHOS_D	68	0.0099	0.0022	0.0003	0.0045	0.0133
D_ORTH_P	68	0.0049	0.0019	0.0002	0.0014	0.0116
NO2NO3T	68	0.1282	0.0222	0.0027	0.0800	0.1780
NH3NH4T	68	0.0179	0.0089	0.0011	0.0060	0.0370
KJEL_N	68	0.2302	0.1044	0.0127	0.0300	0.5500
DSICON	68	78.8235	34.3524	4.1658	22.0000	139.0000
PH	68	8.1906	0.0339	0.0041	8.0900	8.2700
LAB_PH	0	.		.		.
T_ALK	68	92.1075	2.8604	0.3469	71.3300	95.0000
CNDUCT	68	278.5129	4.3941	0.5329	270.0000	285.0000
DO	68	9.9279	0.6191	0.0751	9.1000	11.6000
CHLORDE	68	14.6560	0.5576	0.0676	13.5000	15.5000
SULFATE	68	23.0912	1.0813	0.1311	20.9000	25.5000
CA	0	.	.	.	.	
MG	0	.	.	.		.
NA	0	.	.	.		.
K	0	.	.	.	.	.
T_COUNT	30	91.7000	43.4235	7.9280	26.0000	180.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

--------------------- BASIN=C_EASTERN SURVEY=A_WINTER1 LAYER=B_EPILIMNION ---------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	1	3.5000	.	.	3.5000	3.5000
TURBTY	0	.	.	.	.	.
CHLOR_A	3	1.9200	0.1212	0.0700	1.8100	2.0500
PHPHT_A	3	0.4733	0.1531	0.0884	0.3800	0.6500
PHOS_T	3	0 0164	0.0067	0.0039	0.0124	0.0241
PHOS_D	3	0.0084	0.0003	0.0002	0.0081	0.0086
D_ORTH_P	3	0.0036	0.0011	0.0007	0.0028	0.0049
NO2NO3T	3	0.2627	0 0067	0.0038	0.2570	0.2700
NH3NH4T	3	0.0060	0.0036	0.0021	0.0020	0.0090
KJEL_N	3	0.1567	0.0351	0.0203	0.1200	0.1900
DSICON	3	62.3333	3.0551	1.7638	59.0000	65.0000
PH	2	8.1900	0.0283	0.0200	8.1700	8.2100
LAB_PH	3	8.0967	0.0577	0.0333	8.0300	8.1300
T_ALK	3	99.5000	0.5000	0.2887	99.0000	100.0000
CNDUCT	3	290.0000	0.0000	0.0000	290.0000	290.0000
DO	1	13.3000	.	.	13.3000	13.3000
CHLORDE	3	16.5333	0.0577	0.0333	16.5000	16.6000
SULFATE	3	25.8000	0.1000	0.0577	25.7000	25.9000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

--------------------- BASIN=C_EASTERN SURVEY=A_WINTER2 LAYER=B_EPILIMNION ---------------------

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
W_TEMP	4	0.0000	0.0000	0.0000	0.0000	0.0000
TURBTY	0	.	.	.	.	.
CHLOR_A	4	1.0625	0.3181	0.1590	0.7000	1.4100
PHPHT_A	4	0.1225	0.2645	0.1322	-0.1300	0.4800
PHOS_T	4	0.0116	0.0010	0.0005	0.0106	0.0128
PHOS_D	0	.	.	.	.	.
D_ORTH_P	4	0.0026	0.0004	0.0002	0.0021	0.0030
NO2NO3T	4	0.2745	0.0066	0.0033	0.2680	0.2830
NH3NH4T	4	0.0005	0.0006	0.0003	0.0000	0.0010
KJEL_N	4	0.1275	0.0250	0.0125	0.0900	0.1400
DSICON	4	67.7500	3.7749	1.8875	65.0000	73.0000
PH	3	7.9733	0.0252	0.0145	7.9500	8.0000
LAB_PH	4	7.9575	0.0263	0.0131	7.9200	7.9800
T_ALK	4	98.2500	0.6455	0.3227	97.5000	99.0000
CNDUCT	4	289.0000	1.1547	0.5774	288.0000	290.0000
DO	4	13.4125	0.2529	0.1265	13.1000	13.7000
CHLORDE	4	15.2000	0.1155	0.0577	15.1000	15.3000
SULFATE	4	23.8250	0.3304	0.1652	23.4000	24.2000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	0	.	.	.	.	.

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
BASIN=C_EASTERN SURVEY=B_SPRING2 LAYER=B_EPILIMNION						
W_TEMP	40	2.1275	0.3803	0.0601	1.7000	3.1000
TURBTY	40	2.6334	0.8276	0.1309	1.7200	5.1500
CHLOR_A	40	0.3966	0.2347	0.0371	0.2000	1.0000
PHPHT_A	40	0.0674	0.0555	0.0088	-0.1000	0.2000
PHOS_T	40	0.0128	0.0013	0.0002	0.0109	0.0164
PHOS_D	40	0.0062	0.0006	0.0001	0.0047	0.0078
D_ORTH_P	40	0.0027	0.0007	0.0001	0.0016	0.0043
NO2NO3T	40	0.2876	0.0198	0.0031	0.2430	0.3220
NH3NH4T	40	0.0068	0.0019	0.0003	0.0040	0.0110
KJEL_N	40	0.1217	0.0918	0.0145	0.0300	0.6200
DSICON	40	71.5000	10.9755	1.7354	54.0000	88.0000
PH	40	7.9254	0.0688	0.0109	7.7000	8.0400
LAB_PH	0					.
T_ALK	40	92.3775	1.4633	0.2314	90.0000	95.0000
CNDUCT	40	278.2187	2.0266	0.3204	274.0000	282.0000
DO	39	12.9238	0.5577	0.0893	10.1500	13.4000
CHLORDE	40	14.9356	0.2395	0.0379	14.5000	15.4000
SULFATE	40	23.2012	0.5374	0.0850	21.9000	24.4000
CA	0			.	.	.
MG	0	.				.
NA	0					.
K	0			.		
T_COUNT	13	62.8462	41.6010	11.5380	14.0000	140.0000
BASIN=C_EASTERN SURVEY=C_SUMMER LAYER=B_EPILIMNION						
W_TEMP	24	21.8042	0.3581	0.0731	21.2000	22.5000
TURBTY	24	0.4790	0.4879	0.0996	0.2800	2.7400
CHLOR_A	24	1.3906	0.4322	0.0882	0.7000	2.4000
PHPHT_A	24	0.6135	0.1822	0.0372	0.4000	1.0750
PHOS_T	24	0.0057	0.0013	0.0003	0.0037	0.0085
PHOS_D	23	0.0023	0.0011	0.0002	0.0008	0.0046
D_ORTH_P	24	0.0011	0.0008	0.0002	0.0003	0.0041
NO2NO3T	24	0.1852	0.0214	0.0044	0.1630	0.2510
NH3NH4T	24	0.0066	0.0033	0.0007	0.0020	0.0110
KJEL_N	24	0.2786	0.1190	0.0243	0.1300	0.6600
DSICON	24	75.4583	28.7251	5.8635	39.0000	135.0000
PH	24	8.5528	0.1440	0.0294	8.0700	8.6700
LAB_PH	0		.		.	.
T_ALK	24	92.5156	0.7521	0.1535	91.0000	94.0000
CNDUCT	24	280.2292	1.1299	0.2306	277.0000	282.0000
DO	21	8.8845	0.4531	0.0989	7.7000	9.8000
CHLORDE	24	15.0135	0.3555	0.0726	14.4000	15.6000
SULFATE	24	23.0458	0.8933	0.1823	21.5000	24.1000
CA	8	35.5000	0.5345	0.1890	35.0000	36.0000
MG	8	8.3500	0.1512	0.0535	8.0000	8.5000
NA	8	8.9000	0.1512	0.0535	8.6000	9.1000
K	8	1.3500	0.0214	0.0076	1.3300	1.4000
T_COUNT	7	173.8571	124.5611	47.0797	66.0000	390.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
--------------------- BASIN=C_EASTERN SURVEY=C_SUMMER LAYER=C_MESOLIMNION ---------------------						
W_TEMP	8	13.8375	0.8782	0.3105	12.5000	15.0000
TURBTY	8	0.6108	0.2100	0.0742	0.4000	1.0300
CHLOR_A	8	1.2250	0.6431	0.2274	0.5000	2.4000
PHPHT_A	8	0.6000	0.2928	0 1035	0.3000	1.0000
PHOS_T	8	0.0053	0.0011	0.0004	0.0032	0 0065
PHOS_D	8	0 0021	0.0014	0.0005	0.0007	0 0047
D_ORTH_P	8	0.0014	0.0007	0.0002	0.0006	0.0027
NO2NO3T	8	0.3007	0.0270	0.0096	0.2570	0.3390
NH3NH4T	8	0.0082	0.0108	0.0038	0.0010	0.0340
KJEL_N	8	0 1697	0.0880	0.0311	0.0000	0.3100
DSICON	8	145.5000	93.0023	32.8813	60.0000	346.0000
PH	8	7.9596	0.1052	0.0372	7.8300	8.1000
LAB_PH	0	.	.	.	.	.
T_ALK	8	93.4162	0.6962	0.2461	92.8300	95.0000
CNDUCT	8	284.8750	1.6421	0.5806	282.0000	287.0000
DO	7	7.9262	0.8497	0.3212	6.8500	9 4000
CHLORDE	8	14 9100	0.3065	0.1084	14.4000	15 4000
SULFATE	8	22.6912	0.9086	0.3212	21.5000	23.6000
CA	0	.		.		.
MG	0	.	.	.	.	.
NA	0	.	.		.	.
K	0	.		.	.	
T_COUNT	0	.	.	.	.	.
--------------------- BASIN=C_EASTERN SURVEY=C_SUMMER LAYER=D_HYPOLIMNION ---------------------						
W_TEMP	10	5 8400	1.0977	0.3471	4.7000	8.4000
TURBTY	10	1.5940	0.3976	0.1257	1.0400	2 2800
CHLOR_A	10	0.3700	0.2406	0.0761	0.0000	0 9000
PHPHT_A	10	0.4700	0.1947	0.0616	0.2000	0.8000
PHOS_T	10	0.0071	0.0024	0.0008	0.0031	0.0113
PHOS_D	10	0.0025	0.0008	0.0003	0.0014	0 0038
D_ORTH_P	10	0.0025	0.0009	0.0003	0.0015	0.0040
NO2NO3T	10	0.3461	0.0349	0.0110	0.2820	0.4120
NH3NH4T	10	0.0112	0.0077	0.0024	0.0030	0.0240
KJEL_N	10	0.2140	0.1258	0.0398	0 1200	0.5100
DSICON	10	303.3000	83.0529	26.2636	133.0000	434.0000
PH	10	7.9060	0.0635	0.0201	7.7900	7.9900
LAB_PH	0	.	.	.	.	.
T_ALK	10	94.1500	0.7472	0.2363	93.0000	95.0000
CNDUCT	10	286.6000	1.4298	0.4522	285.0000	289.0000
DO	9	10.1000	1 3219	0.4406	7.6000	11.6000
CHLORDE	10	14 8100	0 2558	0.0809	14.6000	15.4000
SULFATE	10	23.2900	1.1761	0.3719	21.7000	25.3000
CA	0	.	.	.	.	.
MG	0	.	.	.	.	.
NA	0	.	.	.	.	.
K	0	.	.	.	.	.
T_COUNT	1	140.0000	.	.	140.0000	140.0000

L. ERIE DESCRIPTIVE STATISTICS, BY BASIN, SURVEY AND LAYER

VARIABLE	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM
---------------------- BASIN=C_EASTERN SURVEY=C_SUMMER LAYER=E_NEPHELOID ----------------------						
W_TEMP	16	5.6875	1.2049	0 3012	4.7000	8.3000
TURBTY	16	1.9213	0.3273	0 0818	1.4600	2.4200
CHLOR_A	16	0 3016	0 1233	0 0308	0 1500	0 5000
PHPHT_A	16	0.4859	0 1906	0 0477	0.1000	0 9000
PHOS_T	16	0 0075	0.0026	0.0006	0.0021	0 0113
PHOS_D	15	0.0034	0.0021	0 0006	0.0011	0 0082
D_ORTH_P	15	0.0028	0.0006	0.0002	0.0019	0 0038
NO2NO3T	16	0.3492	0.0278	0 0070	0.3105	0 4060
NH3NH4T	16	0.0145	0.0089	0.0022	0.0040	0 0260
KJEL_N	16	0.2403	0.1198	0.0299	0 0900	0.5800
DSICON	16	340 5625	58.7469	14.6867	261 0000	438.0000
PH	16	7.9062	0 0650	0.0163	7.7900	8.0200
LAB_PH	0		.			.
T_ALK	16	94 6328	0 8702	0.2175	92 7500	96.0000
CNDUCT	16	287 0469	1 3173	0.3293	285.0000	289 0000
DO	14	9.6682	1 2907	0 3450	7.4250	11.6000
CHLORDE	16	14.8672	0.2919	0.0730	14.6000	15 4000
SULFATE	16	22.8878	1 1665	0 2916	21.0500	25.0000
CA	8	36 8750	0 8345	0.2950	36.0000	38 0000
MG	8	8 3000	0 1414	0 0500	8 0000	8.5000
NA	8	8.8125	0 0991	0.0350	8 7000	9 0000
K	8	1 3825	0 0167	0.0059	1.3600	1 4100
T_COUNT	4	337 5000	263 4862	131.7431	180 0000	730 0000
---------------------- BASIN=C_EASTERN SURVEY=D_FALL LAYER=B_EPILIMNION ----------------------						
W_TEMP	34	10 4265	0 1880	0.0322	10 0000	10.6000
TURBTY	33	4 1016	3 8393	0 6683	0.9900	18 3000
CHLOR_A	33	0 8227	0.3423	0.0596	0 3000	1.7000
PHPHT_A	33	0.3485	0.1522	0.0265	0.1000	0.8000
PHOS_T	33	0.0153	0.0071	0.0012	0.0094	0.0429
PHOS_D	33	0.0066	0.0008	0.0001	0.0056	0.0080
D_ORTH_P	33	0.0031	0.0004	0 0001	0.0020	0 0039
NO2NO3T	33	0.2045	0.0193	0.0034	0.1710	0 2440
NH3NH4T	33	0 0115	0 0067	0.0012	0.0017	0.0280
KJEL_N	33	0 1788	0.0514	0.0089	0.0700	0.3100
DSICON	33	90.4242	41.4307	7.2122	-11.0000	141 0000
PH	33	8 1045	0 0227	0.0039	8 0500	8.1600
LAB_PH	0	.	.	.		.
T_ALK	33	94.1542	0.7001	0.1219	93 0000	95.5000
CNDUCT	33	283 5424	0.7947	0.1383	281 5000	284.7000
DO	33	9.3556	0.2891	0.0503	8.4500	10.1000
CHLORDE	33	14.6100	0 3386	0.0589	14.2000	15.3000
SULFATE	33	23.2233	0.5314	0.0925	22.3800	24.2000
CA	0	.	.	.	.	
MG	0	.	.	.		
NA	0	.	.	.	.	.
K	0			.	.	
T_COUNT	13	89 1538	62.1434	17 2355	26.0000	210.0000

APPENDIX B

MICROFICHE LISTINGS OF 1985 SURVEILLANCE DATA

The microfiche appended to this report (see pocket on inside of back cover) contains a listing of the entire 1985 GLNPO STORET Great Lakes surveillance database. The database is organized chronologically, by station, that is, all samples collected at station Lake Erie 09, for example, are followed by all samples collected at Station L. Erie 11, etc. The letter "V" following sample depth indicates composited samples, the letter "T" following a parameter values indicates that the measured concentration is below the criterion of detection for that parameter.