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Lake Erie Intensive Study 1978-1979

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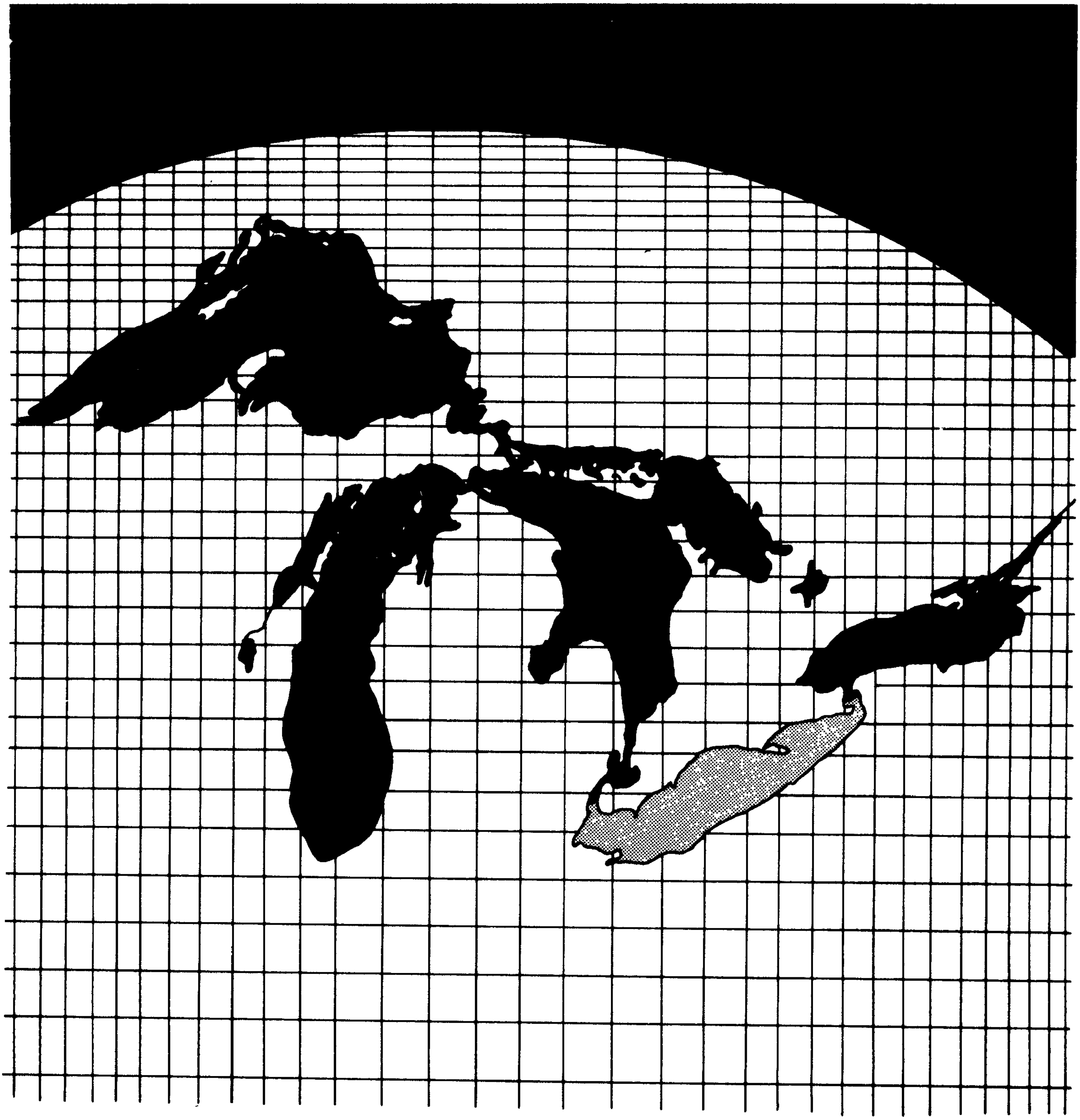

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Lake Erie Intensive Study 1978-1979

Final Report

by

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PREFACE

Lake Erie has experienced several decades of accelerated eutrophication and toxic substances contamination. During the latter part of the 1960s, remedial actions were planned and by the latter part of the 1970s, many of these plans were at least partially implemented. The first signs of lake recovery are now being observed through comprehensive monitoring programs. The intent of this report is to summarize the methods, findings and conclusions of the 1978-1979 Lake Erie Intensive Study. The report also contains a set of recommendations to insure continued improvement of the water and biotic quality of Lake Erie.

Management information in the form of a review of the lake's status and its water quality trends are contained in a companion report entitled, "Lake Erie Water Quality 1970-1982: A Management Assessment." The management report also contains recommendations designed to ensure continued improvements in the quality of the lake's water and biota.

I would like to acknowledge the excellent cooperation of the many investigators who participated in the Lake Erie Intensive Study and thank them for their contributions in the form of reports, data, and helpful suggestions. Also, I would like to thank David Rathke, Larry Cooper, Laura Fay and Gary Arico, and the other members of the Lake Erie Technical Assessment Team staff for the intensive effort in preparing this report.

Charles E. Herdendorf, Chairman
Lake Erie Technical Assessment Team

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Finally, a special recognition should be given to Noel Burns (CCIW) for his contribution to the understanding of the numerous complexities associated with the limnology of Lake Erie.

David E. Rathke
Editor

INTRODUCTION

In many respects Lake Erie has one of the longest and most complete historical Great Lakes databases. The first open lake surveys of the western, central and eastern basins were conducted during the late 1920's and into the early 1930's (Wright 1955, Fish 1960). Although no other major monitoring effort was made until the Federal Water Pollution Control Administration (FWPCA) conducted surveys in 1964 and 1968, numerous independent studies were undertaken. Many of these studies were confined to localized regions primarily in the western and central basins and were generally university affiliated.

During the mid 1960s, public awareness of the eutrophic condition of Lake Erie together with increased concern by the Canadian government and the Canadian and U.S. scientific community, prompted the initiation of the most intensive surveillance program yet to be conducted. Two programs were initiated during the 1970 field season. The first program consisted of ten surveillance cruises spanning April through December. This surveillance program, conducted by the Canada Centre for Inland Waters (CCIW), provided an extensive whole lake database plus a thorough analysis of lake processes. The program culminated in a series of 21 articles presented in the J. Fish Res. Board Can., Vol. 33, 1976. In addition, numerous scientific articles were published further expanding information on lake processes.

A second program, focusing on the central basin hypolimnion, represented a combined effort of the USEPA Cleveland Office and CCIW. This study, "Project Hypo", was designed to examine the processes responsible for the O_2 depletion problem annually encountered in the central basin. Seven central basin surveys were conducted over a 28-day period from late July through the end of August during which time numerous physical, chemical and biological parameters associated with hypolimnion dissolved oxygen depletion were measured. This program culminated in a report, "Project Hypo" (Burns and Ross 1972), consisting of nine papers each dealing with specific aspects of hypolimnion processes. The report concluded by stating:

> "The above findings and estimates lead to one definite conclusion: Phosphorus input to Lake Erie must be reduced immediately; if this is done, a quick improvement in the condition of the lake can be expected; if this is not done, the rate of deterioration of the lake will be much greater than it has been in recent years."

Following the formal scientific recognition and verification of the extensive problems developing throughout the lake, the Canada/US Water Quality Agreement was signed in 1972. This agreement called for reduction in the pollutants entering the lake, specifically phosphorus, in order to curb the increasing eutrophication-related problems. In addition, a continuation of the 1970 Canadian surveillance effort was also agreed upon, and this program began in 1973 under the sponsorship of the USEPA--Large Lakes Research Station. The western and central basins were monitored by the Center for Lake Erie Area Research--The Ohio State University (CLEAR), and the eastern basin was monitored by the State University of New York-Buffalo (SUNY). Reports were issued detailing the 1973 through 1975 open lake studies (Great Lakes Laboratory 1980, Herdendorf 1980a). The 1973-1975 database, together with the 1970 Canadian data set, provided much of the information necessary for the verification and calibration of Lake Erie models. The modeling program was developed to further the understanding of lake processes and aid in predicting responses to efforts designed to slow down the already accelerated eutrophication (DiToro and Connolly 1980, Lam et al. 1983).

The next phase of the Lake Erie program was initiated under the auspices of the International Joint Commission's Water Quality Board. An appointed Lake Erie Work Group was established to specifically develop a long-term study plan for the lake. The Lake Erie Work Group prepared a nine-year surveillance plan in 1977 which was designed to provide an understanding of the overall, long-range responses of the lake to pollution abatement efforts. This plan was eventually incorporated as part of the Great Lakes International Surveillance Plan (GLISP) developed by the Surveillance Subcommittee of the Water Quality Board. The general objectives established by the Surveillance Subcommittee for GLISP included:

1. To search for, monitor, and quantify violations of the existing agreement objectives (general and specific), the IJC recommended objectives, and the individual jurisdictional standards, criteria and objectives. Quantification will be in terms of severity, areal or volume extent, frequency, duration and will include sources.

2. To monitor local and whole lake responses to abatement measures and to identify emerging problems.

3. To determine the cause-effect relationship between water quality and inputs in order to develop the appropriate remedial/preventive actions and predictions of the rate and extent of local/whole lake responses to alternative proposals.

Within the context of these general objectives and considering the key issues specific to Lake Erie, the surveillance plan additionally focused on:

1. Determining the long-term trophic state of Lake Erie and observing to what degree remedial measures have resulted in improvements.

2. Assessing the presence, distribution, and impact of toxic substances.

3. Providing information to indicate the requirements for and direction of additional remedial programs, if necessary, to protect water uses.

Figure 1 outlines the organizational structure responsible for the implementation of the Lake Erie plan.

The Lake Erie plan called for a two-year intensive study of open lake and nearshore conditions in 1978 and 1979 to be followed by seven years of open lake monitoring. Planning and implementation of the two-year field program was coordinated by the Lake Erie Work Group of the Surveillance Subcommittee. This subcommittee served as the Implementation Committee for the IJC Great Lakes Water Quality Board. The Lake Erie Work Group was charged with the responsibility of monitoring the progress of the field investigations, preparation of reports analyzing the results of these studies, and the coordination of a comprehensive assessment of the current status of Lake Erie.

The general objective of the Lake Erie Intensive Study was to provide information for detailed assessments of tributary, nearshore, and open lake water quality. The intensive study was designed to identify emerging problem areas, to detect changes in water quality on a broad geographic basis, and to provide information necessary for trend analyses. This study was to take into consideration the seasonal nature of tributary inputs, lake circulation patterns, and nearshore-offshore gradients. Linkages between the various components of the study were to be explored to permit a detailed "whole lake" water quality assessment. In addition, information derived from this study was intended to serve as a database against which future changes could be measured.

The intensive program was divided into six major categories with the respective responsibilities sub-divided into 33 components each of which were assumed by a specified organization (Figure 2). In order to assist the Lake Erie Work Group in meeting its responsibilities the Center for Lake Erie Area Research (CLEAR) proposed that a Technical Assessment Team (TAT) be established. In March 1980, TAT was established at The Ohio State University by a grant from the U.S. Environmental Protection Agency, Great Lakes National Program Office (USEPA-GLNPO). TAT was formed to synthesized all data from the various contributors into a unified, whole lake assessment. Specific objectives of TAT include the following:

1. To perform an in-depth and integrated analysis of the database for the purpose of a comprehensive assessment.

2. To assure that all pertinent baseline data resulting from United States sources are entered into STORET for the purpose of this assessment and future analysis. Efforts would be made to achieve similar entry of Canadian data into STORET.

3. To bring together the individual Canadian and United States elements of the intensive study to produce a timely, unified whole-lake report which will:

    a. Determine the status of the open water and nearshore areas of Lake Erie in terms of:

        (1) Trophic level
        (2) Toxic substance burden
        (3) Oxygen demand

    b. Provide baseline data for the chemical, microbiological, and physical parameters of water quality against which future changes may be judged.

    c. Compare the present data with past data in order to determine how rapidly and in what manner the lake is changing.

    d. Determine how these changes are related to reductions in waste loading, pollutant bans, nutrient control programs, and pollution abatement programs.

    e. Prepare recommendations concerning the scope of future remedial programs to enhance or maintain current water quality.

Following the establishment of the TAT program, several data acquisitions were necessary in order to analyze and integrate the many programs involved in the intensive two-year study. Preliminary efforts to retrieve U.S. data sets through STORET were plagued with numerous problems. Generally, the difficulty lay in the lack of completeness of the entered information and/or mistakes within the data sets. These problems significantly delayed data analysis of both the open lake and the nearshore. All Canadian data sets were acquired directly from the appropriate agency with little complication.

In addition to the actual data, quality control information was also requested from each Lake Erie Intensive participant. IJC round-robin studies and limited information from the nearshore groups served as the only source of quality control data. Thus, thorough examination of individual group data and comparisons between groups were very limited. Due to inconsistencies within data sets and incompatability between data sets, much of the survey information was difficult to integrate. This situation existed with both open lake and nearshore data sets.

The objective of this report is to present the data collected over the two-year intensive study and evaluate it in terms of our previous knowledge of Lake Erie. This aim is not to present a model, but only to evaluate the current database and attempt to place it in perspective with information accrued over the last decade. Key pieces of missing information will be identified and future investigations will be recommended.

Methods

Open Lake

During 1978 and 1979 both the United States Environmental Protection Agency, Great Lakes National Program Office (USEPA-GLNPO), and the Canada Centre for Inland Waters, National Water Research Institute (CCIW-NWRI) conducted field programs on Lake Erie open waters. The U.S. program was established as a two-year surveillance program designed to provide an extensive baseline data set. The Canadian contribution consisted of two projects designed to examine specific research problems and were extensive enough spatially and temporily to provide detailed data on both the central and eastern basins. Information as to sampling and analytical methods will not be discussed here since this information is available through each of the respective agencies. Only those methods, either field or analytical, resulting in obvious differences in the data will be addressed.

The USEPA-GLNPO scheduled 18 surveys on the western, central and eastern basins over the two-year period. Table 1 lists the cruise dates for each survey. The station sampling pattern employed during the two-year period followed a scheme established in the early 1970's and was utilized annually from 1973 through 1977 (Herdendorf 1980a, Great Lakes Lab 1980). A total of 27 eastern basin, 37 central basin and 17 western basin stations were sampled on each cruise. Figure 3 shows the general cruise track employed during 1978. During 1979, surveys were conducted using a west to east pattern, beginning in the western basin and moving in a criss-crossing pattern toward Buffalo. Each cruise lasted approximately 10 days; however, this varied according to weather and boat maintainence problems. Water samples were obtained using the following scheme:

Unstratified Condition:	1m mid depth 1m above bottom
Stratified Condition:	1m 1m above mesolimnion 1m below mesolimnion 1m above bottom

This design was modified to accomodate differences in thermal conditions (Figure 4).

In 1978, temperature/depth profiles were taken using a Martek probe coupled with an x-y recorder. During 1979, a Guildline bathythermograph (EBT) was the primary instrument with the Martek as the support unit. Temperature/depth plots were taken at each station and were used to determine sample depths. Water samples were obtained with Niskin bottles positioned in tandem on a cable and closed at the appropriate depth by a series of messengers. Water samples were then transferred from the Niskin bottles to appropriate containers for processing. Subsequent sample processing varied for each parameter measured; for example, soluble nutrients (i.e., soluble reactive phosphorus--SRP, nitrate + nitrite - N + N, ammonia - NH_3) were processed on board ship and analyzed shortly after collection, while samples for metals analysis were stored and transported to a land-based laboratory.

The second major open lake data set was collected by CCIW-NWRI in the course of conducting specific research programs. The 1978 database was collected during a project designed to examine hypolimnion oxygen depletion mechanisms in the central and eastern basins and was initiated by N. Burns and F. Rosa. The 1979 CCIW data orginated from a project examining the flux of material through the water column and was initiated by M. Charlton. Since these two data sets were collected and analyzed by the same agency using identical standardized procedures, the data was treated as one set. The major differences in the two CCIW data sets lie in the intensity of station coverage and cruise schedules. The station plan and representative cruise tracks for each year are shown in Figures 5 and 6. The areal coverage in 1978 provides the most comprehensive database to date on the central and eastern basins. The two cruise schedules differ in that the 1979 field season begins earlier and ends later (Table 2). It should be remembered that both these projects were designed around specific research problems and were not designed to be used as lake surveillance databases.

All CCIW temperature/depth profiles were measured with a Guildline EBT. Samples were collected at intervals similar to those used by USEPA-GLNPO (Figure 4). In addition, mesolimnion samples were collected whenever the mesolimnion thickness permitted. Water was collected using a deck-controlled Rosette sampler equipped with Niskin bottles and an EBT sensor. Therefore, samples were taken at known depths and temperatures. Once water was obtained, soluble nutrients were analyzed on board, while samples that could be stored were processed at the land-based laboratory.

A potential sampling problem occurs for both single Niskin bottles and the Rosette configurated samplers. These bottles may entrain and hold water when being lowered through the water column. This is most likely to happen when samples are taken in narrow strata or limnions such as those occurring in the central basin, and since the sample bottle only travels 3-5 meters after leaving the epilimnion, adequate flushing may not occur. This problem requires further investigation.

Analysis of both the CCIW and the USEPA-GLNPO databases by TAT was implemented using identical techniques whenever possible in order to ensure compatability at this level. The first phase of the analyses of the physical and chemical data involved interpretation of the individual EBT traces from both USEPA-GLNPO and CCIW. Limnion[1] depth data for 1978 CCIW data was provided by F. Rosa. From these temperature/depth profiles, estimates as precise as the individual traces would allow were made for epilimnion, mesolimnion and hypolimnion thicknesses and temperatures.

This information was then used to create a data file containing limnion depths and temperatures for each station within a cruise. During the next phase, each sampling depth was assigned a code designating the limnion from which that sample was taken. A hypothetical example follows: Station 9 (USEPA-GLNPO), located in the eastern basin, has a sounding depth of 45 m. By examining the temperature/depth profile, it was determined that the epilimnion extended from 0 to 20 m, the mesolimnion from 20-30 m, and hypolimnion from 30-45 m. Water samples at Station 9 were taken at 1 m, 10 m, 19 m, 25 m, 31 m, 37 m and 44 m. Each one of the sample depths was then coded appropriately, i.e., 1, 10 and 19 meters = epilimnion, 25 meters = mesolimnion, and 31, 37, and 44 meters = hypolimnion. During unstratified conditions, depths were simply coded surface, mid or bottom.

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[1] The term limnion will be used throughout this text to refer non-specifically to one or all thermal layers (i.e., epilimnion, mesolimnion, hypolimnion).

The limnion depth determinations and the sample coding files enabled two computer programs to be utilized. The first and most sophisticated program was developed specifically to be used on Lake Erie data sets. The "Survey 8"-A Budget Calculation Program for Lake Erie developed by B. Hanson, F. Rosa and N. Burns (1978), computes lake-wide or basin-wide volume weighted concentrations and quantities (metric tons) for any given parameter plus plots isopleth distribution maps of each stratified layer. The Survey 8 program also provides an estimate of the area and volume for each limnion. The lake was partitioned into geographical regions based on Sly (1976), i.e., western, central and eastern basins; thus, estimates of limnion volumes and parameter volume weighted mean concentrations were available for each individual basin.

Due to the cost and time necessary to run Survey 8's, a second program was utilized to obtain routine mean concentrations. Sort and means programs available with the Statistical Analysis System (SAS) package were applied to these data sets. Since all station data had been coded as to basin and each sampling depth coded as to limnion, a simple means program could be utilized. This system provided means, standard errors, maximum, minimum, and sample number (n) for any parameter in the data set. Graphical representation of the data sets includes all the previously mentioned statistics (Figure 7). This data was compiled for the individual basins and limnions however, the values were not volume weighted. If total quantities were desired for budget purposes, the volume of each limnion obtained from the Survey-8 program could be multiplied by the mean concentration to obtain total tonnages.

We were confronted with a rather unique situation, having two distinctly different data sets available for the two-year period. Both the CCIW and the USEPA-GLNPO data sets were examined individually before they were compared. Since both station patterns and cruise schedules were significantly different, comparison was somewhat subjective. The 1978 data sets were the most complete, consequently comparisons between agencies were made using the 1978 database. First, the Survey 8 program was run in order to compare limnion volumes and thicknesses. The poor quality of the USEPA temperature/depth profiles made this comparison extremely difficult for most of the surveys (Figure 8). When comparisons could be made, differences in individual limnion volumes ranged from 20 to 50 percent. When Guildline EBT's were taken by both agencies, good agreement existed for limnion volume comparisons; however, the instrument was not used for all cruises and only partially on some surveys conducted by

USEPA-GLNPO. Considering the difference in quality of the temperature/depth profiles, the CCIW data was considered to be the most accurate.

Since the concentrations and quantities of phosphorus are of primary importance in the evaluation of Lake Erie's current trophic status, this parameter was examined to determine data compatability. Volume weighted concentrations by limnion could not be compared due to the differences in estimated limnion volumes as previously discussed; consequently, calculated total basin tonnages were compared. The 1978 and 1979 CCIW-NWRI phosphorus concentrations and quantities were found to be comparable with data sets collected since 1970. The 1978 central basin concentration and quantities of total phosphorus derived from the USEPA-GLNPO data sets were 30-40 percent lower than estimates calculated from the CCIW data. When the 1979 data was compared for the two organizations, total phosphorus determinations were found to be more compatible than in the 1978 data set, however, the USEPA-GLNPO values were still found to be consistently lower. The reason for this discrepancy is not clear; however, the analytical method used by the two agencies was different. Phosphorus determinations made by the USEPA-GLNPO laboratories conformed to USEPA methods for waste water analysis utilizing the molybdate ascorbic acid technique, while CCIW used the molybdate stannous chloride procedure. Based on these two problem areas (volume determinations and total phosphorous concentrations) it was decided to use the CCIW data as the primary data set and USEPA-GLNPO data when Canadian information was not available.

Nearshore.

As a segment of the two-year intensive study on Lake Erie, the nearshore zone was monitored with the intent to provide compatable data sets throughout the nearshore and open lake. The nearshore study was divided among four groups: 1) northshore - Ontario Ministry of the Environment - OMOE; 2) western basin - U.S., CLEAR - OSU; 3) central basin - U.S., Heidelberg College; 4) eastern basin - U.S., GLL - SUNY.

The entire U.S. shoreline was a coordinated study sponsored and managed by USEPA-GLNPO Region V. The program was designed with the three participants monitoring the U.S. nearshore zone using similar schedules, sampling methods, and analytical procedures. Four surveys were conducted each year (Table 3) to examine seasonal variability. The sampling pattern was designed to provide stations parallel to the shoreline as well as clusters of stations perpendicular to the shore in regions of harbors and river mouths (Figure 9). During each survey the individual stations were sampled on three consecutive days in order to estimate short-term variability.

Analytical methods employed by each groups were those outlined by USEPA with details and/or modifications of procedures available from each of the three groups participating in the U.S. program. The number and position of the sampling depths at individual stations varied with the sounding depth. Samples were routinely taken one meter below the surface and one meter above the bottom. This general pattern was modified for sounding depths less than 4 m when only surface samples were taken and soundings greater than 10 m when a mid depth sample was added.

Two significant problems developed when combining the three U.S. data sets. First, even though uniform methodologies were to have been followed, several inconsistencies were evident. For example, in the eastern basin the soluble nutrient chemistry was not carried out on-board ship as was done in the western and central basins. Water samples to be analyzed for soluble nutrients (i.e., soluble phosphorus, ammonia and nitrate plus nitrite) were stored and processed at a shore-based laboratory. Thus, this data must be interpreted as only estimates of shoreline concentrations. An additional interpretation problem existed in the central basin where no temperature/depth profiles were taken at the deeper stations (> 10 m). Consequently, the extent of intrusion of mesolimnion or hypolimnion water into this zone was difficult to verify.

The second problem encountered while attempting to interface the data resulted from the difference in cruise schedules (Table 3). During the spring, scheduling differences were largely due to varying ice conditions from the western to the eastern basin. During the summer and fall, however, no attempt was made to sample the various basins within the same time frame. This added an additional variable to an already highly variable region.

The north shore study conducted by the Ontario Ministry of the Environment (OMOE) was designed independently of the U.S. nearshore study. The sampling pattern covered all three basins (Figure 10) with various levels of effort directed at specified areas along the shore. The cruise schedule differed in 1978 and 1979 and also differed from the south shore plan (Table 3). As with the south shore study, two distinct station patterns were evident: 1) stations forming a chain parallel to the shoreline, and 2) stations forming a chain perpendicular to the shoreline, usually forming a transect originating at a river mouth or harbor and extending into the open lake (Figure 10).

Although major differences existed between the four data sets, the techniques employed to summarize and analyze the data were as uniform as possible. The entire nearshore region was subdivided into homogeneous sections referred to as "reaches" (Figure 9 and 10, Table 4). A total of 20 reaches were designated along the entire lake shore. Areas that presented unique conditions (i.e., exceptionally high nutrient concentration) such as the Maumee River Bay at Toledo, Ohio were designated as individual reaches. This approach was taken in order to avoid areas having significantly large point sources from heavily influencing mean concentration calculations of adjacent regions not subject to strong localized effects. Mean and median reach concentrations were calculated for each cruise and year; however, only yearly values will be presented in this report. In addition, selected transects perpendicular to the shore were examined in order to define the sharp concentration gradient occurring within 5 km of the nearshore zone. Individual stations located in harbors and/or river mouths were examined to obtain yearly mean concentrations in regions considered to be problem areas. In the three types of geographical divisions, all station values measured were averaged. In other words, all surface and bottom values measured over the consecutive 3-day period were averaged in order to obtain a mean for an individual station. The individual station values were then averaged for an entire reach area to yield a reach mean.

Data Compatability

When attempting to summarize the data collected by the agencies involved in the two-year program, data compatability became an extremely important consideration. Consequently, an assessment of data compatability was undertaken in order to determine if the major data sets could be used as one unit. Each of the participating U.S. agencies was contractually obligated to carry out a quality control (QC) program and evaluate their own program as an internal control on the reliability of their individual databases. The Canadian agencies also have similar programs providing internal QC information. Thus, as much of the individual QC data that was available was utilized in the analysis.

Analysis of Split Sample Data. An estimate of precision can be generated from the standard deviation of differences between values obtained in duplicate analyses of the same sample. During the Lake Erie study, agencies split a designated number of samples at the time of collection. These "splits" were processed and analyzed as separate samples, thus the precision estimate encompasses all aspects of the collection and analysis processes.

The mean and standard deviation of the differences were calculated for each parameter. Any differences greater than three times the standard deviation were excluded, and a new mean and standard deviation were calculated. This process was repeated until no additional values were excluded, or until five percent of the data had been excluded. The mean of the differences in this final data set, divided by 1.128, provides an estimate of the standard deviation associated with an analysis for the parameter examined. (This standard deviation applies to the analytical result, not to the difference between a pair of analyses.) (IJC, Data Quality Work Group 1980.)

The procedure for iterative exclusion of large differences was adopted because 1) it could be done automatically by computer; 2) it was an objective process; and, 3) it produces a precision estimate based on most of the data (at least 95 percent) but not inflated by the abnormal situation when the system was, in the broadest sense, out of control.

The results of the split analysis are presented in Table 5. In general, these results suggest that differences in precision between groups were not significant; thus, precision was not a factor in combining the data sets. While the precision associated with a particular parameter varies from year to year and from agency to agency, even the largest standard deviations were not large in context of the concentrations involved (i.e., the relative standard deviations are generally quite small, on the order of one percent or less). The exceptions were encountered with the metal parameters, many of which were at levels close to detection limits. Here the limited data available suggests that precision was often not good enough to permit any but the most coarse-scale data analysis.

Analysis of Round Robin Results. The Data Quality Board of the International Joint Commission provided a continuing series of round-robin studies in which samples were sent to participating labs for analysis. Each study involved analysis of several (usually related) parameters covering a broad range of concentrations. Many of the samples were of natural waters, or natural waters spiked to increase concentrations. The results were evaluated in reference to the range of values reported by the participants with the assumption that the median value reported is the best estimate of the true value for that sample. This assumption may be questionable for some analyses, particularly when concentrations were very close to detection limits, resulting in one or two laboratories doing accurate work but being flagged for poor performance because the majority of the laboratories skewed the mean upward. Generally this approach served to identify laboratories that are erratic or biased in their performance. All laboratories involved in the Lake Erie study participated in the round-robin series to some extent.

Results of the IJC studies involving Lake Erie Intensive Study participants conducted shortly before and during the Lake Erie study were evaluated for indications of bias and erratic performance. The data includes multiple analyses, usually as part of two or three separate round-robin studies, involving 29 parameters. In general, the results show that substantial biases between laboratories are common, that erratic results are common, and that good performance on one round-robin study does not predict good performance on the next study involving the same parameters or visa versa. Several laboratories, mostly Canadian, had consistently good performances for almost all parameters, but most laboratories exhibited poor performance at least occasionally on some parameters.

These results suggest that combining data from different agencies is unwise, at least without careful scrutiny of the data compatibility. It is important to consider such results in context with the purposes for which the data is to be utilized. The results of the round-robins evaluated are presented in Table 6.

Analysis of Data and Adjacent Stations. Since the purpose of combining data sets is to answer questions concerning the lake as a whole, it could be argued that the ultimate data compatibility test lies in the data itself, that is, the comparison of values at stations along the boundaries at which the different agencies interfaced. One could consider the data compatable if differences across boundaries were not large in comparison with day-to-day differences found at each station, or in comparison with some other measures of small scale internal variability.

This approach was examined by choosing pairs of stations which interfaced agency boundaries and comparing the data obtained at stations over the three successive days' sampling. If the two triads of data overlapped, the data were judged to be similar. This judgement was made for each date and level sampled at two or more pairs of stations. The results were tabulated as the number of observations judged the same, the number judged high in laboratory 1 relative to laboratory 2, and the number judged low in laboratory 1 relative to laboratory 2.

The approach was weakened by the spatial and temporal separation of the stations. Some "nearest" station pairs across boundaries were 6 km apart, while others were at the same location within navigational accuracy. Some sampling intervals involved overlap of sampling dates, while others involved intervals of up to 10 days between sampling by the two laboratories. Arbitrarily, any comparisons involving sampling time separations greater than 10 days were not used in the analysis. Allowance was made for expectable seasonal changes such as changing temperatures and dissolved oxygen concentrations in the spring. Bottom samples showing indications of hypolimnion water samples were not included unless all samples in that comparison seemed to be hypolimnion in origin.

An additional problem encountered involved the difference in sampling routine used in the nearshore study versus the open lake program. The nearshore stations were sampled three days in succession, while the open lake stations were sampled only once per cruise. Thus, comparisons between two agencies working in the nearshore zone involve six data points, comparisons between nearshore and open lake agencies involve four, and comparisons between two open lake agencies involve only two data points. Where more data points are involved in the comparison, the likelihood of reaching a no-difference judgement was greater. Indeed, when only two data points are involved, the values will usually be different. Since the final assessment is usually based on 10 to 20 such judgements, and only parameters which showed consistent divergent behavior were judged to contain a between-laboratory bias, this difference in data density is probably not a serious problem. The results of these comparisons are shown in Table 7.

In general, data compatibility is not seriously affected by precision except for metal parameters where water concentrations were at very low levels. However, between-laboratory biases are commonly significant compared to the temporal and spatial variability. The question of data compatibility is a relative one, and judgements about the compatibility of the data must ultimately be made in the context of specific research questions to which the data is applied. However, the implication of the analyses presented here is that it is not safe to assume that data gathered by different agencies, or even by the same agency in different years, is compatible.

During USEPA-GLNPO cruise five 1978 an intercomparison study with OMOE was undertaken. On July 23 water samples were collected at seven stations (29, 30, 31,78, 32, 33, and 34, Figure 3) from Ashtabula, Ohio to the Canadian shore. USEPA sampled at each location with replicate collections split between three groups, USEPA-GLNPO, OMOE Toronto, and OMOE London. Several parameters were analyzed, however, only total phosphorus will be discussed in this text. Preliminary analysis of the data stated:

- data ranged from 2 to 28 ug/l
- All labs reported to the nearest 1 ug/l
- London/EPA correlation was excellent with a scattered range of ± 4 ug/l, London being higher by 1 ug/l
- although on the average Toronto data agrees with the other two labs results below 8 ug/l tend to be high by an average of about 5 ug/l.

All laboratories employed similar methodologies for the total phosphorus analysis using the ascorbic acid procedure with persulfate digestion.

Due to the lack of replication this data set does not lend itself to rigorous statistical treatment, therefore, the results do not provide the information necessary to critically resolve differences between the labs involved in the study. However, it was necessary to statistically resolve some information from the comparison. The Wilcoxon signed rank test was used to compare the medians of two data sets, i.e. USEPA vs Toronto and USEPA vs London, since the distribution of the data was not known. Values from all stations and all depths were pooled for the analysis. The results of the nonparametric test indicated the USEPA-GLNPO results were significantly lower than Toronto (a = 0.02) and significantly lower than London (a = 0.01). No comparison can be made with the CCIW data set since the cruise interval and sample locations were not compatable with this study.

Synopsis. Data compatibility becomes an important issue when attempting to assess such a complex database. Therefore, any program designed to involve numerous agencies must have this consideration. Detailed planning of the project must incorporate a QC program not only for the individual participants, but also provide for comparisons between participants. Precedent for field intercomparison studies has been established by Robertson et al. (1974) and Feder and Zapotosky (1978). This type of study is difficult, but it serves a very valuable and obvious function. Prior to the initiation of the 1978 field season, CCIW (organized by N. Burns) attempted to coordinate such an effort by bringing all the participating groups together to discuss the above mentioned problems. However, little was done to follow through with this effort by the U.S. participants. Consequently, the problem of data compatibility remains one of the major nemeses of these large multi-agency programs.

RESULTS

The results are divided into two sections, OPEN LAKE and NEARSHORE. Within each section the major parameters are presented, providing an adequate database was available. Frequently, both the open lake 1978 and 1979 field season data were available, however, due to the year-to-year similarity in distribution patterns and seasonal concentrations, only the most representative and complete data set was utilized. This policy was adopted to reduce the volume of the document as well as to eliminate the redundancy resulting from providing a detailed description of each parameter for the two field seasons. The CCIW-NWRI 1978 data set was considered the primary open lake database since the basin coverage was extensive and the quality of the analysis was considered to be superior. In contrast, the nearshore was found to be considerably more variable than the open lake, consequently, two year summaries were used to present the nearshore database.

Open Lake

Temperature. The Lake Erie seasonal surface temperature cycle follows a similar pattern annually. A comparison of surface temperature contours from 1970 through 1979 indicates differences only in the rate of spring warming and fall cooling with minor deviations in contour patterns resulting from short-term meteorological episodes. The 1979 surface temperatures for the three basins are shown in Figure 11 and represent a typical annual cycle.

The western basin is generally ice-covered by early January with ice formation on the central and eastern basins by late January. Depending on the severity of the winter, ice is present in all three basins until late March. The western basin is first to lose ice cover, followed by the central and eastern basins in a west to east succession. Frequently, float ice remains in the eastern basin through late April, resulting in delays for surveillance cruises.

The surface waters of the entire lake continue to warm through the spring into the late summer. The shallow western basin is the first to warm, frequently reaching 10°C by mid-May and remaining 2-4°C warmer than the central and eastern basin epilimnion until late July or early August. During late August the surface temperatures of all three basins are nearly uniform, having reached a maximum of 20-25°C. With the onset of fall, the western basin begins cooling and continues cooling more rapidly than the central and eastern basins. Not until late December or early January does the entire lake become nearly uniform in temperature.

Unlike the consistency of surface or epilimnion temperatures, the hypolimnion waters may show significant temperature variation from year to year. The bottom temperatures in unstratified regions, i.e. western basin and nearshore regions, seldom differ from surface temperatures. However, by late summer in the stratified regions of the central and eastern basin hypolimnion temperatures can be 10-20°C colder than the overlying epilimnion water. Through the stratified season hypolimnion waters of the central basin increase from 5 to 10°C. The warming of the central basin hypolimnion varies from year to year depending upon the initial hypolimnion temperature, thickness and climatic conditions through the stratified period. Eastern basin hypolimnion temperatures do not increase at the same rate as the central basin (Figure 12). In the deepest portions of the eastern basin, hypolimnion temperatures may only increase 2°C through the stratified period. In addition year to differences in eastern basin hypolimnion temperatures are less variable than in the central basin.

Thermal Stratification and Structure. In contrast to the western basin, both the central and eastern basins stratify during the summer months. The thermal structure of the central basin is of particular importance due to the recurring anoxic condition associated with the hypolimnion during the late summer months. Since any western basin thermal structure is short in duration and the eastern basin hypolimnion remains thick and well oxygenated throughout the stratified season, much of this text will specifically deal with the problematic central basin.

As mentioned, the western basin does not stratify in the conventional manner as do the other two basins. Due to its shallow nature, the western basin remains isothermal throughout most of the summer months. Generally, two mechanisms can lead to a stratified condition or a strong thermal gradient (Bartish 1984). First a period of warm, calm weather may lead to the formation of a thermal gradient which in turn inhibits mixing of bottom waters with the warmer overlying water. Second, central basin water (mesolimnion/hypolimnion) can be entrained into the western basin during seiche activity. This central basin water mass is cooler and denser than western basin water, resulting in a "stratified" water column. Regardless of how thermal structure is established in the western basin, it only remains stable until wind velocities increase sufficiently to cause the entire water column to mix. Generally, complete mixing occurs within a few days of the onset of the "stratified" water column.

Stratification in the central basin is considerably more consistent and stable than in the western basin. The first indication of stable stratification is evident in late May. The initial thickness and temperature of the hypolimnion are dependent on the spring meteorological conditions; thus, the physical structure of the hypolimnion is somewhat different each year. Figure 13 presents the 1978 central basin hypolimnion thickness contours for each cruise. The central basin stratified period lasts approximately 100 days with fall turnover generally occurring by mid September. The seasonal changes in thermal structure typifying the mid-central basin in 1979 are presented in Figure 14.

The eastern basin is the deepest of the three basins, having a hypolimnion which is thicker and colder than that found in the central basin. The hypolimnion temperature generally does not exceed 6^{o}C and the dissolved oxygen remains closer to saturation ($>$60%) throughout the summer. The eastern basin hypolimnion assumes a conical shape following the basin topography. The thickest portion of the hypolimnion located approximately 13 km east of Long Point is in excess of 25 m (Figure 13). The 1979 annual thermal structure for this region is presented in Figure 15.

The average hypolimnion thickness of the eastern basin is generally twice that of the central basin and the mesolimnion is from 3 to 5 times thicker. The thickness of the mesolimnion was found to be an important factor in the interaction between the central basin hypolimnion and the eastern basin mesolimnion. Boyce et al. (1980) found that eastern basin mesolimnion water could be transported into the eastern portion of the central basin. This intermittent event, induced by specialized meteorological conditions, results in a reverse flow (east to west) over the Pennsylvania ridge, representing a major interaction between the basins. This eastern basin entrainment can significantly re-oxygenate the eastern portion of the central basin; thus, the event is an extremely important consideration when budget calculations are made for either basin.

From May 1979 through June 1980, as part of the two-year intensive study, an array of more than 29 current meters was positioned throughout the three basins in order to obtain detailed information on current directions and speeds as well as thermal structure (Saylor and Miller 1983). This report has only recently been issued. The reader is urged to review this study for further information on the physical characteristics of the three basins.

Limnion Volumes. Accurate measurements of temperature ($\pm 0.1^{\circ}C$) versus depth ($\pm 0.25m$) at each sampling station are a basic requirement for Great Lakes research. Bathythermograph traces, such as those shown in Figures 14 and 15, provide an accurate record of sounding depth and thermal structure, critical for both physical and chemical data analysis. Generally, sampling regimes are based on thermal structure, thus it becomes necessary to have accurate temperature/depth profiles in order to determine appropriate sampling depths in and around the thermocline. Since the thermal structure not only varies from cruise to cruise but from station to station, profiles must be taken as a routine measurement.

Once the detailed thermal structure has been defined, basin-wide limnion depths, volumes and areas can be calculated. This provides the necessary information to calculate volume and area weighted concentrations as well as total quantities (metric tons) for any parameter. These values are subsequently used for basin-wide and whole lake budget calculations. Thus, it is necessary to obtain the most accurate volume estimates possible in order to make year-to-year comparisons meaningful. This becomes particularly critical for central basin hypolimnion dissolved oxygen and nutrient models since small volume differences can significantly influence the analysis.

Western basin limnion volume estimates (USEPA-GLNPO) for 1978 and 1979 are presented in Table 8. It is noteworthy that in June and July of 1978 a thermal gradient was recorded but was not encountered in 1979. The 1978 data indicated a thin layer of colder bottom water in the eastern portion of the basin. As previously discussed, stratified conditions may develop several times during the summer, but lasting only a few days. The fact that stratification was not documented in 1979 only indicates that the thermal condition was not encountered during the cruises and not that it did not exist sometime during the summer.

The two-year (1978-1979) limnion volumes and thickness for the central and eastern basins (CCIW-NWRI) are presented in Tables 9 and 10. The data indicates a somewhat thicker hypolimnion in both basins during 1978. This is particularly evident during the late spring in the central basin. The initial spring hypolimnion thickness in 1978 was over 2 m greater (30%) than that found in 1979 resulting in a thicker hypolimnion throughout the

1978 stratified season. A similar thickness relationship existed in the eastern basin during both 1978 and 1979.

The central basin epilimnion frequently comprises over 60% of the total water volume and during the late summer may exceed 80%. On the other hand, the eastern basin epilimnion rarely exceeds 60% of the total basin volume with the hypolimnion generally comprising 10-25%. As previously pointed out, the mesolimnion in the eastern basin is significantly thicker than the mesolimnion of the central basin. Eastern basin mesolimnion frequently accounts for 30% or more of the total volume while the central basin mesolimnion usually accounts for only 10% of the total volume.

The 1978 and 1979 thermal structure data typify the year-to-year variation encountered in the three basins of Lake Erie. Thus, in order to calculate year-to-year nutrient budgets, verify predictive models or conduct trend analysis, thermal structure data is vitally important.

Dissolved Oxygen (D.O.). Dissolved oxygen has been a major environmental concern associated with the eutrophication of Lake Erie since the early 1950s. The focus of O_2 depletion problems has been on the bottom waters of the western and central basins, while the eastern basin O_2 concentrations have remained above critical levels throughout the current period of record.

The recurring problems of low D.O. concentrations at the sediment-water interface are directly related to thermal stratification in both the central and western basins. The circumstances leading to O_2 depletion in the western basin are as complicated and varied as the situation encountered in the central basin. In either situation the bottom waters do not freely exchange with the O_2 saturated (90%) overlying water mass; thus the limited supply of hypolimnion O_2 is depleted.

All recorded instances of major O_2 depletion in the western basin have been associated to some degree with the formation of a thermal gradient (Britt 1955, Carr 1962, Bartish 1984, Wright 1955, Hartley and Potos 1971). Due to the high oxygen demand rate in the western basin (Davis et al. 1981), anoxic conditions may develop in only a few days following stratification. For example, if a thermal gradient formed 2 meters above the bottom with an initial O_2 concentration of 5 mg/l, it would take between 3 and 4 days for anoxic conditions to develop. When anoxia occurs, both the flora and fauna within the region become stressed. In addition, soluble nutrients are released into the overlying waters, further stimulating algal growth. Since anoxic conditions develop intermittently over the summer, there is little documentation of the frequency or extent of the problem.

The 1978 western basin data (USEPA-GLNPO) shows the average surface concentrations of D.O. (Figure 16). At no time during the field seasons did the average D.O. drop below 7 mg/l in the surface waters, and no critically low values were evident for samples taken 1 m from the bottom. Only during the late June survey were small pockets of stratified waters encountered with limited O_2 depletion west and north of the Bass Island region. This is not to imply that critical oxygen levels at the sediment water interface were not reached other times during the summer of 1978; however, since the conditions leading to low bottom D.O. were largely a function of meteorological events, episodes of low D.O. could be easily missed during a 3-week cruise interval.

The dissolved oxygen database discussed for the central and eastern basins was supplied by the CCIW-NWRI 1978 hypolimnion study. Due to the intense station pattern and number of surveys during the stratified period, this database provided the most thorough examination of hypolimnion O_2 yet undertaken in the stratified basins. The 1978 thermal structure, hypolimnion thickness and temperature represented near average seasonal conditions.

Like the western basin, central basin surface waters remained close to the 100% saturation level throughout the field season with spring values frequently exceeding 100% due to phytoplankton photosynthetic O_2 production (Figure 17). Hypolimnion concentrations, immediately following the formation of the thermocline, are very similar to epilimnion values. During the stratified period, exchange with the highly oxygenated epilimnion waters (90%) is greatly inhibited by the thermocline; thus the quantity of O_2 present in the hypolimnion at the formation of the thermocline is a critical factor controlling the quantity of O_2 remaining at the end of the stratified period. Through the summer months hypolimnion O_2 values continually decreased, reaching concentrations below 4 mg/l by mid-August. The areal O_2 distribution throughout the hypolimnion is not uniform (Figure 18). Concentrations in the western portion of the central basin and particularly in the Sandusky sub-basin reflect the influence of the nutrient and plankton input from the western basin and Sandusky Bay. A distinct southwest to northeast and west to east gradient of increasing O_2 concentrations is evident throughout most of the stratified season (Figure 18). This is most clearly seen in the contour of the late August survey. By early September much of the basin was anoxic (< 1 mg/l) and remained anoxic through the duration of the stratified period. Once turnover occurs, the water column becomes isothermal and homogenous relative to O_2 concentration, returning to levels near 100% saturation. The central basin oxygen budget is more complicated than this explanation and will be dealt with in greater detail later in this report.

The eastern basin epilimnion D.O. concentration remains near 100% throughout the summer months, and during the spring diatom pulse, values increased to greater than 140%. Unlike the central basin, the eastern basin is not subject to periods of anoxia. Hypolimnion mean oxygen concentrations remain above 6 mg/l throughout the stratified period (Figure 19).

Nutrients. The lakewide distribution pattern of the major nutrients remains similar from year to year. The individual basin nutrient distribution patterns most frequently presented reflect the circulation patterns within the individual basins under normal or moderate wind conditions. This "normal" pattern can be altered under extreme wind stress, i.e. severe storms. However, moderate conditions account for the majority of the nutrient distribution patterns seen in contours and generally reflect the water transport model describing major circulation patterns developed by T.J. Simons at CCIW (Simons 1976).

The following sections will illustrate the distribution patterns of the major nutrients using the 1978-1979 CCIW data. This data set provides the most extensive coverage of the central and eastern basins. Unfortunately, the western basin was not sampled during either CCIW research program; thus, the western basin USEPA-GLNPO data was utilized. Graphs of 1978 and 1979 mean basin concentrations for the epilimnion and hypolimnion will be presented whenever the data is available. Tables presenting the limnion concentrations and tonnages of several parameters will also be included. Only a detailed description of the total phosphorus distributions will be presented due to the similarity of high and low concentration regions for most nutrients making additional description redundant.

Total Phosphorus (TP). The seasonal horizontal epilimnion concentrations of TP show several unique distribution patterns. First, a distinct concentration gradient is evident in the transition region between the western basin and central basin. The same gradient is also evident between the central and eastern basins; however, the concentration difference is considerably less. This basin-to-basin gradient leads to a general west to east trend of decreasing concentration. Since the major sources of nutrient loading to the lake (>50%) enter the western basin and the natural lake flow is from west to east (Detroit River to Buffalo River), the gradient evident in many of the contours presented in this report and in similar reports follows a seemingly logical pattern.

This description of the TP distribution pattern represents a simplified explanation of the normal horizontal gradients; it must be re-emphasized that the circulation patterns examined and discussed by Simons, Boyce, Bennett, Saylor and others represent a complex combination of many physical variables, i.e. temperature gradients, thermal structure, wind fields, currents, etc., and together influence the overall distribution of chemicals within the lake. In-depth physical process research is critical to the understanding of the dispersion of pollutants in the three basins. This point is made clear by examining TP dispersion or contour patterns in the central basin. As previously discussed, the transitions between basins are characterized by north-south contours representing the gradient structure, but within the central basin contours are east to west paralleling the south shore. TP concentrations are highest along the south shore with values frequently double those found at the center of the lake. These high south shore concentrations result from two sources: first, western basin water with high nutrient concentrations remain confined to the south shore region as the water mass enters the central basin through the passage south of the island region, and second, point source loading from urban centers along the entire shoreline, i.e. Cleveland. The predominant flow in the nearshore region is west to east, but currents do carry the high nutrient ladened water into the basin to mix and disperse with the open lake. Mixing the nearshore waters into the open lake is a complex dispersal process resulting in unique transition patterns (Figure 20). Central basin south shore contours show a variable cruise-to-cruise pattern shifting in a north-south and east-west configuration depending on meteorologically induced current patterns. Thus, the better our understanding of the hydrodynamic flow structure of the lake, in particular the interface of the open lake with the nearshore region, the greater our understanding of the effect pollutants will have on the lake ecosystem.

In contrast to the western basin and the south shore of the central basin, the north shore of the central basin and the entire eastern basin are not subject to extensive problems resulting from external point source loading. Due to erosion of the clay bluffs lining the north shore of the central basin, nearly 13,500 metric tons of phosphorus are added to the lake annually (Williams et al. 1976). The major phosphorus contribution of this non-point source is in the form of apatite phosphorus which has a very low solubility and is not biologically available (Williams et al. 1980); consequently apatite phosphorus is not a significant source of available phosphorus and is not included in loading calculations. The populace along the north shore areas is confined to small communities and farmland with little or no industrial development. Therefore, when examining the contour maps of the northern shore, localized effects (point sources) and shoreline contributions (non-point sources) are not prevalent features. One exception, the Grand River located in the eastern basin is the largest single point source of nutrient loading to the entire north shore. As with all tributary sources of loading, the most dramatic effects can be seen during the spring when nutrient concentrations and water flows are highest.

An area of future concern is the newly-forming industrial and urban complex developing in the eastern basin at Nanticoke, Ontario. Due to the care taken with the initial planning of this complex, minimal impact has been noted in the area; however, this region must be monitored routinely. To date, numerous reports have been issued by the Ontario Ministry of the Environment (OMOE). The reader can obtain further detailed information by contacting OMOE.

The seasonal changes in TP concentration tend to follow a yearly pattern characteristic of the individual basin (Figures 21-26; Tables 11-13). The 1978 western basin data (USEPA-GLNPO) is too sparse for any meaningful interpretation (Figure 21); however, the 1979 data presents a more typical seasonal pattern (Figure 24). Highest concentrations are encountered during the early spring months, February through April, resulting from a combination of peak external and internal loading events. The external load is high due to both agricultural runoff and the increase in sediment-phosphorus transport of the instream bed load. This source of western basin loading has been characterized and quantified by Logan (1978), Logan et al (1979), Verhoff et al. (1978), and DePinto et al. (1981). Internal loading is also a major source of TP to the basin since spring is frequently characterized by high winds and storms which readily resuspend settled material in the shallow western basin. Consequently, the western basin spring TP values are frequently over 50 ug/l in the open basin and in 1979 the mean western basin concentration exceeded 100 ug/l. Through the remainder of the summer, TP concentrations generally decrease, although sharp increases in concentration can occur during the mid-summer months as a result of an occasional storm or periods of anoxia. The duration of mid-summer sharp concentration increases is usually a few days. During the fall, concentrations again increase as a result of increased tributary loading and resuspension.

A somewhat similar seasonal pattern is evident in the central basin, best seen in the 1979 CCIW database (Figure 22 and 25). The highest TP concentration of the field season generally occurs during the unstratified periods of the spring and fall. This is because the central basin is subject to internal and external loading, influences similar to those the western basin experiences. In addition, the transport of nutrient rich western basin water into the central basin contributes to the concentrations characteristic of these periods. Since the central basin stratifies from approximately late May through early September, resuspension of the settled material does not contribute to the internal loading of the epilimnion within the stratified regions. Increasing hypolimnion concentrations of TP can originate from three sources: first, from decaying plankton settling through the thermocline into the hypolimnion, and second, from anoxic release of sediment-bound P in the later weeks of stratification (late August until turnover in mid-September). Thirdly, peaks of TP occur in the hypolimnion resulting from the resuspension of the loosely-floculated material at the sediment water interface. This occurs during very active storm periods when seiche and internal wave activity induce accelerated hypolimnion current velocities (Ivey and Boyce 1982). If the hypolimnion is sampled before this material resettles, hypolimnion concentrations will be significantly elevated.

The eastern basin is least influenced by either spring loadings or resuspension of bottom materials; thus, the concentrations in this basin do not show the extreme fluctuations encountered in the central and western basins (Figure 23 and 26). Seasonal concentrations indicate a pattern similar to that described for the central basin with the highest values found in the spring followed by a continual decline through the stratified period. A small increase is evident following turnover; however, concentrations did not reach spring levels or approach central basin fall concentrations.

Forms of Phosphorus. In addition to routine measurements of total phosphorus, three additional forms were also measured. The terminology used to delineate the forms unfortunately is not uniform throughout the literature; however, the forms measured are method specific and consequently separation is not difficult. The standards forms measured and synonymy are:

1. Soluble Reactive P (SRP) = Dissolved Ortho P
2. Total Filtered P (TFP) = Total Dissolved P

An additional form which can be measured directly or be obtained by difference is Particulate P (PP):

TP - TFP = Particulate Phosphorus (PP).

These four forms of Phosphorus, TP, TFP, SRP and PP, constitute the normal fractions determined during surveillance studies. It should be mentioned that an additional form can be determined by difference:

TFP - SRP = Soluble Organic Phosphorus (SOP)

This fraction is composed of high molecular weight organic compounds. These various forms of phosphorus are all associated with conceptual compartments which interact within the lake ecosystem. Details as to phosphorus cycling and turnover rates for the various components in the phosphorus pool can be found in a series of papers by Lean (1973), Lean and Nalewajko (1976), and Lean and Pick (1981).

The largest contributing fraction to total phosphorus is the PP fraction, comprising from 50-70% of the total. Particulate phosphorus follows distribution and seasonal patterns similar to those of total phosphorus. PP concentrations are highest during the spring and fall unstratified periods when resuspension is greatest. It also is evident that PP concentrations follow a decreasing concentration gradient from west to east. During periods of high plankton production, i.e. western basin mid-summer and nearshore regions throughout the year, the PP fraction is also increased. Consequently, this fraction serves a dual role as a source and as a sink for available phosphorus.

Soluble reactive phosphorus is the most commonly measured fraction other than total phosphorus. This fraction represents a measure of the biologically "readily available" phosphorus; thus concentrations of this nutrient generally remain low throughout the active growing season. Western basin summer mean concentrations fluctuated from 3 to 12 ug/l with values rarely dropping below 1 ug/l. During peak spring loading or periods of anoxia, concentrations may exceed 10 ug/l in the open basin.

Epilimnion SRP concentrations in the central and eastern basins generally remained below 2 ug/l through the stratified period (Figures 27 and 28; Tables 11-13). It is not uncommon for values in the mid lake to drop below detection limits (<0.5 ug/l) from the end of July through much of August. Hypolimnion concentrations increased throughout the stratified season in both basins: however, a much greater increase was evident in the central basin. As in the western basin, seasonal soluble reactive concentrations peak in the spring as a result of both external and internal loading and increase again in the late fall when storm-induced resuspension is common.

Numerous difficulties have been recognized in measuring concentrations of SRP. Frequently concentrations are found to be near or below detection limits making quantification of this phosphorus form difficult. The analytical problems associated with measuring SRP have been discussed in a series of papers by Tarapchak and Rubitschun (1981), Tarapchak et al. (1982a, 1982b).

Dissolved Inorganic Nitrogen. Dissolved inorganic nitrogen is composed of three fractions, all of which may be important nutrients for plankton growth: (1) ammonia, (2) nitrate plus nitrite and, (3) dissolved nitrogen (N_2). Dissolved nitrogen was not measured in any of these studies and will not be discussed in this text. Generally, the concentration and quantity of nitrate plus nitrite in the lake is nearly ten times that of ammonia while loading of nitrate plus nitrite is roughly 3.5 times ammonia loading.

The distribution pattern and seasonal cycle shown by the two parameters reflect both biological and chemical (redox) influences. Western basin ammonia concentrations are generally 4 to 5 times higher than those in the other basins (Figure 29). High concentrations (100 ug/l) are found in the region of the Ohio tributaries and frequently in the bottom waters of the open basin during the summer. As with soluble reactive phosphorus, ammonia concentrations frequently showed extreme fluctuations during the summer months. The highest basinwide concentrations occurred during the spring when tributary loading was the greatest (Table 14-16).

The 1978 ammonia distribution maps of the central and eastern basins include one map representing seasonal epilimnion contours (September) and a full season of hypolimnion contours (Figure 30). In both basins the epilimnion concentrations of ammonia remain below 10 ug/l from May to September with only small areas of higher concentrations found along the south shore (Figure 30). These pockets of higher concentrations reflect external loading which can be attributed to urban and agricultural sources. The remainder of the lake is relatively uniform in concentration.

Central basin hypolimnion concentrations increase during the beginning of the summer with highest concentrations found along the southern shoreline. Hypolimnion concentrations peak by the end of the stratified season (Figure 31) as a result of plankton decomposition and ammonia regeneration from the sediments in regions where the hypolimnion has become anoxic.

A similar seasonal pattern of hypolimnion ammonia concentrations is encountered in the eastern basin with the peak occurring early in the summer (Figure 32). The eastern basin does not show another increase in the later period of stratification primarily due to the presence of oxic conditions throughout the hypolimnion. In addition, the release of ammonia from the decomposition of plankton is not as quantitatively important to the hypolimnion of the eastern basin as it is in the shallower, more productive central basin.

The lake-wide distribution of nitrate plus nitrite is very similar to that described for total phosphorus (Figure 33). This similarity is expected since the principal external loading sources of these two nutrients are similar. Concentrations in the central basin reflect the loading influence from the south shore and western basin. This pattern is clearly evident up through August in both epilimnion and hypolimnion waters. The shore influence is evident in the eastern basin only during early June after which concentrations are fairly uniform.

Seasonally, epilimnion nitrate plus nitrite concentrations indicate a rapid decline from peak spring values into mid-summer when concentration becomes more stable (Tables 14-16). This yearly cycle is most evident in the western basin where concentrations decline by over a factor of three (Figure 34). Similar trends can be seen in the central and eastern basins but to a lesser degree (factor of 2) (Figure 35 and 36). The hypolimnion concentrations in both basins increase into the stratified season. As anoxic conditions develop in the central basin hypolimnion and reducing conditions prevail, nitrate plus nitrite concentrations begin to decline. This pattern is not evident in the eastern basin since oxic conditions prevail throughout the stratified period. During the late fall, the concentration again increases in both basins due to a slight increase in loading.

Silica. The seasonal cycle of dissolved reactive silica (DRS) is influenced by a combination of external and internal loading plus biological processes within the lake. The effect of external loading is most evident during the early spring in the western basin when mean concentrations can easily exceed 1.0 mg/l and may reach over 5.0 mg/l in the nearshore region (Figures 37 and 38). Vernal point source influences are also evident along the southern shore of the central basin and the north shore of the eastern basin near the Grand River, Ontario. By early summer, surface concentrations in the central and eastern basins have declined to seasonal lows and remain below 200 ug/l in the open lake throughout most of the summer (Figures 39 and 40). Western basin concentrations remained higher than the remainder of the lake and continued to fluctuate through the summer months.

Hypolimnion concentrations in the central and eastern basins increase through the summer reaching peak values by late summer-early fall just prior to turnover. Bottom concentrations in the central basin reach values greater than twice those encountered in the eastern basin largely resulting from regeneration of silica during periods of anoxia. Once turnover has taken place the concentration of silica in the surface waters again increases due to the mixing of hypolimnion waters into the water column plus a small increase in external loading during the late fall.

Following spring loading events, the silica cycle (primarily in the central and eastern basins) is largely controlled by biological activities, namely diatom metabolism and subsequent dissolution of the frustules. Shelske and Stoermer (1972) have shown that phytoplankton species composition and community structure are governed by silica/phosphorus concentrations in Lake Michigan. Although undocumented, silica is likely to play an equally important role in the phytoplankton community structure in Lake Erie. The silica concentrations decrease in the central and eastern basins during the spring until epilimnion silica becomes growth-retarding. During the summer months much of the silica previously complexed as diatom frustules goes into solution in the hypolimnion to be recycled following turn-over increasing silica concentrations sufficiently to support the fall diatom pulse. Nriagu (1978) presents a detailed budget for silica in Lake Erie. He concludes that regeneration of silica from sediments greatly exceeds annual external loading and that most of the biogenic silica is redissolved in the water column or at the sediment-water interface. Little of the diatom bound silica is actually lost to the sediments. It is apparent that the internal recycling together with external loading of silica provides sufficient silica to maintain the diatom community, which comprises 80% of the total phytoplankton (Munawar and Munawar 1976).

Corrected Chlorophyll a and Particulate Organic Carbon. Both corrected chlorophyll a (CCHLA) and particulate organic carbon (POC) were measured during the two years. CCIW and USEPA/GLNPO measured chlorophyll while only CCIW collected data for POC. The USEPA/GLNPO chlorophyll a values will be presented for 1978 due to the longer EPA field season.

The information derived from these two parameters is somewhat compatible since both are used as an indirect measure of biomass. Unlike CCHLA, which indirectly measures only the phytoplankton, POC measures all particulate organic carbon present in the water column. The POC consists of the carbon associated with the phytoplankton community as well as all the remaining members of the plankton community (i.e. bacteria and zooplankton). More importantly, POC also encompasses the detrital carbon which may contribute up to 90% of the total POC measured. Therefore, any correlation between POC and CCHLA/phytoplankton biomass may not necessarily be very useful.

Similar lake-wide distribution and seasonal patterns in the surface waters were evident for both parameters. Contour maps (Figures 41 and 42) indicate a distribution pattern like that previously described for TP. In general, a west to east decrease in concentration can be observed throughout the field season with highest concentrations found in the western basin and along the south shore of the central basin. Only during the first cruise did the Grand River, Ontario in the eastern basin indicate a strong influence relative to these two parameters.

The concentration and total quantities of POC and CCHLA are presented in Tables 17 and 18 for each cruise and year. The western basin CCHLA concentrations (Figure 43) show a unimodal seasonal pattern with the highest concentrations found during the late summer when phytoplankton biomass values are at their peak. Epilimnion CCHLA and POC concentrations (Figures 44-47) indicate similar seasonal patterns in both the central and eastern basins. High spring values result from the vernal diatom pulse plus the resuspension of detrital carbon from the sediments and tributary inputs. Concentrations decreased by late spring and remained low through mid-summer. The early to mid stratified period presents the lowest concentration of particulate material in the epilimnion as shown by low phytoplankton biomass, low CCHLA and POC concentrations, and high transparencies. By mid-August, concentrations begin to increase in both basins but are highest in the central basin. During the fall, values continue to increase with conditions generally comparable to those of the spring.

The central basin hypolimnion CCHLA concentrations were higher than epilimnion values through the early summer due to the settling of the spring phytoplankton community; however, by late August limnion concentations again became similar. In the deeper eastern basin CCHLA hypolimnion concentrations were consistently lower than the epilimnion values reflecting the decomposition taking place in the water column as the phytoplankton community settles into the hypolimnion. POC concentrations reflect this difference between the two basins even more clearly. Central basin hypolimnion POC concentrations are nearly always greater than epilimnion concentrations due to the settling plankton and detrital material during the early summer (Figures 46 and 47). Eastern basin hypolimnion POC concentrations exceeded epilimnion values only during this early summer period, while during the remainder of the year epilimnion values were greatest. This may be attributed to microbial decomposition of detrital carbon in the epilimnion and mesolimnion as the carbon settles through the water column.

Turbidity and Suspended Solids. Transparency measurements comprise one of the longest single historical data records for the lake. Since water clarity can be related to water quality this information can be used for trophic assessments and long-term trend analysis. Water clarity is inversely proportional to the quantity of particulate material suspended in the water column. Turbidity results from the presence of suspended particulate material which is a combination of suspended organic and inorganic particles. The total quantity of particulate material found in the water column is measured when total suspended solids (TSS) determinations are made. TSS determinations are frequently further fractionated into volatile solids (VS), the organic fraction and fixed residual solids (FRS) the inorganic fraction, providing additional information as to the nature of the particulate material.

The composition of the particulate matter varies seasonally and from basin to basin as well as within each basin. For example, particulate material found near the mouths of rivers (i.e., Maumee) or in embayments (i.e., Sandusky Bay) consists largely of inorganic material. Normally, clays make up the largest percentage of inorganic matter originating either from river drainage or resuspension of previously settled material. Organic material, i.e. plankton biomass and detritus (autochthonous and allochthonous in origin), combine to make up the remaining portion of the suspended particulate matter. The 1978 mean TSS distribution pattern presented in Figure 48 and cruise means presented in Table 19 characterize the general distribution of suspended material throughout the three basins. The highest TSS concentrations occur in the western basin from Maumee Bay along the south shore to Sandusky Bay in the central basin. Similarly, the central and eastern basins have the highest values along the shores (both north and south), while open lake regions show the lowest concentrations. This pattern is similar to the 1970 turbidity contours presented by Burns (1976b).

The seasonal cycle of TSS reflects the influence of inorganic and organic particulate matter on water clarity in the three basins. This is most evident in the central and eastern basins (Figures 49 and 50) during unstratified periods when both VS and FRS material are present in high concentrations. Due to the violent nature of the fall storms, the quantity of TSS is highest during the late fall. In the stratified months, the spring plankton and inorganic suspended material settle reducing the TSS values to minimum yearly concentrations in the surface waters. This is accompanied by a concentration increase in the hypolimnion. The western basin is susceptible to resuspension during the entire year (primarily spring and fall) (Figure 51), and receives large loads of inorganic clays from agricultural drainage; thus, the inorganic fraction remains high throughout the year. Western basin TSS values are usually double those of the central and eastern basins with peak fall concentrations up to four times the concentration measured in the other two basins.

The percent composition of VS and FRS also shows seasonal and basin differences. During 1981 a western and central basin study was conducted in order to examine the inorganic and organic makeup of TSS (Fay et al. 1983). Central basin epilimnion values ranged from 80% organic/20% inorganic in the summer months to 17% organic/83% inorganic during the fall. In contrast, western basin values ranged from 45% organic/55% inorganic during the early summer to 10% organic/90% inorganic in the fall, clearly showing the stronger influence of inorganic material in this basin. Burns (1976) determined a relationship between turbidity and suspended inorganic material (SIM) for April 1970:

$$\text{SIM (gm-3)} = 0.92 \times \text{Turbidity (J.T.U.)} + .02$$

This equation was then applied to a transport model used to calculate sediment movements between basins. Considering the ratio of inorganic/organic suspended material changes with season and basins, an entire seasonal comparison would be necessary in order to most effectively utilize the transport model.

The seasonal turbidity cycle for each of the individual basins is presented in Figures 52, 53, and 54. The 1979 data was chosen because early spring (April) data is available which represents an important time period for suspended particulates. Naturally, this is not true for areas with ice cover (i.e. western basin) between January and mid-March. In fact, periods of maximum clarity are probably reached during ice cover. In the late fall through early spring, when ice is not present, strong winds together with high tributary loadings provide the necessary condition to reduce water clarity to minimum values. This is evident in both the western and central basins in 1979. Due to persistent ice cover in the eastern basin, no data was obtained from this basin in April. Western basin turbidity values decrease by a factor of four from spring to early summer. This improvement is a direct result of reduced tributary inputs of particulate matter from the Ohio watersheds and a lessening of the stronger wind events. Western basin summer values fluctuate in response to storm activity and phytoplankton development but generally turbidity decreases into mid-summer and again increases by late August through September due to peak phytoplankton biomass development. Minimum turbidity occurs in late June and early July in both the central and eastern basins with a slight increase evident by September, also due to increased phytoplankton biomass. The fall is again similar to the spring with increased storm activity resulting in an increase in turbidity.

Secchi. Secchi transparency provides the simplest and most frequently employed technique for the measurement of water clarity. Although the technique is a simple one, there are many sources of variability aside from natural patchiness of the water, for example, the whiteness of the disc, the altitude of the sun, the reflection from the water surface and the height of the observer above the water. However, when compared with other parameters such as nutrient chemistry, secchi is probably the longest continuously recorded data base having the least number of methodology changes. For this reason, as well as its usefulness as a trophic status indicator (Gregor and Rast 1979) and historical trend analysis, the secchi disc data was evaluated.

The 1978 and 1979 secchi data was analyzed in a manner compatible with previous Lake Erie studies. Individual station secchi values were area-weighted (Table 20) utilizing the grid pattern established for the 1973-1975 Lake Erie study (Zapotosky 1980). As expected, the western basin consistently had the lowest water clarity with a 2-year average secchi depth of 1.81 m (Figure 55a). The averages for the central and eastern basins were 4.32 m and 4.64 m respectively (Figure 55b, Table 20).

Seasonally, the western basin secchi values can be subject to extreme fluctuation due to the shallow nature of the basin. In general the peak secchi values occur during late July to early August. This was most evident during 1979 with historical data indicating the same trend (Zapotosky 1980). The central and eastern basins show peak secchi values from late June through mid-July with both basins having nearly equivalent values. The intensity of the spring and fall storms is the principal factor governing the water clarity during the unstratified period. An additional factor clearly evident during late August through late September is the development of increased phytoplankton biomass. This can be seen by the increase in corrected chlorophyll a and is most evident in the central basin, when secchi values are reduced at the end of summer. Table 21 shows the area weighted secchi for 1974-75 and 1978-79. Due to incomplete data, only the western and central basin data is presented. The central basin values do not indicate any difference over the time period; however, the western basin averages indicate an increase of over .5 m. If this represents an actual trend, this could have important ramifications for the basin.

By normalizing all western basin cruise averages to a value of 1 and multiplying this factor by the central and eastern cruise means, basin ratios were calculated to illustrate spatial differences (Table 22, Figure 56). The results clearly illustrate the difference between the turbid and productive western basin and the other deeper but less productive basins. The central and eastern basin area weighted secchi values are greater than the western basin values by nearly 100 percent for the two years period.

TABLE 21

AVERAGED AREA WEIGHTED SECCHI DEPTH (m)

	WB	CB	EB
1974	1.3	4.4	--
1975	0.9	4.0	--
1978	1.9	4.6	4.7
1979	1.7	3.9	4.5

Applying the trophic classification established by Dobson et al. (1974) for yearly mean secchi data, the western basin would be classified as eutrophic (0-3 m) and the central and eastern basins as mesotrophic (3-6 m). The problem with such indices is that they can indicate any of the three major trophic categories depending upon which portion of the seasonal data is utilized. For example, if one were to utilize the maximum secchi readings found in July (7 m) it would indicate an oligotrophic condition for the open lake portion of the central basin for a one month period each year. This is obviously a misleading measure as would be the use of early spring or late fall values when the water is more turbid. Therefore the use of such indices should only be made with knowledge of the full year's data set.

Principal Ions. The principal ions routinely examined are those which make the greatest contribution to ionic salinity of the water body. The total ionic strength of a lake is generally measured as conductivity, and in bicarbonate lakes conductivity has been shown to have a proportional relationship with the concentrations of the principal ions (Hutchinson 1957). Several Lake Erie studies have measured the principal ion concentrations throughout the lake, while conductivity is routinely measured during most all surveillance programs (Kramer 1961, Weiler and Chawla 1968, Don 1972). During the intensive two-year study, conductivity, chloride (Cl) and sulfate (SO_4) were measured on every cruise during 1978 and calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) were measured during one summer cruise. Due to the spatial and seasonal uniformity of these principal ions only the June 1978 surface concentrations will be presented as contour distribution maps (Figure 57).

Conductivity remains uniform throughout the open lake with no extreme seasonal or spatial fluctuations evident. Station means for the two-year study indicate a west-to-east increase from 240 umhos/cm near the mouth of the Detroit River to 300 umhos/cm in the eastern basin. The low values found near the Detroit River would be expected since this water mass originates from Lake Huron which has conductivity values ranging from 190-200 umhos. The highest concentrations found in the open waters of western basin (280 umhos/cm) were found near the mouth of the Maumee River and the Monroe power plant. The highest central basin values occurred near Cleveland with a mean of 314 umhos/cm, exceeding the IJC 1978 objective of 308 umhos/cm.

The individual species contributing to total conductivity can be classified into two categories: first, the principal ions which are considered to be conservative, that is, only show very minor changes in concentration resulting from biotic interaction, Cl, Mg, Na and K. For example, Cl is frequently the conservative ion used in hydrodynamic model calibration. The second category includes the remaining major species, Ca, SO_4 and CO_3, which can show significant fluctuations resulting from metabolic processes induced by the lake biota and therefore are not considered conservative.

Of the four conservative ions, Cl concentrations are the most important quantitatively contributing over 12% of the conductivity. Chloride concentrations range from 10-21 mg/l with a mean value of 20.0 mg/l. The lowest concentrations are found in the western basin in the region of the Detroit River mouth. The highest concentrations occur in the central basin near the Cleveland-Fairport region and extend into the entire eastern basin. Of the total external chloride loading to the central basin, 80% enters via the Grand River at Fairport, Ohio. As would be expected, the chloride concentrations show only minor seasonal fluctuations at all limnion depths in both the central and eastern basins (Figures 58 and 59), while western basin concentrations show a distinct decrease from May through November (Figure 60).

Magnesium, sodium and potassium combined contribute only 10% of the conductance. Distributions of these ions reveal no distinct or related pattern either vertically or horizontally. No seasonal fluctuations were evident as would be expected since biological utilization of these ions is minimal. Similar seasonal results were confirmed from contour maps of Na and K presented by Burns et al. (1976c). An indication of south shore loading of Na near Cleveland was evident during 1970 but was not seen in the 1978 data.

The non-conservative ions SO_4, Ca and CO_3 are known to show changes in concentration both with depth and through the season; however, no major fluctuations were evident for these three ions. Sulfate concentrations in the surface waters contribute approximately 15 percent of the conductivity. Concentrations indicated only small horizontal variations (median range 18-30 mg/l) and minimal seasonal changes (Figures 61-63; Table 23). Concentrations in the central and eastern basins during 1978 indicated almost no change throughout the field season in any of the limnions while western basin concentrations indicated some fluctuations showing a peak during August. One might expect to see a significant seasonal change in hypolimnion sulfate concentrations of the central basin. During the late summer when reducing conditions are often prevalent, SO_4 is reduced to H_2S; thus a concentration decrease is expected (Burns and Ross 1972) however no concentration change was found in 1978. Lowest concentrations were found near the Detroit River and highest values were evident near industrial centers. Three areas of high concentrations were noted: (1) near the Monroe power plant, western basin; (2) Lorain and Cleveland, central basin; and (3) the north and east end of the eastern basin. All three areas of high concentrations are the result of industrial emissions from fossil fuel power plants and heavy industry. As with the previous ions, calcium does not indicate any unusual pattern of distribution. Lowest concentrations are found near the Detroit River mouth and near Cleveland, with the remainder of the lake showing concentrations from 33-40 mg/1. Calcium is an important component of the conductivity, comprising from 15 to 20 percent.

Alkalinity was measured routinely throughout the three basins of the lake during the intensive program. Alkalinity values expressed as mg/l $CaCo_3$ equivalents provide a measure of CO_2 forms (carbonate-bicarbonate-carbonic acid buffering system) in the lake. Normally alkalinity values ranged from 85 to 105 mg/l with little spatial difference evident between the basins. Highest values were generally recorded in the more productive regions of the lake, i.e., the western basin, Sandusky Bay and the south shore of the central basin. Phenolphthalein alkalinities were not uncommon in these productive regions indicating pH values greater than 8.4. Seasonally alkalinity values were somewhat higher during the more productive months. The carbonate ion was the most significant ionic species, contributing over 50% to the conductivity in the open lake.

The precipitation of $CaCO_3$ has been reported by USEPA-GLNPO in the western basin of Lake Erie. The phenomenon known as "whiting" has been documented in other Great Lakes, i.e., Lake Ontario, but as yet no studies have confirmed the event in Lake Erie (Jerome, personal communication).

Sediment Metal Analysis. During the June cruise of 1979, USEPA-GLNPO obtained sediment samples at each of the survey stations where suitable substrate made coring possible. The top 10 cm of each core was homogenized and analyzed for 19 metal elements: silver, aluminum, boron, barium, beryllium, cadmium, cobalt, chromium, copper, iron, mercury, manganese, molybdenum, nickel, lead, tin, titanium, vanadium, zinc. The remaining section of the core below 10 cm was analyzed as a second sediment layer however, due to the incomplete and inconsistent nature of the data it will not be included. Due to detection limit problems, boron, beryllium and tin will not be reported.

Concentrations reported by USEPA-GLNPO are expressed as mg kg-1 dry weight except as noted. Contour maps were prepared to show the distribution of the elements in the open lake sediments (Figure 64). Statistical analysis of the data was limited by the nature of the survey, i.e., only one core per station was taken. In addition, data was unavailable at 11 stations (3, 4, 8, 11, 23, 34, 40, 50, 51, 82 and 85). In some cases, the values reported were known to be higher than actual values; these data were not included in the mapping or data analysis. The distribution of each element is briefly discussed below.

Aluminum is a major constituent of the natural sediment found in all three basins. Since clays are a predominant component of the sediments, particularly in the fine grain depositional regions, and aluminum (primarily as illite) is a primary constituent of the clay minerals, its distribution is largely ubiquitous. Highest concentrations were found in the major depositional regions.

Titanium is closely related to aluminum as a component of the sediments and is probably associated with illite (Kemp et al. 1976). As with aluminum it is ubiquitous in distribution with the highest open lake concentrations found in the depositional zone of the eastern basin.

Iron and manganese both occur at high concentrations in the sediments with iron being one of the most abundant elements found in the open lake sediments. Highest concentrations were found in the major depositional areas. Kemp et al. 1976 reports both these elements to be vertically mobile in the sediments with highest concentrations found at the sediment water interface. In the western and central basins where the sediment water interface is subject to anoxic conditions, both iron and manganese are known to migrate from the sediments into the overlying waters.

Cobalt concentrations were fairly uniform throughout the lake with higher values encountered in the major depositional zones.

Nickel and zinc both show distributional patterns of high concentrations near known loading sources. Highest values were primarily found in the western portion of the western basin and along the south shore of the central basin. Kemp et al. (1976) states that the major increase in concentration has likely occurred since 1950.

Molybdenum showed somewhat higher values in the major depositional zones of the central and eastern basins.

Cadium, chromium, lead and copper constitute four of the five major metal contaminants in the lake. All four indicate similar distribution patterns showing the highest open lake concentrations in the western basin and within major depositional areas in the central and eastern basins. Nearshore areas of high concentrations were found in the western portion of the western basin and along the south shore of the central basin.

Silver was found in low concentrations throughout the lake. Only in the western basin adjacent to the Detroit River and in the eastern portion of the central basin were concentrations reported above detection limits.

Barium and vanadium both indicate a rather ubiquitous distribution with the highest open lake values occurring in the major depositional areas of the basins.

A cluster analysis was used to group similar sediment types together based on the concentrations of the 9 elements for which a complete data set was available. The analysis was dominated by Al and Fe, the most abundant metals of the lake sediments. Except for Cluster No. 1 (Figure 65a and Table 24), the groups show a general ordered increase in mean concentrations of the elements. However, Cluster No. 1 includes Station 1, having high concentrations of five elements in conjunction with relatively low levels of Al and Fe. Data from Station 1 does not conform to any information previously reported for this area (Thomas and Mudroch 1979). Since there are no point sources which would lead to extensive metal deposition in this area and contamination from shipping is unlikely, it is expected that this data is incorrect. The USEPA-GLNPO was not able to provide any additional information as to the validity of the data at this station.

The areas of the lake corresponding to Cluster No. 4 (highest mean concentrations) are located in the central and eastern basins. Also high concentrations (Cluster No. 3) were found in the middle portion of the western basin and in the central and eastern basins. Moderate levels (Cluster No. 2) are located in parts of all three basins. Low concentrations of Al and Fe (Cluster No. 1) were found in the northeast part of the central basin and at Station 1.

Figures 65a and 65b show the sediment depositional pattern determined for Lake Erie and the results of the cluster analysis plotted as a contour map. The light areas represent depositional zones of fine-grained silt, clay particles and organic matter located in the deepest areas of the central and eastern basins. In general, the depositional zones correspond to the areas of highest element concentrations. In addition, the large non-depositional area in the northeastern part of the central basin corresponds with the low concentration area evident from the cluster analysis.

The mercury concentrations in the surface sediments of Lake Erie have decreased markedly in the past 10 years. Sediment cores taken at the mouth of the Detroit River in 1970 (Thomas and Jaquet 1976) yielded surface concentrations over 2000 mg/kg (Figure 66a), decreasing exponentially with depth to background concentrations of less than 100 mg/kg. High surface values were attributed to waste discharges from chlor-alkali plants which operated on the Detroit and St. Clair Rivers between 1950 and 1970. Contamination from the Detroit River appears to have spread throughout the western and most of the central basin. Localized high concentrations in the eastern basin seem to be related to local point sources. Samples taken during the Intensive Study, nearly ten years after the plants ceased operation, indicate that recent deposits have covered the highly contaminated sediment. A thin layer of new material having mercury concentrations approaching background levels is now evident (Figure 66b). In a like fashion, mercury levels in Lake St. Clair walleyes have declined from 2 ug/g in 1970 to 0.5 ug/g in 1980. The rapid environmental response subsequent to the cessation of point source discharges can be attributed to flushing of the St. Clair -Detroit River system and the high load of suspended sediment delivered to western Lake Erie covering the contaminated sediments.

In addition to the data just discussed, work by Thomas et al. (1976), Kemp et al. (1974, 1976) and Nriagu et al. (1979) have characterized the sediments of all three basins as well as estimated sedimentation rates and fluxes of elements to the sediments. Using an intensive sampling pattern (275 sites) and a detailed analysis of the surficial sediments, Thomas et al. (1976) characterized the sediment texture and, utilizing grain size analysis, defined energy regimes at the sediment water interface. In further work on the sediments, Kemp et al. (1976) attempted to trace the cultural impact on Lake Erie through the concentrations of various elements found in 10 cores distributed throughout the three basins. After grouping the elements examined into six categories (conservative, enriched, nutrient, carbonate, mobile and miscellaneous elements), each element within its category was examined and characterized relative to recent cultural changes influencing the lake. In particular, the enriched elements (Hg, Pb, Zn, Cd and Cu) were found to have increased to high concentrations above the Ambrosia horizon. This was attributed to anthropogenic loading especially since 1950. Most recently, Nriagu et al. (1979) examined the record of heavy metal contamination using cores taken from all three basins. Profiles of Cd, Cu, Pb and Zn were determined in order to evaluate loadings of metals to the lake. Using Pb dating techniques, sedimentation rates and fluxes of elements were calculated for each of the basins plus a mass balance was determined for the lake. An inventory of the sources and sinks for Cd, Cu, Pb and Zn is presented in Table 25.

TABLE 25
Sediment Source Loading
(From Nriagu et al. 1979)

Flux Rate, x 10^3 kg yr-1

Source	Cadmium	Copper	Lead	Zinc
Detroit River (import from Upper Lakes)	--	1640	630	5220
Tributaries, U.S.A.	--	100	52	271
Tributaries, Ontario	--	31	19	140
Sewage discharges	5.5	448	283	759
Dredged spoils	4.2	42	56	175
Atmospheric inputs	39	206	645	903
Shoreline erosion	7.9	190	221	308
TOTAL, all sources	--	2477	1906	7776
Export, Niagara River and Welland Canal	--	1320	660	4400
Retained in sediments	--	1157	1246	3376

It is evident that the major sources of loading are from atmospheric inputs, sewage discharges and, most importantly, the Detroit River. The Detroit River contributed 66% of the Cu load, 32% Pb and 67% Zn while sewage and atmospheric sources contributed 26%, 49% and 22% respectively. Over 40% of the metal loading is retained in the lake and in the case of Pb, 65% is sedimented in the basin. It is evident that the most important point source of contamination to the lake is from the Detroit River; thus this must be considered the principal target for open lake loading reductions.

Phytoplankton. Before the 1978 - 1979 open lake program, a phytoplankton population study which incorporated all three basins had only been conducted once during the last decade. Munawar and Munawar (1976) reported phytoplankton community structure in the three basins for seven cruises from April through December 1970. As part of the 1978 - 1979 Intensive Study, phytoplankton species composition and community structure were examined in order to detect any changes that would reflect on water quality (DeVault and Rockwell 1981). During 1978, samples were collected at each station using the same sampling pattern utilized for chemical analysis (Figure 67) while a reduced sampling pattern was followed during 1979. Sample analysis employed a modified Utermohl technique with cell number and biomass estimates derived for each count.

Western basin biomass indicated a somewhat similar pattern during the first half of both field seasons. The initial diatom peak was not encountered either year; consequently, spring and early summer biomass values were low. As the western basin warmed in the late spring and early summer, a rapid biomass increase continued through mid-summer. In 1978, biomass showed a decline into the fall, while in 1979 fall biomass remained high with peak values occurring in November (Figure 68). These extreme oscillations are characteristic of the western basin, particularly if blue-green bloom conditions are encountered, as was the case in 1979. In general, the western basin phytoplankton biomass is dominated by diatoms in the spring and co-dominated by diatoms and blue-greens through the summer and fall (Figures 69 and 70). This pattern is similar each year with only the intensity of these fluctuations varying, as was also shown by Munawar and Munawar (1976).

The central and eastern basins showed a somewhat similar biomass pattern and species composition during both years (Figures 71 and 72). The diatoms and greens represented the major contributors to the phytoplankton community throughout the season (Figures 73-76). Initial spring biomass is generally high relative to the summer months due to diatom populations found in both basins. Through mid-summer, values remained low with a gradual biomass increase toward mid-August and September resulting from increasing populations of the green algae. Following turnover in the central basin and later into the fall in the eastern basin, diatoms again became dominant members of the community.

The relative abundance of the taxa contributing greater than 5 percent to the total biomass by basin and year is presented in Tables 26-31. In addition, each taxa considered to be indicative of eutrophic conditions is indicated. The taxa comprising the species most commonly encountered in the western basin represent diatoms, blue-greens, greens and cryptomonads while in the central and eastern basins blue-greens do not represent the influence found in the western basin. Diatoms are the most important group throughout the lake in terms of total biomass with greens having the next greatest contribution. No one taxa or group characterizes any single basin; instead, most any of the taxa listed were found to be ubiquitous throughout the three basins.

Biomass distribution indicate a west-to-east decrease in standing crop with higher concentrations found along the U.S. shore of all basins. Comparison between the two years indicated somewhat higher concentrations occurring in 1979, particularly in the western basin (Table 32). Very little change was evident in the eastern basin, while the central basin increase can be attributed to an increased diatom biomass during the late fall cruise of 1979. The western basin increase was also due to a diatom pulse during the same fall cruise in addition to a large population of blue-greens in early August through September. Both the fall pulse of diatoms and August population of blue-greens contribute significantly to year-to-year variation, particularly considering the long interval between surveys.

TABLE 32

Total Mean Basin Phytoplankton Biomass by Basin

	Western	Central	Eastern
1978	4.0 g/m3	1.8 g/m3	1.2 g/m3
1979	9.4 g/m3	3.4 g/m3	0.9 g/m3

Nearshore Zone

The nearshore segment of the Lake Erie intensive study 1978-1979 was the resultant effort of four groups, each responsible for individual segments of the nearshore region, i.e. western basin (U.S. - CLEAR), central basin (U.S. - Heidelberg College), eastern basin (U.S., GLL - SUNY) and the entire north shore (Canada - OMOE). A more complete description of the nearshore program is presented in the Methods section.

The combining of the nearshore data sets was not confluent; however, in order to present a comprehensive view of the nearshore region the data was pooled and mean values were determined for the two-year study period. Figure 77 presents the mean concentrations of several parameters for each of the individual reaches. The figures are ordered by basin and shoreline, i.e. north shore of the eastern basin (reaches 1-4) followed by central basin north shore (reaches 5-7) and so on. A more complete yearly summary of the data is presented in Appendix A, presenting a list of primary parameters for each reach together with median, mean, maxima, minima, standard error, and number of samples (n).

"Nearshore" is an ambiguous term also referred to as the littoral zone (an interface zone between the drainage basin and the open water of the lake) (Wetzel 1975). The expanse of this region in relation to the open water (pelagic zone) varies among lakes depending on geomorphology and sedimentation rates. Wetzel states that most of the world's lakes are relatively shallow and areally small with the littoral zone constituting a major portion of the lake basin. The littoral zone generally is a major contributor to total lake productivity with submerged macrophytes responsible for much of the production. This does not represent the situation observed in Lake Erie. Submerged aquatics were not observed at any of the shore stations; however, primary productivity was indeed high compared with the open lake due to profuse populations of phytoplankton. For example, corrected chlorophyll a values frequently used as an indication of primary production, reached a maximum of 209 ug/l in the nearshore area of Sandusky Bay.

Many authors have attempted to define Lake Erie's nearshore zone (Cooper 1978, Gregor and Ongly 1978, Gregor and Rast 1979, Herdendorf 1980b, Richards 1981a, Rukavina and St. Jacques 1971) but no one has been able to establish the physical boundaries or determine objective criteria for nearshore waters. To establish definite boundaries for the nearshore, one must establish the criteria to be utilized. Several of the above-mentioned authors have suggested the following criteria:

1. Physical description
   a. depth contour
   b. distance from shore
2. Chemical
   a. high mean concentrations
   b. steep inshore-offshore chemical gradients
3. Dynamics
   a. high energy sediment deposition
   b. high variability mixing zone

Indeed the nearshore zone is highly variable, and one can sample an inshore-offshore transect on one day and find uniform concentrations throughout while on the following day concentrations at inshore stations can be 10 to 100 times greater than at a corresponding offshore station. The resultant problem is to find criteria that can be used independently of short- and long-term variability, i.e. daily vs. seasonal fluctuations. The demarcation of this zone and the interface with the open lake will be presented in the Discussion.

Temperature Regime. Thermal stratification in the nearshore area is ephemeral, most commonly occurring in the central and eastern basins. Stratification was not observed in the nearshore region west of Sandusky Bay during this study. Since the western portion of Lake Erie is shallow and does not form a permanent thermal structure, the likelihood of any thermal structure in the nearshore would be very remote. The occurrence of a thermal regime in the nearshore of the central and/or eastern basin is also not frequently encountered. The nearshore region can be characterized as a high-energy mixing zone due to breaking waves and accompanying orbital velocities of the water mass beyond the breakers. Thus any thermal structure encountered in this zone would be expected to last only a few days, depending upon meteorological conditions. The mechanisms involved in the formation of a thermocline or thermal gradient in the nearshore zone are similar to those previously discussed for the open waters of the western basin. Essentially two conditions could result in the formation of thermal structure. First and probably the least stable condition occurs during several warm, calm days when a thermal gradient develops. The thermal gradient persists until wind stress induces sufficient vertical mixing to destroy any gradient. The second condition occurs during periods of strong wind events and seiche activity resulting in a temporary tilting of the hypolimnion in both the central and eastern basins. This tilting can result in transport of hypolimnion and/or mesolimnion water into the shore region of either basin and, as previously mentioned, this water mass may also move into the western basin. Most frequently this tilting of the hypolimnion effects the southwest corner of the central basin known as the Sandusky sub-basin. Water depth in this region is less than 15 m and by late summer permanent thermal stratification no longer exists. However, during periods of seiche activity central basin bottom waters may move into the sub-basin for short periods of time. For example, during a summer nearshore cruise in 1979, stratification was found near Huron, Ohio. Stations in the region were sampled on three consecutive days, with stratification encountered at the Huron station on the first and third days but not on the second. During the second day, thermal structure was encountered approximately 0.5 km northeast of the original location. This type of hypolimnion/mesolimnion water transport is not unusual for the shore regions of the central basin. Similar recordings of thermal structure movement were also made at Cleveland, Ohio, Erie, Pennsylvania, and Dunkirk, New York.

A second type of thermal event, potentially important to the nearshore region and known as "thermal bar," has been described for the Great Lakes (Rodgers 1966). Thermal bar formation occurs during the spring when nearshore and tributary water-temperatures are $4^{o}C$ and greater. A $4^{o}C$ interface between the nearshore waters and the colder open lake water mass forms, resulting in a somewhat impermeable barrier to mixing of the two water masses. The most notable effect in Lake Erie is to inhibit the mixing of the tributary water with the open lake; for example, the turbid, warmer water of the Maumee River is confined to the south shoreline of the western basin during the presence of a thermal bar. This phenomenon was observed during the spring cruise of 1979. The thermal bar was not observed in the south shore region of the central and eastern basins due to the lateness of the spring cruises (late May, early June) and north shore coverage was not sufficient to document this event. Wetzel (1975) hypothesized that thermal bars probably occur in all lakes; however, the duration of their effect may be only transitory. Due to the shallowness of Lake Erie compared with the other Great Lakes, the spring warming period is rather rapid resulting in a short time frame when the thermal bar could have an important lakewide effect.

Nutrients. When examining the nearshore data collected during the two intensive years three sources of variability were considered: (1) spatial or regional differences, (2) seasonal differences, and (3) year-to-year differences. Each of the nutrient parameters are influenced to various degrees by these three sources of variability. After preliminary analysis of the data the entire nearshore of the lake was geographically divided into sections referred to as "reaches." The sectioning of the nearshore was designed to reduce spatial variability. For example, the spatial variability in total phosphorus concentrations one finds along the U.S. shoreline of the western basin is considerably greater than that found along the Canadian shoreline of the central basin. Consequently, areas of the greatest variability with respect to concentrations, or regions having uniquely high or low values were segregated. These regions are represented by reaches 2 (Port Maitland), 11 (Maumee Bay), 13 (Sandusky Bay), 16 (Cleveland), and 19 (Erie Harbor). Each of these locations represents an area of high concentrations and loading compared with the adjoining reaches. By separating these regions, some of the major effects of spatial variability were removed.

Neither the seasonal nor yearly variability was stringently dealt with in the framework of this report. Appendix A presents standard error, and maximum/minimum values for each year providing information on the yearly differences, however seasonal values were not presented. For each of the five major nutrient parameters, total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate plus nitrite (N+N), ammonia (NH_3), and dissolved reactive silica (DRS), seasonal variability proved to be greater than year-to-year variability. The exception was TP where seasonal vs. yearly variations were similar.

When examining the western basin nearshore mean nutrient concentrations for year to year vs. seasonal fluctuations, several points become obvious (Table 33). First, if the seasonal high and low concentrations are compared it can be seen that over a 75% change in concentration occurred between cruise mean values for all parameters with the exception of TP. For example, 1978 spring western basin nearshore concentrations of SRP were 36.2 ug/l while fall values were 6.8 ug/l indicating an 81% change through the field season. Second, if yearly means for 1978 and 1979 are compared, it is apparent that the difference is considerably less than that found within a single season.

TABLE 33

WESTERN BASIN NEARSHORE NUTRIENT VARIABILITY BETWEEN YEARS
(ug/l)

	TP	SRP	N+N	NH_3	SRS
1978					
Mean concentration	130	16	785	86	1388
Difference between seasonal max. and min.	44%	81%	95%	86%	89%
1979					
Mean concentration	88	9	1148	92	1128
Difference between seasonal max. and min.	38%	76%	94%	81%	75%
Difference between years	35%	48%	27%	6%	23%

It is important to remember that the western basin represents the extreme in seasonal variation not only evident from the percent change but also the actual differences in concentrations. For example, 1978 eastern basin cruise mean concentrations of TP ranged from 38 to 24 ug/l (37% difference) while the western basin values ranged from 185 to 104 ug/l (44% difference). The percent differences are comparable; however, it should be noted that there is an 81 ug/l difference in the western basin and only a 14 ug/l seasonal difference in the eastern basin.

The extreme seasonal variability found throughout the nearshore is primarily a reflection of tributary flow and is most evident in the western basin. The Detroit River accounts for over 35% of the total loading of most nutrients to the lake (Fraser and Wilson 1982); however, it is due to the high flow (quantity) and not the input concentration. Most frequently, the concentrations of phosphorus and nitrogen at the mouth of the Detroit River are less than ambient open basin values.

The nearshore is greatly influenced by many smaller tributaries characterized by low flows and high concentrations. Nearly all the areas of localized high concentrations are found near an urbanized area adjacent to a tributary. The combination of municipal waste, industrial effluents and agricultural runoff gives rise to a situation where the nearshore zone in and around such communities have very high concentrations of most nutrients. At seven western basin tributaries mean concentrations of TP, N + N and NH_3 illustrate the localized effect of these point sources (Figure 78-80). The cruise mean concentrations of TP at offshore locations (open western basin) ranged from 14 to 40 ug/l for the two-year period except for an extremely high concentration encountered in spring of 1979 (102 ug/l). In contrast the cruise mean nearshore concentrations (western basin) of TP ranged from 70 to 185 ug/l over the two year period. In almost all cases, highest nearshore and open lake concentrations occurred during the spring coinciding with peak loading from all tributaries. As evident by Figures 81-85 the two-year mean concentrations in the nearshore region around the western basin tributaries were as high or usually higher than peak spring open water values, further illustrating the year-round localized effect of these smaller tributary inputs. This same relationship between high localized concentrations and tributaries is also evident in the central and eastern basins.

As previously discussed, these numerous tributaries contribute greater than 40% to the total loading (Great Lakes Water Quality Board 1983); however, their influence within the mixing zone of the lake is very dramatic. They produce both esthetically unpleasant conditions, i.e. turbidity, and greatly enhance the eutrophication of the nearshore. Frequently, in conjunction with high nutrient loading, the input of contaminants is also significant. In nearly all such regions, elevated concentrations of heavy metals and organics have been measured. Since the nearshore portion of the lake represents the maximum-use area both recreationally and for municipal and industrial purposes, the pollution of the region is particularly important.

Total Phosphorus. Total phosphorus will serve as an exemplar for the reach distribution of the major nutrient parameters. Since phosphorus concentrations provide a good indication of external loading from both agricultural and municipal sources, the high and low reach concentrations of TP are generally indicative of the other nutrient parameters. From Figure 81 it is evident that the highest concentrations of TP are found in the western basin and the south shore of the central basin. Only two other reaches indicate exceptionally high values, both in the eastern basin, reaches 2 (Port Maitland), site of the input of the Grand River, Ontario, and 19 (Erie, PA Harbor). The entire north shore of Lake Erie and the south shore of the eastern basin, with the exception of the two previously mentioned reaches, have concentrations below 30 ug/l for the two-year mean. Maumee Bay and Sandusky Bay maintained the highest values (160 ug/l) both receiving the major percentage of phosphorus loading from agricultural sources; however, the city of Toledo is also a significant contributor to the Maumee Bay phosphorus load. Since much of the Maumee River flow remains confined to the south shore portion of the basin, the reach immediately east (12) is also influenced by the high values originating from the Maumee. The central basin south shore concentrations primarily reflect municipal point sources, i.e. Cleveland (16) and Faiport (17).

Soluble Reactive Phosphorus. SRP reach means similarly reflect point source contributions along both the northern and southern shorelines. High values were encountered at reaches 2 (Port Maitland) and 11 (Maumee Bay) with intermediate concentrations found near Leamington (8) and along the southern shore of the western basin and the central basin west of Cleveland (Figure 82). High SRP values were anticipated in Erie PA Harbor due to the high TP values but were not observed. This may have been due to a methodology problem discussed previously and/or rapid biological uptake of soluble phosphorus in the eutrophic bay.

Dissolved Inorganic Nitrogen. Nitrate plus nitrite and ammonia concentrations were found to be highest in the western basin and along the southern shore of the central basin (Figures 83 and 84). As with total phosphorus, ammonia and N+N originate both from agricultural and municipal sources; however, the primary source of both forms of nitrogen during the spring is from agricultural drainage. Point sources proved to be the most important in terms of localized effects, particularly in Maumee Bay and the Cleveland area, where the highest values of the nearshore region were recorded.

Seasonal concentrations of ammonia are considerably more stable than those of nitrate plus nitrite along the entire U.S. shoreline. For example, at select stations in the western basin where variability is the greatest, ammonia concentrations changed from spring peak values to seasonal lows by approximately 500% while nitrate plus nitrite values showed a seasonal change in concentration of over 15 fold (1500%). The most dramatic example of seasonal fluctuations for an entire reach is found in the Maumee Bay (reach 11) where 1979 spring concentrations of NH_3 were greater than 350 ug/l and nitrate plus nitrite exceeded 4,700 ug/l while fall mean values were 90 ug/l and 800 ug/l respectively. The very large reduction in nitrate plus nitrite results from reduced tributary concentration and flow. Since agricultural runoff is the principal source of this form of dissolved nitrogen during the spring, such a drop would be expected. Loading of ammonia, on the other hand, represents more of a combination of two sources, agricultural and municipal. Following the spring loadings of ammonia, concentrations remain relatively high due to the constant input from municipal sewage treatment plants.

Silica. Dissolved reactive silica (DRS) concentrations indicate shoreline and seasonal distribution characteristics similar to those previously described for nitrate plus nitrite (Figure 85). Sources of loading do differ; external loading of silica enters the lake only through land drainage, or agricultural runoff and through internal loading such as dissolution of particulate silica and DRS found in interstitial waters. Points of highest concentations are reaches 11 (Maumee Bay) and 13 (Sandusky Bay). Both areas are subject to extensive loading of sediments from agricultural drainage and continual bottom resuspension.

Corrected Chlorophyll a. Classical definitions of the nearshore region or littoral zone allude to a region of high primary production. Frequently this region is heavily populated with macrophytes and attached epiphytes. However, macrophyte populations are not plentiful along the shorelines of Lake Erie; being present only in isolated marsh areas such as Long Point Bay. Consequently, only phytoplankton and Cladophora are responsible for the high production evident along the shores as reflected by CCHLA concentrations. The more eutrophic reaches are clearly evident throughout the U.S. shore of the western basin (reaches 10 through 14) and Erie PA Harbor (reach 19), with the most abundant algal growth found at reach 13, Sandusky Bay (Figure 86). The two-year mean CCHLA was 60 ug/l with maximum values of over 200 ug/l occurring in the upper regions of the bay near the Sandusky River mouth. Erie Harbor represents the only region of high CCHLA values outside the western basin reflecting high nutrient input and limited exchange with the open lake.

Only in the western basin did any significant change in the mean concentration occur throughout the season. The cruise-to-cruise mean concentrations over the two-year period did not change more than 2 ug/l in the central or eastern basins, while in the western basin cruise means doubled from the spring cruise to early summer and remained high into the fall. It is important to notice that a doubling of CCHLA values in the western basin is greatly more significant than an equivalent increase in the other two basins.

In all three basins, nearshore zone concentrations were greater than the offshore values. In the western basin, nearshore concentrations were usually 100 percent greater than those from the open basin. The central basin nearshore concentrations were only 40% greater while eastern basin nearshore concentrations varied from 20 to 75% greater than the open lake values. Eastern basin nearshore mean values were never greater than 6 ug/l at any time during the two years, thus the inshore-offshore differences of actual concentration were small (1 ug/l-2 ug/l).

Seasonally, the highest concentrations occurred during September for all basins which is similar to the pattern found in the open portion of the lake (Figures 44 and 45). The northern nearshore zone was not sampled with the same intensity as the south shore, thus it is difficult to interpret this data.

Secchi. Water clarity provides an indirect measure of water quality incorporating several parameters. As discussed in the open lake section, secchi, turbidity, CCHLA and particulate organic carbon all show a relationship to water clarity. Decreased secchi depth for the nearshore region is significantly affected by two factors: first, resuspension of the sediments due to wave action, and second, tributary inputs. The resuspension of bottom material adds turbidity to the nearshore region during increased wave activity with the intensity determining the degree of resuspension. During moderate wave conditions this effect is minimal, influencing only the area inside 0.5 km in most regions; however, during severe storm activity the effect can be evident several kilometers from shore. During the late fall and early spring, resuspension influences the entire water column throughout all three basins.

The second significant influence on water clarity originates from tributary flow. Other than the Detroit River, most of the tributaries entering the lake have secchi values less than .25 m, turbidity values of 100 NTU and total suspended solids of greater than 40 mg/l. Therefore the mixing zone represents a highly turbid region compared with the open lake.

In addition to these factors, the inshore zone also may contain a high density of phytoplankton further decreasing water clarity. This is particularly true in Sandusky Bay where blue-green populations may frequently reach bloom conditions. In general, however, phytoplankton are not the major form of particulate material responsible for the reduced transparency encountered in the nearshore region.

It is evident that the clarity of water improves once removed from the western basin influence (Figure 87). Nearly the entire north shore and the eastern basin maintain mean secchi values greater than 2 m. Much of the central basin south shore values were two to three times greater than western basin values.

Dissolved Oxygen. Low dissolved oxygen values in the nearshore region of any basin were not a frequent occurrence (Figure 88). Based on the International Joint Commission objective of 6 mg/l, only an average of 5% of all values reported from the U.S. nearshore were below the objective level. Many of the low D.O. values were associated with temporary thermal stratification particularly in the central basin. For example, nearly 40% of the low D.O. values recorded in the central basin in 1978 occurred in the Huron, Ohio area. As previously discussed due to the pendulum-like mobility of the mesolimnion/hypolimnion water of the central basin moving into the Sandusky sub-basin, D.O. values as low as 0.1 mg/l were encountered. Low values were also found adjacent to a dredge spoil construction site near the Detroit River, at an open lake dredge disposal area near Conneaut and at the mouths of the Maumee, Huron, Cuyahoga and Buffalo Rivers. Low D.O. values were noted along the north shore in 3 of the 9 reaches (1 - Port Colborne, 6 - Port Stanley, and 7 - Wheatley) at least once over the two-year period. A complete violation listing was not available for the north shore.

The seasonal fluctuations in dissolved oxygen concentrations encountered in the nearshore zone can mainly be attributed to changes in solubilities resulting from the annual lake temperature cycle. Based on 100% saturation, D.O. concentrations could range from 14 mg/l during periods of cold water to 8.5 mg/l in the warmest months. The mean values during this study range from 81 to 99.9% saturation with the concentration means ranging from 7.5 mg/l to 10 mg/l. Only three reaches indicate saturations below 90% (Figure 89): reaches 6 (Port Stanley 82.2), 9 (Colchester 81.1) and 14 (Sandusky Bay 88.6), none of which indicate any specific problem in terms of an entire reach.

Principal Ions. The principal ions (chloride, sulfate, bicarbonate calcium, magnesium, sodium, and potassium) are all natural constituents of Lake Erie water as a result of interactions between bedrock and groundwater (weathering, leaching and erosion). These constituents of Lake Erie chemistry historically have been used as indicators of long-term changes in water quality (Beeton 1961). Thus a more detailed explanation of their distribution is pertinent.

The full complement of ion parameters was measured during the nearshore study, not because the nearshore area was expected to have chronic or toxic concentrations (Table 34), but to establish an extensive seasonal and spatial data base for further use in trend analysis. Due to the conservative properties of ions, they lend themselves to analysis of long-term changes in the lake resulting from external inputs, i.e. changes in chloride concentrations originating from municipal sources.

Using the south shore central basin nearshore data, Richards (1981a) determined that this section of the lake was very similar to the standard bicarbonate lake described by Hutchinson (1957) with the exception of chloride and potassium (Figure 90). Lake Erie chloride concentrations are two times higher than those found in other bicarbonate lakes. In contrast, potassium concentrations were found to be only 40% of concentrations normally encountered. This general uniformity between lakes due to the principles of geochemistry also implies uniformity within a lake. This has been documented by several investigations on Lake Erie (Kramer 1964, Don 1972) with the exception of certain harbors. The Canada Centre for Inland Waters (Don 1972) has stated that it is unnecessary to measure offshore Lake Erie principal ion concentrations because they can be estimated from conductance values in conjunction with conductance factors for the individual ions. To test this assumption, the data base utilized consisted of all the principal ion data collected during the two-year period (4 cruises/year) at over 250 nearshore stations. The full compliment of ion data was available for the south shore reaches only (Table 35), while only chloride and alkalinity were recorded for the north shore reaches (1-9). Data for ions is available as annual reach means in Appendix A, and annual river/harbor means in Appendix B.

Chloride reach means ranged from 17.8 to 27.5 mg/l (n=20). The reaches having the highest means are located along the south shore: Maumee (27.5), Cleveland (26.3), Fairport (25.4) and Sandusky Bay (24.4) (Figure 91). Two north shore reaches also exhibited noticeably higher concentrations: Colchester (23.3) and Port Maitland (23.2 mg/l). Many of these high values are due to loadings of chloride from tributaries entering the lake within the designated reach. Of all the rivers that were monitored (n=22), the four that demonstrated the highest concentration of chloride and subsequent loading were located along the south shore:

Grand River, Ohio	67.5 mg/l
Cuyahoga River, Ohio	55.6 mg/l
Rocky River, Ohio	49.7 mg/l
Ashtabula River, Ohio	40.3 mg/l

Large quantities of chloride ($\bar{x}$ = 2270 mg/l) have been reported for stations in the Grand River, Ohio since 1950. The high concentrations resulted from two sources: soda ash production by the Diamond Shamrock Company which utilized the brine from salt wells adjacent to the river and from the mining of salt by the Morton Salt Company. The Diamond Shamrock Company closed their chromate plant in January of 1972 and the remainder of their facilities in 1976, while the Morton Salt Company is still in operation. A USEPA in-house memo discussing the chloride problem associated with the Grand River indicated another possible chloride source, Mentor Marsh (USEPA 1974). Herdendorf (1982) stated that the marsh's chloride source resulted from leaching of brine from land fill wastes buried within the marsh. Data from the open lake intensive study also shows that the Cleveland-Fairport area has some of the highest chloride concentrations found in the offshore regions.

Sulfate reach means ranged from 25.8 - 95.8 mg/l (n=11) with the highest values found in the upper portion of Sandusky Bay (Figure 92). All the stations in this area had means greater than 100 mg/l. Most likely the source of these high sulfates can be attributed to leaching from the United States Gypsum Company mines (Figure 93). High sulfate concentrations were also observed in the Maumee reach ($\bar{x}$ = 45.4 mg/l). Sulfate concentrations observed for the open lake portion of the intensive study ranged from 18.2 to 30.3 mg/l, with the maximum concentrations adjacent to areas where fossil- fuel power plants are located.

Kohlraush's Law states that the conductivity of a neutral salt in a dilute solution is the sum of 2 values, one of which depends upon the cation (positive ions) and the other upon the anion (negative ions); in other words, each ion contributes a definite amount to the total conductance of the electrolyte. Although the concentration of an ion may vary between samples, the amount of conductance resulting from one milligram of this ion is consistent. This constant is known as the conductance factor. The American Public Health Association (1974) presented conductance factors for principal ions. The Canada Centre for Inland Waters (1972) presented monthly conductance factors (adjusted for temperature) for the principal ions. Utilizing these factors and the cruise means of the 7 major ions, specific conductance was calculated. The difference between calculated conductance and the measured specific conductance was less than 3% for the 1970 open lake data set. When this technique was applied to south shore reach data, the differences ranged from 6 to 10%. Since the larger differences between the measured and calculated conductances were consistent, the possibility of analytical error was dismissed. The explanation of the differences remains unknown, but there may be some indication that the offshore conductance factors are not appropriate for the nearshore zone.

The conductance factor technique is not meant to calculate conductance but merely to test the possibility of back calculating in order to estimate the individual ion concentrations once the conductance is known. In addition, it is necessary to know the percent contribution each of the ions makes to the conductance before the concentrations can be estimated:

TABLE 36

	Open Lake CCIW 1970	Nearshore 1978-1979
Bicarbonate	51.0%	44.9%
Chloride	11.0%	10.9%
Sulfate	11.0%	16.6%
Sodium	5.0%	5.6%
Potassium	1.0%	0.9%
Magnesium	3.0%	4.2%
Calcium	17.0%	16.9%

The percent contribution of each component is very similar between data reported during the 1970 open lake and the 1978-1979 nearshore studies with the exception of bicarbonate and sulfates. Ionic percent contributions for all the south shore reaches are presented in Figure 94. The major difference in ionic composition occurs in reach 13 (Sandusky Bay) as a result of high sulfate concentrations. When comparing actual ionic concentrations (Table 36) and variability (% standard error) for the 2 main lake data sets (1970 and 1978, 1979) and the nearshore 1978-1979, it is evident that the greatest variability existed for the nearshore region. The large variability of sulfate (18%) is due to the high concentrations in the Sandusky and Maumee Bays (Figure 94). The second most variable ion was potassium, which is not suprising being the most active of the metals (Table 36).

Conductivity. The International Joint Commission established a total dissolved solids (TDS) objective of 200 mg/l in the 1978 Water Quality Agreement. Due to the lengthy time involved in the TDS measurement, an alternative method was employed for the TDS determination during the two-year study. Since there is a linear relationship between conductivity and TDS, a conversion factor of 0.62 was employed to indirectly calculate TDS (Fraser 1978). The IJC has established a conductivity objective of 308 umhos/cm (Great Lakes Water Quality Board 1974). Five of the 20 nearshore reaches had means greater than 308 umhos (Figure 95): Port Maitland, Maumee Bay, Sandusky Bay, Cleveland and Fairport. All five of these reaches represent highly industrialized or urbanized areas. The four south shore reaches have been repeatedly mentioned throughout this report for their high concentrations, Sandusky Bay for its extremely high sulfate ($\bar{x}$ = 95.8 mg/l) and chloride ($\bar{x}$ = 24.4 mg/l) concentrations and Cleveland and Fairport for their high chloride concentrations (26.3 and 25.4 mg/l respectively). It was not surprising that the Maumee Bay reach had the second highest specific conductance since it had the highest chloride values (27.5 mg/l) and the second highest sulfate concentrations (45.4 mg/l)

All five reaches that exceeded the IJC objective level of 308 umhos/cm were among the 7 highest reaches (out of 20) in chloride concentrations, and three of them (Maumee Bay, Sandusky Bay and Cleveland) were the top three ranking in sulfate concentrations. Although the relationships between conductivity and chloride is not a strong one, there are some similarities (Figure 95).

DISCUSSION

In the results section of this report, the present status of individual parameters for the OPEN LAKE and the NEARSHORE were documented. It is also necessary to examine these individual parameters in relation to the system as a whole rather than isolated regions. The Discussion will examine the relationship between the two regions and will provide detailed information on several specific topics.

Nearshore-Offshore Relationships

The nearshore-offshore region is a transitional zone physically, chemically, biologically and sedimentilogically. Unfortunately, the intensive study program data sets were not designed to examine the interface between the open lake and the nearshore. One of the problems in defining either region is knowing which characteristics can be used to delineate the two. In order to help understand this transitional zone, an effort was made to define or at least characterize what constitutes the nearshore. After review of the nearshore literature and query of several Great Lakes investigators, it became evident that no one definition or set of criteria was possible.

A general definition might be: The nearshore zone is an artificially bounded unit that exhibits different processes than those observed in the more centrally located portions of the lake. A more specific definition can be determined once the processes considered important are delineated. The nearshore area is defined differently by physical, chemical, biological and sediment lake specialists, each utilizing different parameters resulting in definitions unique to the specific discipline. To examine the variety of nearshore definitions the following list was assembled from literature and personal communication with Great Lakes limnologists:

Physical Limnology

1. The zone between the zero depth contour and the point at which the long waves are effectively reflected. This distance is different depending on whether we are dealing with surface seiches or internal seiches (Boyce 1982).

2. The zone contained between the edge of the lake and the bottom contour whose depth equals the mean depth of the lake (WB $\bar{x}$ = 7.4, CB $\bar{x}$ = 18.5, EB $\bar{x}$ = 24.3, whole lake $\bar{x}$ = 18.5) (Boyce 1982).

3. The zone where the vertically integrated flow is downwind (Bennett 1974).

4. The zone which can be defined during stratified conditions by the Rossby radius of deformation for internal waves. The internal Rossby radius is 2 km for the central basin of Lake Erie (Boyce 1982). (This definition would not be applicable to the western basin.)

5. The zone that demonstrates low frequency shore parallel motions. In the offshore zone, the spectral peak at the local intertial period becomes more pronounced and the current vector tends toward clockwise rotation (Murthy and Dunbar 1981).

6. The distance between the shore and the point at which the offshore component of the anisotropic viscosity is maximum (Boyce 1982).

7. The coastal boundary layer (CBL) is composed of two distinct layers, an inner frictional boundary layer (FBL) and an outer intertial boundary layer (IBL) (Murthy and Dunbar 1981). Although the calculation of these boundary layers has not yet been completed for Lake Erie, Boyce (1982) feels that the FBL is about 1 km wide. "An effluent discharged well within this zone would mix relatively slowly with the waters of the open lake."

8. The hydrodynamic boundary layer between the open lake and the shore with variable width up to 10 km (Coakley 1982).

Geology

1. The zone defined by the wave base depth (one-half the wave length of the prevailing waves). The wave base for the western basin has been calculated as 19.5 m, thus classifying all the western basin a nearshore area (Coakley 1982).

2. The zone defined by the break in slope between the shore face and the lake bottom. This boundary most closely approximates the point where wave and current deposition (nearshore) processes change to gravity settling (offshore). Using this definition, the nearshore zone would be narrow but of more irregular width around the lake (Coakley 1982).

3. The zone between the shore and the maximum depth at which sand occurs. This maximum depth varies across the north shore of Lake Erie from 10-18 m (Rukavina and St. Jacques 1971).

4. "Newly formed organic material is resuspended and redeposited more frequently at nearshore locations (9 meters depth and 2 km from shore) than offshore locations (40 meters depth and 16 km from shore). Both enhanced mineralization and particle sorting as a result of wind induced turbulence lead to the low content of organic material in nearshore sediments and are responsible for POC/PON concentration differences. This emphasizes the crucial importance of nearshore resuspension for the overall metabolism of Lake Erie." (Bloesch 1982).

5. "In the nearshore, wave action provides most of the erosional energy and part of the transportive energy; such activities may be separated into processes associated with longshore drift and inshore-offshore migration. Lack of sands in most deep water sediments indicate that onshore-offshore processes are limited in extent and only rarely provide an escape from what is essentially a closed system in the nearshore" (Sly and Thomas 1974).

6. "The nearshore zone is the zone of a lake adjacent to the shoreline where sediments are transported and sorted by waves" (Rossman and Seibel 1977). The inshore zone (<18 m) has moderately sorted fine sands (mean phi = 2.08).

The intermediate zone (18-27 m) contains poorly sorted fine sands (mean phi = 2.92) and the offshore zone (>27 m) is composed of poorly sorted coarse silts (mean phi = 4.14). "If the wave period is known the nearshore zone of any region of shoreline can be defined" (Rossman and Seibel 1977).

General Limnology

1. The zone separated from the open waters by virtue of its relatively shallow depth, high nutrient concentration, dynamic mixing, and high variability due to input loading and hydraulic characteristics. The physical expanse of the zone varies considerably resulting from changes in wind intensity and duration and from the natural variation in shoreline and bottom morphology (Gregor and Rast 1979).

2. At the outer edge of the nearshore zone, more than 90% of the transition from watershed to lake water has occurred in the central basin (Richards 1981a). However, Richards does not suggest a specific width for this zone.

Following sediment analysis of all the Great Lakes nearshore areas (shore regions <18.3 meters), Chesters and Delfino (1978) found them all to be non-depositional in nature. Inside the 18.3 m contour, sediments are temporarily deposited only to be eventually transported by currents and storm activity. The western basin does not conform to this concept since the input loadings to the basin are in excess of sediment exported to the central basin (Thomas et al. 1976). The mean sediment grain size found in the western basin is smaller than that found in other lakes and is composed primarily of clay and not the more conventional nearshore sandy sediments. Thus, the inclusion of the entire western basin into the nearshore zone as was done by Gregor and Rast (1979) may not be appropriate.

For purposes of this report, the nearshore will be considered the zone extending from the shoreline to 7 km into the open lake. Considering the wide variation in what is considered to be "nearshore," careful attention must be given to the criteria when future sampling schemes are designed. This would greatly enhance the database and possibly broaden the application. Future research and monitoring efforts, particularly in the shore and harbor regions, need to consider the zone where pollutants begin to mix with the open lake in order to aid in determining the fate of the various pollutants in the ecosystem.

One sampling scheme used in the nearshore study was helpful in examining the transitional zone. In each basin, several transects perpendicular to the shore were monitored. This data indicated that the differences encountered along each transect from shore to open lake varied depending on the location around the lake. For example, the western and central basin transects along the U.S. shoreline indicated a substantial nutrient concentration decrease from the shore to the open lake (Figures 96 and 97). The change was most distinct in areas of exceptionally high concentration such as Maumee Bay and Sandusky Bay. As would be expected, the greatest differences were associated with tributary mouths where flows were relatively low and concentrations high. This was true to some extent for all rivers except the Detroit where the volume is great but concentrations are low. Inshore areas with nominal concentrations such as those found along most of the Canadian shoreline and along the U.S. eastern basin indicated little if any gradient into the adjacent off-shore zone (Figures 98 and 99).

The two-year mean concentrations and basin ratios of total phosphorus and corrected chlorophyll a calculated for the three U.S. portions of the nearshore and basin ratios are presented in Table 37.

TABLE 37

TOTAL PHOSPHORUS AND CHLOROPHYLL CONCENTRATIONS
AND BASIN RATIOS FOR THE U.S. NEARSHORE, 1978-1979

	Western Basin	Central Basin	Eastern Basin
TP ug/l	110.0	40.0	25.0
(Basin ratio)	(1.0)	(0.36)	(0.23)
CChla ug/l	25.8	6.6	4.0
(Basin ratio)	(1.0)	(0.25)	(0.16)

Mean nearshore concentrations of total phosphorus for the central and eastern basins were less than 40% of the western basin mean, while chlorophyll concentrations were less than 25%. Not only were there significant differences in concentration between basins but also between the nearshore and offshore concentrations within each basin.

TABLE 38

NEARSHORE (NS) AND OPEN LAKE (OL) TOTAL PHOSPHORUS AND CHLOROPHYLL CONCENTRATIONS AND PERCENT DIFFERENCE BY BASIN 1978-1979

	Western Basin		Central Basin		Eastern Basin	
	NS	OL	NS	OL	NS	OL
TP ug/l	110.0	37.0	40.0	14.5	25.0	12.5
	34%		36%		50%	
CCHLA ug/l	25.8	12.4	6.6	4.8	4.0	2.6
	48%		73%		65%	

Table 38 presents the nearshore vs. open lake mean concentrations of total phosphorus and chlorophyll a found in each basin. In nearly every comparison there is over a 50% difference in concentrations between the regions. Seasonally, the differences between nearshore and offshore concentrations is the least in the spring when loading to the lake is highest. It should be noted that the actual concentration differences between the two regions are greatest in the western basin and least in the eastern basin. The load to the eastern basin south shore from tributaries is very small compared to the western basin, thus the eastern basin nearshore values are more comparable to the open lake.

The horizontal transport and subsequent mixing of nearshore or tributary water masses with the open lake yields a unique distribution pattern in each basin. In many instances, the open lake circulation pattern (Simons 1976), together with a transport model (Lam and Simons 1976) are adequate to predict the fate of pollutants entering the lake. The application of the model is particularly pertinent to the Detroit River influence. For example, the distribution of mercury from the Detroit River through the lake follows the major circulation pattern shown by Simons (1976). This movement resulted in accumulations in the depositional areas of the central and eastern basins (Thomas and Jaquet 1976). Equally important is the distribution of nutrients and toxic substances in and around harbors and tributaries in the nearshore. Both the localized effects and the eventual mixing with the open lake are important considerations. Presently, models do exist to describe the mixing of river pollutants with the lake waters. For example, Sheng and Lick (1976) and Shook et al. (1975) examined the distribution of water in and around Cleveland Harbor. Numerous other models have been developed for river/harbor interactions with the open waters of many bodies of water. Understanding dispersal patterns in and around the numerous smaller tributaries, i.e. Raisin, Maumee, Sandusky, Black, Huron, Cuyahoga and Grand Rivers, is important because of the high nutrient and toxic substance concentrations found in these regions (Figures 78-80). Since cities in and around each of these tributaries utilize the lake for drinking water as well as for recreational purposes, an understanding of the localized dispersion pattern is critically important.

Nearshore Trophic Status

The localized effects of pollutants along the nearshore zone are evident when trophic indices are applied to the region. Reviews of the numerous trophic classifications and trophic indices have been prepared by Rawson (1956), Zafar (1959), Dobson et al. (1974), Rast and Lee (1978), Gregor and Rast (1979), Maloney (1979), and Steinhart et al. (1981). Of the many classification systems, two indices have been specifically designed for Great Lakes nearshore regions. Steinhart et al. (1981) developed a multi-parameter index utilizing toxic organic and inorganic compounds plus standard nutrient parameters. A simpler index, the Composite Trophic Index (CTI) was developed by Gregor and Rast (1979) utilizing only three parameters: total phosphorus, chlorophyll a and secchi depth. Total phosphorus was chosen because of its relationship with primary production, and is generally considered to be the limiting nutrient controlling production (Gregor and Rast 1979). Chlorophyll is used as an estimate of biomass and production, while secchi depth is inversely related to biomass and is an estimator of water clarity. The Composite Trophic Index was applied to each reach of the Lake Erie nearshore.

Gregor and Rast verified three different relationships (A,B,C) between total phosphorus, chlorophyll and secchi depth during their analysis of 1972 and 1973 Great Lakes nearshore data (Table 39).

TABLE 39

RELATIONSHIP OF TOTAL PHOSPHORUS, CHLOROPHYLL AND SECCHI (TAKEN FROM GREGOR AND RAST, 1979)

Relationship	Characterization
A	High Chlorophylls (2.0-20 ug/l) and small secchi depths (0.8-3.3m)
B	Low chlorophylls (0.3-1.5 ug/l) and large secchi depths (4.6-9.2)
C	High inorganic turbidity (0.92-4.6 m secchi) and intermediate chlorophyll values (0.5-4.0 ug/l)

Before using the CTI to determine the trophic status of the nearshore region it was necessary to characterize each of the designated reaches. This was accomplished by plotting 2.3/secchi depth versus chlorophyll a concentrations. In 18 of the 20 reaches, an A type relationship was found, while reach 8 (Leamington) was considered a B region and reach 9 (Colchester), a C region (Figure 100).

Utilizing the total phosphorus, chlorophyll a and secchi two-year reach means, a CTI value was calculated using the appropriate equations for the specified relationship:

$$CTI_A = \frac{\left(\frac{28.52}{SD} - 3.84\right) + (1.67\ \mathrm{Chl}\ \underline{a}) + (0.31\ TP)}{3}$$

$$CTI_B = \frac{\left(\frac{14.04}{SD} - 0.556\right) + (1.67\ \mathrm{Chl}\ \underline{a}) + (0.31\ TP)}{3}$$

$$CTI_C = \frac{\left(\frac{7.91}{SD} - 0.409\right) + (1.67\ \mathrm{Chl}\ \underline{a}) + (0.31\ TP)}{3}$$

The Lake Erie nearshore CTI results for the individual reaches are presented in Table 40 and Figure 101 and are contrasted with the results reported by Gregor and Rast (1979) (Table 41). The greater the CTI value the poorer the water quality. The maximum CTI calculated in 1972-1973 was 16.2 in the western basin north shore region corresponding to reach 8. The current study calculated a CTI of 10.7 for this region (Figure 102). This does not necessarily indicate improved water quality since 1973 but likely reflects the difference in sampling schedules for the databases utilized. Gregor and Rast used only summer data, since only limited information was available for spring and fall. In contrast, the data utilized for the 1978-1979 analysis included the spring, summer and fall with the exception of some north shore reaches. An additional difference in the results may be attributed to selection of the individual shoreline segments used to represent reaches. Gregor and Rast (1979) selected reaches prior to any analysis of the data primarily using the location of tributary inputs, while the selection of reaches for this analysis was based on the preliminary results of the nearshore data sets. Another important difference resulted from Gregor and Rast (1979) classifying the entire western basin as nearshore area, versus the 7 km zone selected for the 1978-1979 analysis.

The result of the 1972-1973 trophic analysis for Gregor and Rast's regions resulted in 8 oligotrophic/mesotrophic, 9 mesotrophic, 1 eutrophic/mesotrophic and only 3 eutrophic areas (Table 41) with twelve areas having insufficient data for analysis (Figure 102).

For the two-year intensive study, each of the 20 reaches was assigned a trophic status (Table 40) based on the associated CTI value established by Gregor and Rast (1979) (Table 41). Of the 20 reaches, 10 were considered eutrophic, 2 eutrophic/mesotrophic, 7 mesotrophic and 1 oligotrophic/mesotrophic. The north shore of Lake Erie was generally mesotrophic with the exception of reach 2 (Port Maitland) which was determined to be eutrophic. This reach is significantly affected by the Grand River, Ontario, previously noted for high nutrient loadings. The reaches of the west and southwest shoreline of the western basin, the reaches of the south shore central basin, and the Erie, Pennsylvania Harbor reach of the south shore eastern basin were all eutrophic. The maximum CTI values were located along the U.S. portion of the western basin. Sandusky Bay (reach 13) had the highest value (81.1) followed by Maumee Bay (56.4) both noted for their eutrophic condition.

Steinhart et al. (1981) critiqued Gregor and Rast's (1979) index concluding that the linear regressions determined for total phosphorus and secchi were not successful in explaining the actual data. However, analysis of recent Lake Erie nearshore data indicated a good fit along the Group A line although it was necessary to extrapolate the line to accommodate some of the high chlorophyll areas (>20 ug/l).

The water quality index developed by Steinhart et al. (1981) was applied to the nearshore reach data for comparison with the Gregor and Rast (1979) CTI. The Steinhart index is based on 5 groups of water quality parameters: (1) biological -- fecal coliforms and chlorophyll a; (2) chemical -- total phosphorus, conductance and chlorides; (3) physical -- suspended solids, aesthetic status; (4) inorganic contaminants -- arsenic, cadmium, lead, mercury and nickel; and (5) toxic organic compounds -- toxaphene, PCBs, phenols and chloroform.

A detailed description of the calculated method is available in Steinhart's text, An Environmental Quality Index for Nearshore Waters of the Great Lakes (1981); therefore, only the methods directly related to this study will be discussed. Index values were calculated using yearly reach means for all specified parameters except aesthetic status and the toxic inorganic group. In the case of aesthetic status, the maximum value was applied in each case due to the spotty nature of the data. With the inorganic toxic compounds a different approach was necessary since the data were frequently reported only as present or absent. For these cases, if the ratio of data reported above the detection limit to the number below the detection limit was greater than 1, the parameter was said to be in violation of the established cutoff point.

Parameter data in the physical, chemical and biological groups were fairly complete. Inorganic toxic data for the reaches along the U.S. shoreline were mostly complete, but organic toxic data was sparse. Of the organic compounds Steinhart chose to use, the CLEAR and Heidelberg data sets contained only one compound, PCBs; the SUNY set also contained phenol data. Samples from the entire Canadian shoreline did not include toxics data; therefore the Canadian index values are based only on the first four groups of data.

The index values calculated for the individual reaches are shown in Figure 103 and Table 42. Index values can range from 0-100 with 100 representing ideal Great Lakes conditions and 0 representing the worst possible conditions. Index values prefixed with an asterisk (*) indicate the index value is based on an incomplete data set. A subscript indicates which mean parameter group concentration was below the cutoff point considered to be polluted or unpolluted as defined by Steinhart (p - physical, c - chemical, b - biological, and t - toxics).

Examination of calculated index values shows that the poorest Lake Erie water quality was found in the Sandusky Bay area in both 1978 (25.28), and 1979 (29.22). The best water in the lake was generally found along the Canadian shoreline. In both years, reach 2 was the only Canadian reach that had an index value below 60, 54.15 in 1978 and 56.53 in 1979. Along the southern shoreline the index values were lowest in the western basin and generally increased eastward, excluding Sandusky Bay.

Although the water along the Canadian shoreline is perhaps the best quality nearshore water in the lake, one must be careful when using these index values. No toxic data was used in the calculation of the index values for these reaches, whereas all other index values included some toxic input. Although weights were applied proportionally when using incomplete data sets, these index values have fewer chances of losing points. This situation is particularly extreme in the case of toxics where an "all or nothing" situation exists. For example, when one examines the U.S. index values, it is evident that every index in 1979, excluding those for reach 19, had at least one toxic in violation. Thus, all index values along the southern shoreline were penalized for high toxic concentrations, but the values along the Canadian shoreline had no chance to be penalized.

A comparison of the two trophic index procedures indicates good agreement between the results for the nearshore reaches. With the Composite Trophic Index, low values indicate good water quality while low values in the Steinhart index represent poor water quality. Due to the inverse numbering scheme of these two indices, a uniform ranking (1-20) was utilized to compare the success of both systems in determining trophic status. Table 43 shows the CTI and Steinhart Trophic values and lists the trophic rank for each reach. When the two rankings were summed (Sum of Ranks) and the sum re-ranked (Rank of Sums), a combined index resulted providing the same general picture previously discussed: the best water quality (low rank) exists along the north shore and in the eastern basin; the poorest water (high rank) exists in the western and central basin south shores. Discrepancies in trophic rank occurred at four reaches: 7 (Wheatley), 14 (Huron), 18 (Conneaut) and 20 (Dunkirk). This was attributed to incomplete data particularly with the toxic group.

Total Phosphorus

The accelerated eutrophication of Lake Erie has been attributed to increasing concentrations of phosphorus over the last century. Unfortunately, the historical database necessary to substantiate the change in phosphorus concentrations is very weak. In fact, the most reliable data sets available span only the years 1970 to present. Table 44 presents the mean total phosphorus concentrations for the three basins since 1970.

TABLE 44

TOTAL PHOSPHORUS CONCENTRATIONS (ug/l) IN LAKE ERIE
1970-1980

		BASIN					
		WESTERN		CENTRAL		EASTERN	
YEAR		$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
1970	(CCIW)	44.6	9.6	20.5	7.8	17.5	7.0
1973	(CLEAR/GLL)	34.7	11.9	18.5	6.2	31.1	22.6
1974	(CLEAR/GLL)	35.1	8.8	16.8	2.7	20.8	6.9
1975	(CLEAR/GLL)	42.3	8.6	20.3	6.8	27.6	9.2
1976	(CLEAR)	44.9	15.0	22.6	5.2		
1977	(CLEAR)	40.7	1.9	24.1	8.1	18.3	4.1
1978	(CCIW)			14.2	1.2	13.9	2.5
1979	(CCIW/GLNPO)	33.9	24.8	14.2	2.9	12.1	3.2
1980	(CLEAR)	28.8	6.6	13.7	6.9		

The problem with such presentations is the lack of information concerning cruise schedules, number of samples taken or sampling pattern. Any one of these variables has the potential to significantly influence the database. For example, if the sampling schedule consisted only of information taken during the unstratified season, one would expect considerably higher concentrations with much greater year-to-year variability. Lake Erie, as compared to the other Great Lakes, is very susceptible to internal loading from storm-induced resuspension during the unstratified seasons, therefore a rather unrepresentative data set would be developed. Conversely, values obtained only during the unstratified season may be low due to settling and low loadings during the summer months. Considering the year-to-year variation in cruise schedules, mean concentrations of total phosphorus may not necessarily depict any trend if the data is not subjected to more sophisticated statistical treatment.

Another important factor in the phosphorus picture for Lake Erie is the quantification of phosphorus loading to the lake. External loading has been a topic of major concern since the late 1960s. The first loading estimates were primarily concerned with the Detroit River, since it contributed greater than 60% of the total load. It became evident during the early 1970s that the lower flow but high concentration tributaries also required an indepth treatment. The quantification of the load to Lake Erie via the Detroit River proved to be a difficult task. First, a good cross-sectional sampling pattern was necessary and the resulting measured concentrations had to be flow-weighted. Once the Detroit River portion of the total loading was estimated, loadings from the smaller tributaries had to be determined. This mainly meant monitoring the rivers from Detroit to Cleveland which drain agricultural lands.

Two major complimentary programs were implemented in order to evaluate loadings to Lake Erie. First, the Pollution from Land Use Activities Reference Group (PLUARG) (IJC 1980) was designed to study land use around all the Great Lakes and to determine types of land use activities which resulted in pollution. PLUARG estimated that from 1/3 to 1/2 of the phosphorus loading to the lakes was associated with land use, and in the case of Lake Erie, crop land drainage was the major contributor. Second, a Lake Erie Wastewater Management Study (LEWMS) was established in 1973. Three phases of the project provided detailed information on phosphorus loading, land use practices and their effect on loading culminating in the development of a management strategy to reduce diffuse loadings (U.S. Army Corps of Engineers 1982).

The actual annual loading estimates developed by these two groups as well as others are not always in agreement (Fraser and Wilson 1982). DeToro and Connolly (1980) present loading data via the Detroit River, showing the variation in loading estimates, and provide a description of the various methods employed to estimate the loadings. Dissimilar loading estimates exist even in the most current studies; however, the differences have been reduced. Accurate measurement of diffuse sources, as a result of LEWMS, together with somewhat standard estimates of upper Great Lakes water and atmospheric loading have reduced the variability. For example, the LEWMS estimate for total 1980 loading to Lake Erie was 16,455 mt/yr while the IJC estimate was 14,855 mt/yr.

A target load of 11,000 mt/yr has been determined to be sufficient (DiToro and Connolly 1980) to reduce the anoxia in the central basin by up to 90%. In order to achieve the 11,000 mt/yr target, the diffuse load must be reduced together with total compliance to the 1 mg/l discharge from municipal treatment plants. The proposed management plan developed by LEWMS calls for improved agricultural practices to be instigated throughout the drainage basin in order to reduce the diffuse load. The problem of excessive diffuse or agricultural loads results from erosion or runoff during storm events or in particular during the spring thaw. It is proposed that agricultural practices be modified so as to utilize no-till or modified till practices in order to reduce runoff. This potential reduction in loading together with reduced municipal contributions should make the 11,000 m tons attainable. Models used to predict the lake response to the 11,000 m tons indicate oxygenated conditions can be maintained (>1.0 mg/l D.O.) in the central basin hypolimnion throughout the stratified period. The reduction in TP loading will limit the biomass produced and subsequently decomposed in the bottom waters of the central basin. The eastern half of the central basin is most likely the first region to demonstrate the improved condition. Areas of the western basin and Sandusky sub-basin where organic carbon production is likely to remain high for several years following reduced loading, will likely continue to periodically go anoxic for some time.

Phosphorus Trends

The 1970-1982 total phosphorus concentrations for each of the basins are presented in Figures 104 and 105. The values plotted represent an annual mean of the individual cruise means for the entire basin. For example, the data point for 1970 western basin (Figure 104) is the mean concentration of the ten cruise means calculated for that year. A simple regression analysis was applied to each of the three basin data sets. All three basins showed a decreasing trend in total phosphorus over the twelve year period. Phosphorus concentrations indicate a decrease of nearly 0.5 ug/l per year. This analysis does not take into account either seasonai or spatial variability, thus these results should not be considered conclusive.

In order to reduce seasonal variability, total phosphorus concentrations from the central basin epilimnion during early stratification (mid-June through mid-July) were plotted (Figure 106). The early period of stratification was chosen to reduce variability resulting from resuspension, also loading is generally approaching a seasonal low, further reducing external influences. In addition, phytoplankton biomass is very low at this time following the spring diatom pulse. The total phosphorus resulting from the early spring internal and external loading processes has largely settled either as organic plankton or inorganic clay bound phosphorus. Even this selective treatment to reduce variability in the data does not adequately improve the data so as to conclusively resolve a trend.

Recently, other attempts have been made to see if Lake Erie phosphorus concentrations have been affected by efforts to reduce external loading. Kasprzyk (1983) analyzed the 1974-1980 phosphorus and chlorophyll databases. Data were partitioned into spring and fall in order to reduce seasonal variability, and geographically sectioned to reduce spatial effects. Total phosphorus showed no clearly detectable trend using this approach.

In a significantly more sophisticated approach, El-Shaarawi (1983) examined several parameters in the Lake Erie database for long term trends. Available data from 1968-1981 was utilized. The data were not seasonally partitioned, however, each of the basins was examined separately. A model was developed to adjust for seasonal and spatial variability and applied to the data set. Results indicate a decreasing trend for total phosphorus in all three basins. Total phosphorus has decreased substantially since 1971, with the western basin showing the greatest decrease, followed by the central and eastern basins, respectively.

From these results it is evident that Lake Erie is beginning to respond to the reduction in loading. In the next ten years it will become evident if the effort to reduce phosphorus inputs to the lake has had a significant effect on curbing the accelerated eutrophication.

Chlorophyll Trends

The 1970-1982 corrected chlorophyll a concentrations for each of the basins are presented in Figures 107 and 108. A simple regression analysis was applied to each data set to detect if any change in concentration was evident over the thirteen year period. All three basins indicated a decrease, with the western and central showing approximately 0.3 ug/l per year decrease and the eastern basin a 0.6 ug/l per year decrease. As was mentioned with the analysis of the total phosphorus data, these results should not be considered conclusive.

Kasprzyk (1983) reported a decreasing chlorophyll trend for the fall in the central and eastern basins, while no trend was evident in the spring in either basin. No trend was evident during either period in the western basin. El-Shaarawi (1983) indicated a similar trend, reporting decreasing concentrations of chlorophyll in the central and eastern basins and a non-significant increasing trend for the western basin.

Since the program to reduce the phosphorus loading to Lake Erie was based on the assumption that decreases in lake concentrations of phosphorus would result in decreases of phytoplankton biomass, the relationship between total phosphorus and chlorophyll trends was examined (El-Shaarawi 1983). Figure 109 presents chlorophyll values corrected for seasonal and spatial variabilities plotted against corrected total phosphorus values. The relationship was fitted with a straight line:

$$y = 1.6 + 0.206174x$$

where x is the concentration of phosphorus and y is chlorophyll. The average 1971 and 1980 seasonally and spatially corrected concentrations are shown, indicating the response of the phytoplankton biomass (chlorophyll) to decreasing phosphorus concentrations.

Dissolved Oxygen

Low concentrations of dissolved oxygen in the bottom waters have been considered a key issue in the eutrophication of Lake Erie for more than three decades. The seriousness of the oxygen problem was not fully recognized until the early 1950s when a severe period of anoxia resulted in the eradication of massive populations of the benthic mayfly nymphs (*Hexagenia*) in the western basin (Britt 1955). Since 1950, numerous accounts of oxygen depleted bottom waters have been documented for both the western and central basins. The major focus in terms of dissolved oxygen monitoring efforts has been on the central basin hypolimnion. Even though western basin bottom waters are subject to recurrent episodes of anoxia during the summer months, such events are too intermittent to monitor using a conventional survey schedule. Since the central basin remains stratified throughout the summer and is characterized by a progressive decline in oxygen concentration through the stratified season, changes in hypolimnion oxygen concentrations have been considered the best indicator of response to programs designed to curb the accelerated eutrophication of the lake.

The most obvious effect concerning anoxic conditions at the sediment water interface or in the hypolimnion is the resultant elimination of aerobic organisms. For example, an attempt to document the changes in O_2 concentration in the central basin hypolimnion using fossil remains of ostracods has shown a species shift which has been attributed to periodically low dissolved oxygen concentrations (Delorme 1982). Similar biological effects on fish and invertebrates have also been noted by other investigators. In addition to effects on the biota, anoxia serves as a mechanism for significant internal loading of soluble phosphorus, ammonia, dissolved silica and numerous metallic species (Svanks and Rathke 1980). Internal loading, particularly of phosphorus, provides an additional nutrient source to further stimulate the eutrophication of the basin.

Anoxia (defined as concentrations of $O_2 < 0.5$ mg/l) was first documented in the central basin in 1959 (Beeton 1963) and has since been reported to have gone anoxic each year surveyed. This does not imply that anoxic conditions did not exist prior to 1959 but sufficient survey documentation is not available. For example, during the 1929 study (Fish 1960) the lowest dissolved oxygen recorded was 4.4 mg/l during mid-August at a station 42 km northwest of Cleveland. Since the following survey was not conducted until after turnover, any anoxia that might have developed late in the stratified period would not have been detected. In 1930, Wright (1955) measured oxygen values of < 0.8 mg/l just north of Marblehead, Ohio. This area is the border between the western and central basins; thus, it cannot be interpreted as indicative of the open waters of the central basin. In fact, this region, referred to as the Sandusky sub-basin located in the southwest corner of the central basin is shallow (mean depth 12-13 m) and generally considered the most eutrophic open water area of the basin. It is very likely this was the first central basin region to suffer extensive oxygen depletion problems since it has a very thin hypolimnion (< 2 m) and receives a high organic loading from the western basin and Sandusky Bay. Recurring anoxia may develop in this region after destratification if central basin hypolimnion waters move back into the area, i.e. during seiche activity.

The total areal extent of anoxia in the open lake portion of the basin has been examined since first documentation in 1959 (Figure 110). The total area represents the composite anoxic area recorded during the entire stratified season; therefore, it does not indicate the extent of stratification at any one point in time. For example, if the Sandusky sub-basin was anoxic in mid-summer and destratified by late summer, remaining oxygenated, it was included in the total estimated area. The cumulative areal extent reported is entirely dependent on the timing of cruise schedules, and estimates are likely to be conservative since conditions may change rapidly during later stages of stratification.

The processes involved in the depletion of oxygen from the hypolimnion (HOD) center around the decomposition of organic matter in the water column (WOD) and at the sediment-water interface (SOD) (Figure 111). In addition, many reduced metallic species also contribute to the oxygen depletion as chemical oxygen demand (COD).

The oxygen demand in the water column (WOD) is mainly a result of the decomposition of dying planktonic organisms (primarily phytoplankton) and respiration of living planktonic organisms, including bacteria, referred to as biochemical oxygen demand (BOD). The accumulation of plankton biomass and detrital carbon in the hypolimnion water column results from settling of organic material originally located in the euphotic zone or epilimnion. In addition to the BOD, COD may periodically contribute to the O_2 depletion in the water column, particularly following severe storm activity. Turbulent conditions in the hypolimnion result in the resuspension of the upper, floculant sediment layer, resuspending both organic and inorganic material. The COD becomes even more significant after anoxic conditions have been established when reduced chemical species (i.e., Fe, S, and Mn) are released into the overlying waters acting as an additional sink for oxygen.

The sediment oxygen demand (SOD) portion of the HOD is also a combination of BOD and COD. The seasonal accumulation of organic material not totally decomposed in the water column eventually exerts an oxygen demand at the sediment water interface. In addition, the benthic community primarily made up of Oligochaete and Chironomid populations, consumes O_2 through respiration. COD exerted at the interface between the oxygenated sediment surface and anoxic lower sediments certainly is more significant than the COD in the water column.

It should be noted that a third factor has been proposed as an additional contribution to the HOD. DiToro and Connolly (1980), in an attempt to model the O_2 depletion process, have proposed that the deep sediments also exert a significant O_2 demand; however, there is as yet no experimental SOD data that has verified this theory.

The percent of the total demand exerted by the individual processes just discussed has been studied intensively, but, as yet, remains unsolved. Certainly all the components mentioned make up the major portion of the HOD; however, factors such as temperature, light penetration and hypolimnion thickness influence the O_2 depletion rate of each individual process.

The DiToro model proposed that 60% of the HOD is due to WOD while the remaining 40% was attributed to SOD (Table 45). Using a somewhat different approach, Burns and Ross (1972) concluded that 88% of the depleted O_2 resulted from bacterial decomposition of sedimented algae (BOD) and 12% resulted from oxidation of reduced metallic species (COD). These two estimates are not comparable since they do not encompass the same factors or combination of factors accounting for O_2 depletion. As yet, a strict quantification of the processes leading to depletion has not been adequately devised.

TABLE 45

PERCENTAGE CONTRIBUTION OF OXYGEN SINKS TO DISSOLVED OXYGEN DEFICIT AT THE TIME OF MINIMUM D.O. IN THE CENTRAL BASIN HYPOLIMNION
(From DiToro and Connolly 1980)

Oxygen Sink	Percent Contribution 1970	1975
Deep Sediment Oxygen Demand	28.7	22.8
Surface Sediment Oxygen Demand	11.5	8.2
Organic Carbon Oxidation	42.5	46.9
Phytoplankton Respiration	17.3	22.1

In-situ attempts to measure WOD and SOD have had only limited success. Measurements of SOD were first made on Lake Erie during Project Hypo (Lucas and Thomas 1972, Blanton and Winklhofer 1972). Also, in 1978 and 1979, three studies were undertaken to measure SOD rates in the central basin (Davis et al. 1981, Snodgrass and Fay 1980, Lasenby 1979). The techniques employed by all of the above investigators utilized an in-situ chamber positioned on the sediments, except Lasenby (1979) who measured rates using cores manipulated under laboratory conditions. Table 46 summarizes the calculated rates.

WOD measurements have not been made as frequently as SOD measurements, and some of the studies have not as yet been published due to problems in interpreting the data. The methodologies employed to measure uptake rates are prone to various analytical problems, making interpretation of the data difficult. Davis et al. (1981) reported WOD values measured at two locations in the central basin during 1979 (Table 47). Note that the percent contribution of WOD to the HOD increases through the summer stratified period, due to the increase in phytoplankton biomass and POC found in the water column during late August. The shift from 80% SOD in June to 76% WOD by August is indicative of the quantity of organic material accumulated in the hypolimnion water column. This shift is not reflected in DiToro's model.

In attempting to quantify the depletion rate in the central basin, a discrepancy between the rates calculated from the combined in-situ measurements of SOD and WOD and the more conventional method of calculating the rates via changes in D.O. concentration measured on consecutive surveys (cruise interval technique) is evident. The in-situ rate (SOD + WOD = HOD) is a direct measurement of the two oxygen consuming processes and does not account for any physical processes which might influence the introduction or elimination of oxygen in the hypolimnion through the stratified period. The mean HOD rate for the central basin measured by <u>in-situ</u> techniques was 0.36 g 0_2 $m^{-3}d^{-1}$ or 10.8 mg O_2 $l^{-1}mo^{-1}$ assuming an average hypolimnion thickness of 4.35 meters (Davis et al. 1981). This indicates that if the central basin hypolimnion were a closed system, the oxygen would be depleted within a few weeks. If these measurements are representative of the actual rates, the oxygen supplied to the hypolimnion via outside sources is sufficient to prevent the more immediate and severe O_2 depletion resulting from the combined WOD and SOD. The cruise interval technique measures the oxygen concentrations in the hypolimnion over several cruise intervals throughout the stratified period. The depletion rate is calculated as the difference between the O_2 concentrations between successive cruises, thus providing information as to the net quantity of O_2 depleted for a specific period of time. As a net measure of the oxygen lost this procedure alone does not allow for quantification of physical processes affecting oxygen concentrations over the interval. Thus, both procedures lack the sophistication necessary to determine the true oxygen consumption rate.

Dissolved oxygen has been one of the key issues in evaluating the eutrophication problem in Lake Erie; consequently, methods had to be developed to measure rates and examine historical data in hopes of determining if the lake has changed over the period of record. The first attempt to examine historical data was in conjunction with the 1970 Hypo Project. Dobson and Gilbertson (1972) used a simple cruise to cruise difference in O_2 concentrations averaged over the stratified season in order to determine a rate for each historical data set. They estimated an increase in depletion rates from 0.05 g 0_2 m^{-3} day^{-1} in 1929 to 0.11 g 0_2 m^{-3} day^{-1} in 1970. Data from sixteen studies spanning this time frame were plotted and a trend line was drawn over the time period (Figure 112). The data indicated an annual increasing 0_2 demand rate from 1950 to 1970 of 0.075 g m^{-3} mo^{-1} yr^{-1} or a 3% per year increase.

Following the completion of the Hypo Project, it became evident that accurate determinations of depletion rates required a significantly more sophisticated treatment of the data if future trends were to be documented. It was evident that oxygen transfer across the mesolimnion by exchange must be taken into account if oxygen depletion calculations of an accuracy of $\pm$ 3% were achieved (Burns 1976). The data from Project Hypo and the surveillance program accumulated during the CCIW 1970 monitoring effort provided adequate information to develop a model to account for internal physical processes affecting hypolimnion O_2 concentrations. It was found that during the stratified period the central basin hypolimnion is subject to several processes which alter its volume and/or O_2 concentrations. The oxygen added to the central basin hypolimnion by the exchange process during 1970 was in the order of 12% of the oxygen depleted, while the oxygen added by this process to the eastern basin hypolimnion constituted approximately 5% of the oxygen depleted from that water mass. These processes act independently of the biological and chemical oxygen demands.

In order to estimate or quantify the interaction between the layers, a model was developed which included the following processes:

1. The incorporation of a layer of the mesolimnion downwards into the hypolimnion leading to a hypolimnion volume increase;

2. The incorporation of a layer of the hypolimnion upwards into the mesolimnion leading to a hypolimnion volume decrease; and,

3. Downwelling of a part of the mesolimnion and epilimnion into the hypolimnion with the simultaneous upwelling of a part of the hypolimnion elsewhere into the mesolimnion or epilimnion. This process would lead to an exchange of water between hypolimnion and epilimnion with no volume change in the hypolimnion.

Since 1970, the Sequential Mesolimnion Erosion Model (Burns and Ross 1972) later modified to a Mesolimnion Exchange Model (Burns 1976a) has been employed to calculate depletion rates for both Canadian and U.S. surveillance programs.

Once again, the historical data was examined in light of the importance of thermal structure and temperature (Charlton 1979). A calculated temperature-hypolimnion thickness relationship was developed applying a regression analysis to current data sets. The relationship was then applied to temperature values in order to estimate hypolimnion thickness in historical data sets lacking this information. A log-log regression was then developed using the hypolimnion thicknesses (measured and estimated) and plotted against oxygen depletion rates in order to correct the original rates calculated by the simple cruise interval method (Figure 113). This resulted in a new standardization of the rates to a uniform hypolimnion thickness. After re-analyzing the 1929 to 1976 data, Charlton concluded that "the hypothesis of a large long-term trend to increasing oxygen depletion does not seem to be supported by the present analysis of available data" (Charlton 1979).

During 1977 and 1978, intensive studies were undertaken by Rosa and Burns (1981), Ivy and Boyce (1982), and Boyce et al. (1980) on the central and eastern basins. The studies were designed to further investigate the variability within the individual basins due to sampling locations, hypolimnion depth, temperature, mesolimnion/hypolimnion exchange and transport of water between the eastern and central basins. It was necessary to resolve these questions before adequate corrections or modifications could be made to historical data sets. The study was designed to provide a complete compliment of data to be used in conjunction with the Mesolimnion Exchange Model and aid in determining a homogeneous area within each basin. These areas were then used in conjunction with historical data sets, first to calculate a rate using only stations within these areas, followed by corrections to reduce variability resulting from year-to-year differences in temperature and hypolimnion thickness.

Two important physical processes were studied, resulting in a better understanding of how these processes can affect the depletion rate. First, Ivey and Boyce (1982) examined the vertical mixing of the mesolimnion into the hypolimnion in the central basin. It was determined that downward entrainment accounted for approximately 10-20% of the O_2 consumed in August 1979. This varies from year to year depending on meteorological conditions; however, it must be accounted for in order to obtain an accurate measure of the actual consumption rate.

Second, Boyce et al. (1980) studied the movement of eastern basin mesolimnion water into the central basin hypolimnion across the Pennsylvania ridge. During 1977, two major transfers of water from the eastern basin mesolimnion into the central basin hypolimnion occurred. The second of the two occurrences was considered most important to the oxygen regime of the central basin. During early August, 7 km^3 of water passed from the eastern basin mesolimnion into the central basin hypolimnion. This additional volume was equivalent to 17% of the total hypolimnion volume at that time, but more significantly the new water mass transported oxygenated water into the oxygen depleted central basin hypolimnion. This event raised the mean central basin O_2 concentration between 0.5 and 1.0 mg/l, or an equivalent of 5-10 days' worth of observed oxygen demand. However, it was calculated that this newly transferred water mass influenced only the eastern third of the basin leaving the western two-thirds relatively unaffected.

With this additional insight into lake processes, the Mesolimnion Exchange model could then be applied to the 1977 and 1978 data sets to account for exchange processes affecting the rate (Rosa and Burns 1981). After applying the Exchange Model to the stations within the homogeneous area, two additional corrections were applied. First, it was necessary to adjust for the year to year variation in hypolimnion temperatures. Since changes in temperature primarily affect biological reaction rates, a Q_{10} coefficient was used to compensate for the year to year temperature variation. Second, hypolimnion thickness was adjusted to the mean of 4.7 m when profile information was available (1961 to present). The results of each step-by-step adjustment to the data sets are presented in Table 48 and illustrated in Figure 113 (Rosa and Burns 1981). The resultant historical depletion rate was determined to be 0.035 mg $l^{-1}mo^{-1}yr^{-1}$ from 1929 to 1980.

In a recent report, El-Shaarawi (1983) presented a statistical model developed for dissolved oxygen concentrations in the central basin of Lake Erie. Two major conclusions were reported. First, the central basin oxygen depletion rate has increased from 1967 to 1979 and second, the increase in depletion rate was due to an increase in phosphorus levels.

We have seen definite indications of eutrophication effects on the lake such as the eradication of the mayfly and a substantial decrease in many cold water dependent fish populations. Lake Erie central and western basins are exceptionally shallow compared with water depths of the other Great Lakes; thus, natural eutrophication plays an important role in the changes measured in the lake. However, cultural stress primarily as phosphorus loading should not be underestimated as a major factor in accelerating the natural eutrophication process.

Objectives and Standards

Environmental measurements have been made each year since 1973 to assess compliance with the general and specific objectives of the 1972 and, subsequently, 1978 Water Quality Agreements. These measurements have been used to evaluate the effectiveness of remedial programs and to anticipate the changing trends in water quality. Responsible agencies within state, provincial, federal-Canada and federal-United States governments contribute information and recommendations at three levels: site-specific, lakewide and systemwide (Great Lakes Water Quality Board 1981).

The Water Quality Board (e.g. 1979, 1980) reported on "problem areas" until 1981. A problem area was any locality where agreement objectives and/or standards of the local jurisdiction were exceeded or desired water quality objectives could not be attained. Starting with its 1981 Report, the Water Quality Board initiated a process to establish "areas of concern" based on environmental measurements of sediment, biota and water. Although the process is recognized as containing a subjective element, the importance of this procedure lies in its application of uniform criteria across jurisdictional boundaries.

This section applies the "area of concern" criteria to water quality data collected during the 1978-1979 intensive study period of the Great Lakes International Surveillance Program (GLISP) on Lake Erie. The criteria were applied in a uniform manner to all water quality data collected during the study period and recorded in STORET.

Data for water quality analysis was retrieved using the STORET standards program. The original databases were collected from tributary studies or connecting channels, i.e., Detroit River, intensive nearshore and open lake surveillance programs, municipal water intake plants and other miscellaneous sources. The individual data sets were analyzed to determine violations or identify problem areas as defined by the International Joint Commission (IJC) Water Quality Objectives and by the respective state or provincial water quality standards.

The Water Quality Board has noted (1981) that whenever an Agreement or jurisdictional value is exceeded, there is a potential or real threat to public health, impairment of water use or deleterious impact on the human health or aquatic life. To aid the environmental management plans within each jurisdiction, Agreement objectives and jurisdictional standards are compared and reported in individual discussions.

Recurring violations were recorded for conductivity, pH and iron. These parameters made up a major portion of the violations at many stations, particularly in and around the tributaries and the nearshore region of all three basins. In general, neither conductivity or pH violations were considered to be a result of effluents entering the lake from either municipal or industrial sources. The principal ion concentrations for Lake Erie, particularly chloride and bicarbonate are naturally greater than those found in the other Great Lakes resulting in higher conductivity values. One exception was the Grand River, Ohio where chloride loading from industrial sources is very high (70 mg/l) resulting in conductivity values of 500 umhos/cm. Similarly, mean pH values for the lake are in the order of 8.0 and on occasion may exceed 9.0 primarily in biologically productive regions. Neither pH or conductivity values recorded in the lake posed any health problem to the populace utilizing the lake or to the biota.

The other major violator was iron and as with pH and conductivity is naturally high in concentration. Highest concentrations were generally found in and around tributaries during the peak spring loading period. Some contribution is made by the heavy industry around the lake which can be an important localized source. Iron poses no health dangers to the lake community and any problems are aesthetic in nature, resulting from the precipitation of iron hydroxide. None of these three parameters will be further discussed in this section, and the reader can assume frequent violations for all three parameters throughout the lake.

State of Michigan. A total of 21 parameters were retrieved for analysis of water quality in the water governed by the state of Michigan (Table 49). Of the 21 parameters retrieved, only fluoride, arsenic, selenium, and un-ionized ammonia values did not exceed IJC or state limits during the two-year study period.

Phenolic compounds were recorded in concentrations exceeding the objective at one tributary monitoring station, two water intakes and at 35 of 36 stations located along the Detroit River. Heavy industry, largely steel production, effluents entering the Detroit River and its tributaries are the principal sources of contamination. Too few samples were collected at nearshore or open lake stations for evaluation of phenolic compounds. Phenols represent a substantial violation in the connecting channel and contributed to the designation of the region as a problem area (GLWQB 1980).

Fecal coliform bacteria counts from samples collected in the connecting channel and the nearshore zone frequently exceeded the 200 organisms/100 ml standard for total body contact with the water (swimming). The sources of fecal contamination, principally the Detroit Sewage Treatment Plant, contributed to the designation of the Detroit River as a problem area (GLWQB 1980). Fecal coliform data taken over the two-year period indicated the Detroit River and nearshore waters south of Detroit (Herdendorf and Fay 1981) represent a significant problem area.

In addition, a number of the trace metal parameters retrieved revealed concentrations exceeding standards. Cadmium, copper and mercury values exceeded standards at several tributary, water intake, connecting channel, nearshore and open lake stations.

State of Ohio. Lake Erie water quality data were compared with water quality objectives set forth by the IJC and the standards established by the Ohio EPA respectively. Maximum and minimum criteria values for IJC objectives and Ohio standards are listed in Table 50. Since Ohio waters comprise a dominant portion of the southern half of Lake Erie and receive a majority of the lake's agricultural and industrial inputs, a summary of the number and extent of observations exceeding criteria in Ohio waters as a unit would not usefully delineate water quality problem areas. For the purposes of this report, exceptions to the criteria limits were examined and summarized by county jurisdiction (Figure 114). Sampling stations within each county were divided into three categories: tributary monitors, nearshore surveillance stations and water intake monitoring stations, while open lake data was not sectioned into the county boundaries.

Ottawa and Lucas Counties. Violations for this region, located in the westernmost section of Ohio waters, include water quality monitoring stations located in the Maumee River near Waterville; water supply intakes for Marblehead, Port Clinton, the Bass Island area, Catawba, and Toledo; and the nearshore surveillance stations centered around Toledo and Port Clinton. Data from only one tributary, the Maumee River, was retrieved for this section of Ohio waters although other tributary data was available. Violations occurring in the Maumee River include those reported for cadmium, manganese, copper, lead, mercury, zinc and phosphorus. Of these parameters, cadmium and copper values exceeded the established criteria most frequently. Cadmium values ranged from 1.0-13.0 ug/l; however, data for this metal is suspect, due to the consistent reporting of the detection limit value, i.e. 5 ug/l. Since the detection limit exceeds the violation limit, false conclusions concerning cadmium violations were inevitable. Data for manganese, copper, iron, zinc, lead and mercury indicate that these metals may constitute a problem in the Maumee River.

Fourteen nearshore stations were sampled in the vicinity of Toledo and Maumee Bay in Lucas County. Violations occurred consistently for phosphorus, cadmium, chromium, copper, nickel, zinc, manganese and fecal coliform bacteria. Phosphorus values were in violation at nearly every station sampled in the Toledo area, but represent only 4% of the total number of samples taken. The highest values arise during sampling intervals coinciding with high runoff periods from the Maumee drainage basin. Of these parameters, cadmium values violated standards most frequently. Heavy metal contamination appears to be rather severe in the Toledo area. Nearly 100% of cadmium records, 75% of the copper observations and 50% of zinc, nickel and manganese samples violate standards. The severity of these violations indicates that the Toledo area may be identified as an area of concern.

Nearshore surveillance stations located in Ottawa County waters include 14 stations sampled in the vicinity of Port Clinton. Violations were most often found for cadmium, copper, nickel and zinc. Occasional violations were reported for dissolved oxygen, chromium, selenium, manganese, mercury and fecal coliform bacteria. Due to the number of parameters found in violation and the severity of violations reported, the Port Cinton area may be regarded as an area of concern.

Water intake data for this section of Ohio waters was rather limited. Intake data from Marblehead, Port Clinton, Put-in-Bay, Catawba, Oregon and Toledo all showed violations of cadmium and copper values. Fecal coliform bacteria violations appeared at the Port Clinton and Oregon intakes only, while zinc violations were found at the Put-in-Bay, Catawba and Oregon intakes, and lead violations occurred only at the Catawba intake. Violations of phosphorus, nickel, selenium and phenols occurred at the Oregon intake only. It appears that while not a great percentage of violations was detected at any one intake, the data from the Oregon water intake contained violations of more parameters and at higher percentages.

Erie and Sandusky Counties. Included in this region of Ohio waters are three tributaries, nearshore stations in Sandusky Bay and along the southern shore, and municipal water intakes for the cities of Vermilion, Huron, Sandusky and Milan.

Of the three tributaries sampled (Sandusky, Huron and Vermilion Rivers), violations occurred most frequently and involved more parameters at sampling stations in the Sandusky River. Copper concentrations violated IJC objectives (Ohio does not have a copper standard) more often than any other parameter measured in the Sandusky River. The mean concentration of copper in the Sandusky River was 32.82 ug/l, well below levels reported to cause adverse effects to humans. The frequency, extent and magnitude of copper violations has contributed to the designation of the Sandusky River as a problem area (GLWQB 1980).

Measurements of other parameters which frequently resulted in violations included cadmium, phosphorus and lead. Cadmium data must be viewed with skepticism in that it was reported by OEPA at a constant concentration of 5.0 ug/l (detection limit).

Phosphorus measurments in excess of criteria do not appear often at the Sandusky River sampling stations, with a total of nine violations from 26 samples, or 35 percent.

Dissolved oxygen, total phosphorus, copper and cadmium were the only parameters which were found to exceed IJC objectives or Ohio standards in the Huron River. Phosphorus values exceeded objectives in 103 out of 579 total samples (17.8 percent) in the Huron River, but the sample mean (336 ug/l) was below the state standard of 1.0 mg/l, but close to the IJC objective of 500 ug/l. It is interesting to note that the percentage of phosphorus violations in the Huron River was similar to that found in the Sandusky River even though the principal sources were different (municipal and agricultural respectively).

Copper and cadmium violations occurred infrequently, but the concentrations reported were consistently indicative of detection limits and were above the upper limit of the established criteria. Violations of this nature could not be adequately assessed. Violations of dissolved oxygen involved 6 of 12 samples ranging from 2.0 to 5.3 mg/l with the sample mean ($\bar{x}$ = 5.07 mg/l) below the standard of 6.00 mg/l. Thus, dissolved oxygen may be a problem in the Huron River and contributed to its designation as a problem area (GLWQB 1980).

Violations in the Vermilion River were limited to copper, cadmium and zinc. Copper and cadmium values were suspect due to reasons previously noted for the Huron River. Only two samples were analyzed for zinc, both of which exceeded standards. One of the samples was in violation of standards by more than an order of magnitude. Sample size for zinc violations was too limited to adequately assess the extent or source of contamination.

Nearshore surveillance stations situated in Erie and Sandusky counties included six stations located within Sandusky Bay and fifteen stations located along a southern shore region extending from the Sandusky water intake to Old Woman's Creek. Cadmium, copper, nickel and zinc measurements exceeded standards for at least 50% of all samples taken at each station within Sandusky Bay. Although an infrequent number of violations occur for fecal coliform bacteria, at least one sample exceeded standards at every station in Sandusky Bay. Given the frequency of heavy metal violations coupled with high conductivity and fecal coliform bacteria values, the Sandusky Bay area is one of concern.

The fifteen stations located along the southern shore from the Sandusky water intake to Old Woman's Creek contained a substantial number of heavy metal violations. Every cadmium value recorded was in excess of standards. Copper, nickel and zinc averaged approximately a 50% violation rate with at least one sample from each station having at least one heavy metal in excess of standards. The dissolved oxygen standard was exceeded on occasion reflecting water quality problems in this area of the nearshore zone.

Water supply intakes for Kelleys Island, Milan, Vermilion, Huron and Sandusky were sampled too infrequently to adequately describe any water quality problems. Cadmium criteria were violated whenever samples were measured; however, these measurements were suspect due to a constant record of 5 ug/l. Zinc is the only other parameter which frequently exceeded standards at all sites, with a mean concentration at all intakes in Erie County of 67.0 ug/l, well above the maximum criterion limit of 30.0 ug/l and may be reason for concern.

Lorain County. Data from the two tributaries monitored in Lorain County were retrieved for analysis, the Black River and the Vermilion River. The Black River was intensively sampled by the USGS and OEPA. Both agencies reported numerous violations for many parameters including (in order of frequency and magnitude): cadmium, copper, phosphorus, phenols, fecal coliform bacteria, dissolved oxygen, nickel, manganese, nitrate-nitrogen and cyanide. Due to the large number of parameters for which violations were reported and the large percentages of violations which occurred for most parameters, the Black River has been designated a problem area in Lake Erie (GLWQB 1980).

The Vermilion River did not contain the magnitude or severity of violations which were reported for the Black River. Phenols and fecal coliform bacteria were the only parameters which violated standards or objectives in sufficient numbers to warrant concern. Records in excess of criteria for copper, cadmium and nickel were suspect due to the consistency of the values reported. Other parameters such as phosphorus, nitrate-nitrogen, chromium, lead and zinc infrequently exceeded standards.

Nearshore surveillance stations sampled for this region included 19 stations near Lorain, Ohio. Trace metal concentrations in excess of criteria were severe, especially cadmium, copper and zinc, with frequent violations for nickel and manganese. Total mercury concentrations in excess of criteria were infrequent. In addition to trace metal violations, dissolved oxygen standards were frequently violated. A substantial number of objectives were frequently exceeded in the nearshore area surrounding Lorain; thus, considering the magnitude and number of violations in the vicinity of Lorain, this region is considered an area of concern.

Water intake data for this section of Ohio waters was scarce. Copper and cadmium violations were inconclusive due to the consistent reporting of detection limits. Only two other parameters were found to violate standards: lead at Avon (one sample was collected), and fecal coliforms at Lorain.

Cuyahoga County. Data from the four tributaries monitored in Cuyahoga County (the Cuyahoga River, Euclid Creek, the Rocky River and Big Creek near Cleveland) were retrieved from STORET for comparison with IJC and Ohio water quality standards. Of these four tributaries, records from the Cuyahoga River included the greatest number of parameters violating the IJC Objectives and OEPA Standards. Copper, nickel, zinc and phenols exceeded standards wherever sampled; however, the data for copper and nickel are suspect since the majority of the concentrations were reproted as 30 ug/l and 100 ug/l, respectively. It was assumed that these values represent the detection limits and were retrieved as violations. Zinc and phenol concentrations appear reasonable and represent a real problem in the Cuyahoga River. Other parameters which frequently violated standards include cadmium, lead, fecal coliform bacteria, total phosphorus and dissolved oxygen, and occasionally selenium, chromium, ammonia, nitrogen and manganese. The magnitude and frequency of violations of the many different criteria indicate the Cuyahoga River is an area of concern.

Euclid Creek ranks second to Cuyahoga River in total number of violations and number of parameters violated in Cuyahoga County. Parameters most frequently violating standards include cadmium, lead, nickel, copper, phenol and fecal coliform bacteria. Detection limit problems previously noted for copper and nickel were evident, and in addition, cadmium values were suspect due to a constant reported concentration of 5.0 ug/l. Phosphorus and zinc violated standards/objectives infrequently; however, fecal coliform bacteria and phenols exceeded criteria routinely. Thus, Euclid Creek represents a potential area of concern.

The concentrations of trace metals in the Rocky River exceeded standards or objectives more frequently than the other tributaries in Cuyahoga County with 100% of the manganese concentrations exceeding the criteria, followed by copper (76%), lead (29%), phosphorus (24%), zinc (22%) and cadmium (12%). This tributary was monitored by the U.S. Geological Survey; USGS records did not contain consistent concentrations for copper and cadmium as did stations monitored by OEPA. These violations resulted in the designation of the Rocky River as a problem area (GLWQB 1980).

Although concentrations of ten parameters were found to exceed criteria at Big Creek near Cleveland, an insufficient number of samples (N_{max}=7) were collected during the period of record to adequately identify this tributary as an area of concern.

Nearshore surveillance stations sampled in this region of Ohio included 33 sites extending from east of the Rocky River to west of Euclid, Ohio. The majority of sampling stations were located in the vicinity of Cleveland. Cadmium and copper records most frequently exceeded criteria (50-100%) with violations occuring at every station. Other trace metals which frequently exceeded criteria include lead (21%), nickel (31%) and zinc (40%) with manganese and mercury concentrations only occasionally exceeding criteria. Dissolved oxygen records occasionally exceeded the limits in the nearshore zone, with approximately 10.5% of the total number of records falling below the standard. Although the percentage of violations at each station was low, violations occur at every nearshore station and were at times severe. Frequent dissolved oxygen violations coupled with numerous trace metals violations served to identify this reach as a problem area (GLWQB 1980).

Water intakes in Cuyahoga County include those for Cleveland-Baldwin, Cleveland-Crown, Cleveland-Divison, Cleveland-Nottingham, East Cleveland and Lakewood. Only copper and cadmium values were available from these locations and were reported at detection limits; thus assessment of these areas was not feasible. Sample size at water intake monitoring stations in Cuyahoga County was too small to discern if the area of concern designation was warranted.

Lake and Ashtabula Counties. Station data retrieved from STORET for comparison with water quality criteria from this portion of Ohio's Lake Erie waters included four tributaries: the Ashtabula River, Conneaut Creek, the Grand River and the Chagrin River. Nine surveillance stations near Conneaut, 19 stations near Fairport and 18 stations near

Ashtabula were used for the nearshore analysis. Water intake monitoring data was retrieved for intakes serving the cities of Madison, Mentor, Painesville, Geneva, Ashtabula and Conneaut.

Of the tributary monitoring data retrieved, criteria were exceeded most frequently at stations located in the Grand River at or near Painesville. Violations occurred consistently at different locations in the lower portion of the Grand River for cadmium and copper, with standards exceeded 100% of the time. Cadmium and copper violations were suspect, since constant concentrations of 5.0 ug/l for cadmium and 30.0 ug/l for copper were reported. Other parameters which frequently exceeded criteria in the Grand River included dissolved oxygen, lead, nickel, zinc, manganese, phenols and fecal coliform bacteria. Phosphorus values exceeding criteria occurred rather infrequently, although they were occasionally present (5 violations from 42 samples, or approximately 12%). Mercury values exceeded the standard in 1 out of 8 samples (12.5%). Due to the large number of violations per sample coupled with the wide variety of parameters that exceeded criteria, the Grand River is considered an area of concern.

Parameters with concentrations in excess of standards or objectives in the Chagrin River included copper, cadmium, nickel, phenols and fecal coliform bacteria. Again, copper and cadmium values were highly suspect. Nickel appears to be suspect at this location for similar reasons; violations (>25 ug/l) occur 100% of the time with all reported concentrations constant at 100 ug/l. Values reported for phenols exceed criteria in every record from the Chagrin River. Point sources of phenols should be monitored in order to locate point sources and subsequently reduce these inputs. Fecal coliform bacteria densities were excessive in the Chagrin River, with 71% of the total samples exceeding Ohio standards. Municipal waste should be monitored to reveal sources of heavy contamination. Phosphorus, lead, manganese and zinc values also exceeded criteria on occasion. The total number of violations was insufficient to warrant designating the river as an area of concern.

Measurements recorded from stations in the Ashtabula River include violations of limits for the following parameters (in order of frequency): copper, phenols, cadmium, lead, phosphorus and dissolved oxygen. Copper and cadmium could not adequately be assessed for reasons previously discussed. Phenols exceeded the standards 100% of the time with a sample mean (5.3 ug/l) well above the 1.0 ug/l limit. Lead values exceeded criteria relatively frequently (approximately 20%) while the remaining parameters (i.e., phosphorus and dissolved oxygen) seldom exceeded the criteria. The number and frequency of violations resulted in the designation of the Ashtabula River as a problem area (GLWQB 1980).

Samples were collected at 19 nearshore surveillance stations near Fairport, Ohio. Measurements exceeding trace metal criteria occurred most frequently with cadmium, copper, lead, nickel and zinc observations violating standards at every station. In addition, measurements of mercury and manganese concentrations occasionally exceeded criteria.

The results of the data retrieved from the 18 nearshore stations located near Ashtabula, Ohio were similar to the results of the analysis from the nearshore Fairport region. Trace metal violations appeared most frequently, with cadmium, copper, nickel and zinc. Less frequent violations occurred for manganese, mercury and lead, while dissolved oxygen measurements exceeded lower criteria limits only on occasion.

Data from 9 nearshore stations in the vicinity of Conneaut were examined, indicating cadmium, copper and nickel concentrations were the only trace metal parameters that exceeded criteria at all 9 stations. Copper and nickel measurements in excess of criteria occurred 12.5-25.0% of the time, and may be indicative of contamination near Conneaut. Other parameters which exceeded criteria rather infrequently include dissolved oxygen, fluoride, fecal coliform bacteria, selenium, cyanide and phenols. Although the number of violations per sample total was not significant, the parameters did exceed criteria at most of the 9 stations sampled. Given the frequency and severity of trace metals violations near Fairport, Ashtabula and Conneaut, these three locations may be areas of concern for nearshore waters.

Water intakes for the cities of Mentor, Painesville, Madison, Ashtabula and Conneaut were also examined for records in excess of IJC or State of Ohio criteria. Parameters measured at the Mentor and Ashtabula intakes exceeded standards and objectives more often than other locations. Cadmium, copper and nickel could not be adequately assessed due to data reporting problems. At Conneaut, 100% of phenol samples were in violation, while phosphate violations were only 9%. Mentor water supply records in excess of criteria included those for phosphate (99%), fecal coliform bacteria (8%) and dissolved oxygen (2%). The remaining intakes examined were found to violate only copper and cadmium criteria.

Open Lake, State of Ohio Inclusive. Data from 50 open lake stations were retrieved from STORET. Measurements in excess of criteria were noted for at least 1 parameter at each of the 50 stations. Twenty two of the open lake stations were sampled by Canada Centre for Inland Waters (CCIW). Dissolved oxygen violations were noted consistently at the 22 CCIW stations located in Ohio waters. Dissolved oxygen measurements below the minimum criteria occurred more frequently than any other parameter measured at the other 28 sampling locations. Oxygen concentrations below 6.0 mg/l in Ohio waters reflected oxygen depletion in the central basin hypolimnion during the summer months.

Dissolved mercury violations were found at 9 of 28 stations, ranging from 0.3 to 1.0 ug/l. Although relatively few stations were involved, violations appear often enough in open lake waters to consider this potentially toxic substance as a possible cause for concern. Of the remaining parameters sampled, only measurements of trace metals including cadmium, mercury, nickel, copper, zinc, chromium and lead exceeded water quality criteria. Cadmium values require further interpretation due to the consistent reporting of a 1.0 ug/l value. This value may represent the detection limit used in analysis; thus the violations reported are not necessarily reflective of actual concentrations. The number of violations per sample total at each station was rather low. Thus, these metals do not necessarily represent significant or substantial water quality impacts in the Ohio open lake portion of Lake Erie.

Commonwealth of Pennsylvania. A total of 42 parameters (Table 51) were compared with IJC objective values and Pennsylvania Department of Environment Resources (PDER) standards. Comparisons were made using observations recorded from 70 stations composed of water intake, tributary, nearshore and open lake stations. Observations exceeding objective and/or standard limits were noted for 22 of the 42 parameters retrieved with a maximum number of eight parameters exceeding limits at any one station.

Dissolved oxygen values below the objective/standard were recorded at nearly half of the stations sampled over the two-year interval. Low dissolved oxygen records in Presque Isle Bay (Erie Harbor) contributed to the designation of this area as a problem area (GLWQB 1980). During the winter months of 1977-1978, low dissolved oxygen levels in the bay resulted in a massive winter kill of gizzard shad (Dorosoma cepedianum) (Wellington 1980). In addition, low dissolved oxygen levels in hypolimnetic waters of the open lake resulted in violations of the IJC objective at open lake and nearshore stations.

The intrusion of hypolimnetic waters into the nearshore zone was indicated by the occurrence of dissolved oxygen violations recorded for only a portion of a profile at any given station.

Records of fecal coliform bacteria in excess of the PDER limit of 200 organisms/100 mls were noted at 14 tributary and nearshore stations. Fecal coliform violations contributed to Presque Isle Bay being designated a problem area (GLWQB 1980) An intensive beach sampling program recorded exceptionally high bacterial counts at Presque Isle State Park and in Erie Harbor during the late summer months (Wellington 1980). The completion of additional sewage treatment facilities should alleviate this problem. The remaining violations were principally trace metal concentrations with no apparent pattern of occurrences. As a result, trace metal violations were considered technical in nature and require no remedial action.

State of New York. A total of 22 parameters were retrieved and compared with IJC water quality objectives and New York State water quality standards (Table 52). Observations exceeding one or more objective/standard were noted at 42 sampling stations in the New York State waters of Lake Erie. Values in excess of limits were recorded at tributaries, connecting channels (Niagara River), nearshore and open lake stations. Over the two year interval, no more than 8 parameters were noted with one or more violations at any one station.

Low dissolved oxygen values (< 6.0 mg/l) recorded at nearshore and open lake stations were the most frequently noted violations. Low values were recorded at 10 of 16 open lake stations and 18 of 19 nearshore stations in the Barcelona-Dunkirk-Silver Creek reach of the New York shoreline. Low dissolved oxygen values in the nearshore primarily resulted from intrusion of hypolimnetic/mesolimnetic waters into the nearshore zone during the stratified season. This was evident from profile data recorded at nearshore stations.

The remaining parameters exceeding objectives/standards in New York waters of the lake were confined to the trace metals. Cadmium, copper, nickel and zinc values were the most common of the trace metal violations. IJC objective limits were considerably lower than New York State standards (Table 52); as a result, the violations noted were primarily violations of IJC objectives rather than state standards. Although not frequent, violations of the IJC objective for total nickel and total zinc were consistent throughout the New York waters. The relatively high values recorded for the nickel and zinc parameters may reflect the nature of the bedrock substrate in the tributaries of this portion of the lake. The trace metal violations are probably technical in nature, although the matter requires clarification.

Province of Ontario. For the purpose of evaluating Canadian water quality, 26 parameters were screened from a total of 181 stations. Ninety-eight were nearshore surveillance stations and 83 were open lake stations. Nearshore collections were made by the Ontario Ministry of the Environment (OMOE); open lake collections were made by CCIW (48 stations) and USEPA-GLNPO (35 stations). Parameters used for the evaluation were the water quality objectives set forth by the Ontario Ministry of the Environment (Table 53). Of the 26 parameters entered, 11 exceeded objectives at one or more stations. The total phosphorus criterion was most commonly exceeded, followed by 5 phenol violations and 7 trace metals (zinc, cadmium, silver, barium, beryllium, lead, chromium and nickel) with zinc being the most common. It should be noted that not all stations were sampled equally. Nearshore stations recorded in STORET (OMOE, 98 stations) contained data for total phosphorus and phenols, while one set of open lake stations (USEPA-GLNPO, 35 stations) contained data for total phosphorus, and 8 trace metals while the CCIW data set contained only total phosphorus data.

Total phosphorus exceeded the objective at a total of 155 stations; 86 nearshore and 69 open lake stations, with 23% of observations in violation. The range of individual violations was 21-215 ug/l, with most violations occurring within ±10 ug/l of the objective. The mean of all total phosphorus sample-means was 16.3 ug/l (S.D. = ± 6 ug/l), which is close to the objective of 20 ug/l. The seasonality of the phosphorus violations is indicative of fluctuating seasonal inputs, and the ubiquity of violations is indicative of cultural eutrophication in Lake Erie.

Five phenol records in excess of criteria occurred in the nearshore area ranging from 1.4 to 3.0 ug/l. Of all samples tested for phenol (63 observations at 5 stations), four stations showed single violations and one station showed 2 (9.5% of total observations in excess). The mean of sample means was 1.03 ug/l, which marginally exceeded the objective phenol concentration limit.

Trace metal data was collected by the USEPA, Region V (USEPA-GLNPO) during an open lake cruise in July 1979. Zinc was the most common trace metal exceeding limits with 40.6% of observations in violation (30 stations) having a violation range of 9-52 ug/l. Cadmium and silver were the next most common trace metal violations. Cadmium violations occurred at 22 stations with values ranging from 1-50.4 ug/l and silver violations occurred at 19 stations ranging from 1-36.0 ug/l (both with 28% of observations in excess).

Beryllium concentrations exceeded the criterion in one sample at each of 7 stations. Six stations had concentrations in excess of 50.2 ug/l. The remaining violation had a concentration of 17.0 ug/l and occurred the previous year. When considering the similarity of the concentrations in excess of observations at the six stations, in addition to their close temporal and spatial proximity, it would seem an indicator of an ephemeral point-source of beryllium. Four lead violations ranging from 21 to 69 ug/l were observed. Two chromium violations (138 and 156 ug/l) and one nickel violation (87 ug/l) were also recorded.

Synopsis. Discrepancies were noted between sample means, sample medians, violation ranges and parameter objectives casting doubt on the validity of the sample means retrieved from the STORET system. For this reason, ranges for objective violations were given main consideration. Trace metal data were sparse enough to cause difficulties in making any statement regarding water quality.

Table 54 provides a summary of the violation section of the Lake Erie report. It is evident that the river/harbor areas as well as much of the U.S. shoreline of the western and central basins represent the majority of the serious problem areas in the lake. This is particularly critical considering this region constitutes the primary use area of the lake, thus having the greatest impact on the populous living in this vicinity. Considering most of the municipalities around the lake use lake water as a source of drinking water and, to a lesser extent, for food processing, contamination represents an important concern. In addition, there are aesthetic implications which are important; however, they are not health related. It is evident that our database is definitely weak and sometimes nonexistent as in the case of many municipal water treatment plants. From a potential human health related aspect, toxic substance investigations need to be strongly emphasized with well-designed and managed programs in order to properly evaluate lake-wide problems as well as localized conditions.

Trace Metals

Due to the importance of metal contaminants, a special segment is presented examining trace metal concentrations in Lake Erie. In compliance with the International Surveillance Plan, trace metal analyses were conducted on water samples collected throughout Lake Erie during 1978 and 1979. Eight different agencies participated in monitoring the following related areas: tributaries, point sources, connecting channels, water intakes and nearshore zones. Water samples were collected and analyzed for one or more of the following elements: aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, vanadium and zinc.

The results of the trace metal data are summarized in this report. Figure 115 summarizes the Intensive Nearshore portion of the Surveillance Program. The figure presents data collected along a defined segment of the nearshore zone, presented as quarterly means over the two-year study interval. The presentation of standard errors of the means allows preliminary analysis of statistically significant differences between quarterly mean values (Richardson 1980). The source of the data presented herein was calculated using the statistical means procedures available through the STORET system.

Total iron values were available for ten of the 14 lake segments making iron the metal with the largest single Lake Erie database in the STORET system. Total iron was reported under two different STORET parameters as total iron (code no. 01045) and total iron as Fe (code no. 74010). The second largest metal database in the system is that for total mercury. Sufficient total mercury data was available to allow presentation of quarterly mean values for six nearshore segments of the lake. Data for the remaining trace metals are available for four regions of the U.S. nearshore zone only. For the open lake portion of the program, samples were collected and analyzed for trace metals in June of 1978. Due to technical problems with this database, it must be considered of marginal value (Elly 1982).

Reports of raw data were received from Michigan, Pennsylvania and New York state authorities. Discussions of trace metal data in the lake were not received from any agencies participating in the Lake Erie Intensive Study.

Aluminum. There are no applicable water quality or drinking water standards for aluminum nor is there an objective status in the Great Lakes Water Quality agreement of

1978. Aluminum data collected by the nearshore survey is relatively complete. Figure 115 lists data summarized for the U.S. nearshore reaches. Total aluminum values are rather high throughout the U.S. nearshore zone with the highest concentrations recorded during the second quarter of both years and with 1978 values greater than 1979 values. Mean nearshore concentrations from the western basin and western portion of the central basin were higher than those recorded from the eastern portion of the Lake (Figure 115).

Arsenic. Arsenic (technically a non-metal) is quite widely distributed in natural waters occurring at levels of 5 ug/l or more in approximately 5 percent of the waters tested (Sawyer and McCarty 1978). The toxicity of arsenic depends on acclimation. To unacclimated individuals, it is quite toxic while acclimated individuals can consume daily doses of arsenic which would be lethal to naive persons. Effects of arsenic on human health are summarized in Table 55. Arsenic in certain forms is suspected of being oncogenic (tumor forming). For this reason, the standards and objectives have been devised for arsenic in Lake Erie waters (Table 56.)

Summarized quarterly statistics for total arsenic concentrations measured during the intensive U.S. nearshore survey are depicted in Figure 115. Several problems were evident with the data set. Data was either not collected or not entered into the STORET system for the eastern basin in 1978 nor the eastern portion of the central basin during the third and fourth quarters of 1978. In addition, 1979 eastern basin values are recorded as a constant 2 ug/l, indicating detection limit problems. Western basin data must also be regarded with skepticism due to the low number of stations sampled. In general, nearshore arsenic concentrations were well below standards and objectives and do not pose any deleterious threats to Lake Erie aquatic life.

Estimates of arsenic loadings revealed that the Detroit River was the major contributor to Lake Erie during the intensive survey. Relatively large loading estimates were also calculated for the Maumee River, the Sandusky River, the Rocky River, the Black River, the Cuyahoga River, the Grand River, the Ashtabula River and Conneaut Creek.

Linear trend analysis was conducted for areas where greater than five years of surveillance data was available. Methodology for trend analysis was the same used by Rush and Cooper (1981). Of the areas where sufficient data existed, decreasing trends for total arsenic were found in the Maumee and Cuyahoga Rivers.

Cadmium. Cadmium is used extensively in the manufacture of batteries, paints and plastics. It is also used in iron plating and corrosion prevention with plating operations contributing the most cadmium to the water. At low levels of exposure over prolonged periods it can cause high blood pressure, sterility among males, and kidney damage (Sawyer and McCarty 1978) (Table 55). Due to the toxicity of this metal, standards and objectives were devised for cadmium concentrations (Table 56).

Quarterly statistical summaries of total cadmium concentrations in the nearshore zone of Lake Erie are listed in Figure 115. In general, nearshore mean concentrations for 1978 data exceed those for 1979, and quarterly mean values calculated from the nearshore portion of the west central basin were higher than mean values from other nearshore segments of the lake. Mean values were generally below most jurisdictional standards, yet exceeded both IJC and OMOE objectives.

Individual cadmium measurements in excess of standards and/or objectives were widespread. A majority of the violations occurring in Ohio waters were due to the relatively low concentration established as a water quality standard in that jurisdiction. Violations of objectives and standards in respective jurisdictions are as follows (data are reported as the number of stations in which at least one violation was reported):

TABLE 57

SUMMARY OF CADMIUM VIOLATIONS

Jurisdiction	Total No. of Stations	Nearshore Stations	Main Lake Stations	Tributary Stations	Intake Stations	Connecting Channel Stations
Ohio	249	147	15	27	40	--
Pennsylvania	57	22	0	5	0	--
New York	38	9	6	0	N/A	1
Michigan	73	27	1	2	2	1
Ontario	35	N/A	22	N/A	N/A	--

The majority of violations occur in the nearshore zone in all jurisdictions.

The Detroit River was the major source of cadmium input into the lake. Other significant contributors included the Maumee, Sandusky, Black, Cuyahoga, Grand, Rocky, and the Chagrin Rivers.

Of the stations where adequate data existed, decreasing trends were found for cadmium values at Sandusky water supply intake and for the Cuyahoga River at Independence. Nearshore, tributary and water supply intake databases were screened to determine if any existing values exceeded USEPA published criteria (Federal Register, Vol. 45, No. 231, Friday, November 28, 1980) for freshwater biota. Values exceeding the criteria were noted only for the hardness-related metal criteria (Table 58). Hardness data, per se, were not collected during the intensive nearshore survey and, as a result, violations were summarized only for tributary and water intake stations. Cadmium records exceeding criteria were relatively numerous and represent a source of concern.

Chromium. In the aquatic environment, chromium exists primarily in the form of chromate. Only minor amounts are actually left in solution due to precipitation of hydrolyzed trivalent forms as hydroxide (Sawyer and McCarty 1978). Chromium is used extensively in industry to make alloys, refractories, catalysts and chromate salts. Chromate poisoning causes skin disorders and liver damage, and is believed to be carcinogenic (Table 55). The standards and objectives instituted are presented in Table 56.

A quarterly statistical summary of total chromium data in the nearshore zone is presented in Figure 115. Mean quarterly concentrations in the nearshore segments of the western basin and western portion of the central basin were the highest mean values calculated. In addition, 1978 mean concentrations exceeded those calculated for 1979 in all segments of the U.S. nearshore study area.

A summary of water intake data indicated inadequacies due to the reporting of the detection limit used by the Ohio Environmental Protection Agency (OEPA) and by the Pennsylvania Department of Environmental Resources (PDER). These agencies consistently reported values of 30 ug/l and 10 ug/l, respectively.

Chromium values in excess of standards and/or objectives were infrequent. These exceptions are summarized by the number of stations where at least one sample record exceeded criteria in each of the jurisdictions:

TABLE 59

SUMMARY OF CHROMIUM VIOLATIONS

Jurisdiction	Total No. of Stations	Nearshore Stations	Main Lake Stations	Tributary Stations	Intake Stations	Connecting Channel Stations
Ohio	249	30	4	7	1	N/A
Pennsylvania	57	0	0	0	0	N/A
New York	38	0	2	0	N/A	0
Michigan	73	6	0	0	0	0
Ontario	35	N/A	0	N/A	N/A	N/A

The Detroit River was the major contributor of chromium with substantial chromium loadings occurring in the Sandusky, Maumee, Grand, Black and Rocky Rivers.

Linear trend analysis of chromium data indicated a significant increase in the Maumee River from 1974 to 1980, while no change was noted in the Sandusky or Cuyahoga Rivers for the same period of record.

Copper. Standards imposed on copper concentrations in Lake Erie serve to protect aquatic life. Concentrations above 1.0 mg/l may pose aesthetic taste problems in drinking water supplies; however, there is no evidence to indicate that copper is detrimental to the public health at levels which are aesthetically unacceptable. In surface waters, copper is toxic to aquatic vascular plants, phytoplankton and some fish at concentrations near 1.0 mg/l (Sawyer and McCarty 1978). Standards and objectives have been imposed on Lake Erie waters by the agencies involved (Table 56.)

Quarterly statistical summaries for total copper are depicted in Figure 115. With the exception of third and fourth quarter mean values for the eastern central basin, 1978 values were higher than those collected in 1979.

In general, 1978 loading values were higher than 1979 values, especially those data collected by state agencies. Major inputs of copper originated from the following tributaries: the Detroit River, the Maumee River, the Sandusky River, the Rocky River, the Cuyahoga River, the Grand River, the Black River, the Chagrin River and Conneaut Creek.

Copper concentrations in excess of objectives and/or standards occurred frequently in the nearshore zone, while relatively few stations at the remaining sites exhibited one or more violations. The following table lists the number of stations in each jurisdiction in which at least one sample collected exceeded limits:

TABLE 60

SUMMARY OF COPPER VIOLATIONS

Jurisdiction	Total No. of Stations	Nearshore Stations	Main Lake Stations	Tributary Stations	Intake Stations	Connecting Channel Stations
Ohio	249	142	6	26	43	--
Pennsylvania	57	24	3	1	1	--
New York	38	12	2	1	0	1
Michigan	73	26	2	2	2	5
Ontario	35	N/A	0	N/A	N/A	N/A

The majority of violations occurred in the nearshore zone. However, this observation may be misleading since the nearshore zone was the most intensively sampled of the five station types. No significant increasing or decreasing trend resulted from the linear regression analysis at any location from 1974 to 1981. Nearshore, tributary and water supply intake databases were screened to determine if any existing records exceeded USEPA published criteria for freshwater aquatic life. Copper records exceeding criteria were relatively numerous and represent a potential source of concern.

Total Iron. Iron in the water can be detrimental to aquatic life, but seems to do no harm to humans. However, water containing iron can become turbid and unacceptable from an aesthetic point of view. In addition, iron interferes with laundering operations, leaves objectionable stains on plumbing fixtures, and causes problems in distribution systems by supporting growth of iron bacteria (Sawyer and McCarty 1978). For these reasons, authorities have set standards for maximum allowable levels of iron in unfiltered samples of water. Standards which apply to waters sampled according to the Surveillance Plan are presented in Table 56.

The IJC and OMOE objective, and the State of New York standard for total iron is 300 ug/l. This objective was exceeded at 7 of 38 water intakes. The true frequency of violation of the objective is impossible to ascertain due to the infrequent sampling of total iron data at intakes. Total iron data reported for River Mile 3.9 on the Detroit

River consistenly approached or exceeded the 300 ug/l objective. Tributary streams in Pennsylvania occasionally exceeded the objective as well.

Quarterly means of total iron in the nearshore zone of Lake Erie were highest in the western basin and lowest in the eastern basin. In the western basin, values consistently exceed the IJC and OMOE objective. In the central basin, quarterly mean values were highest for the segment extending between Marblehead and Cleveland, Ohio, with the IJC objective exceeded by 5 of the 6 quarterly means. Quarterly mean values exceeded the objective in the eastern basin only once during the second quarter of 1978 in the segment extending from Port Maitland, Ontario, to Buffalo, New York (Figure 115). No seasonal or temporal pattern was apparent in quarterly mean values. Although total iron values often exceed the ICJ objective of 300 ug/l, these violations are technical in nature and reflect the natural state of water in Lake Erie rather than a substantial violation or significant problem requiring remedial action.

Lead. Water quality monitoring of lead concentrations in surface waters is extremely critical in order to maintain safe levels for drinking water standards. Lead poisoning has been recognized for many years and has been identified as a cause of brain and kidney damage (Table 55). The standards and objectives for total lead are given in Table 56.

Summarized quarterly mean values calculated for the four nearshore segments of the U.S. shore are listed in Figure 115. With the exception of the fourth quarter western-central basin reach, 1978 mean concentrations were higher than 1979 values. In addition, concentrations calculated for the eastern portion of the central basin and the eastern basin nearshore segment were higher than other portions of the nearshore zone.

Lead measurements in excess of water quality criteria were infrequent, the majority of which occurred in the nearshore zone. A summary of surveillance stations in which at least one sample exceeded standards or objectives is listed below:

TABLE 61

SUMMARY OF LEAD VIOLATIONS

Jurisdiction	Total No. of Stations	Nearshore Stations	Main Lake Stations	Tributary Stations	Intake Stations	Connecting Channel Stations
Ohio	249	36	3	22	3	--
Pennsylvania	57	1	0	0	0	--
New York	38	0	1	0	N/A	1
Michigan	73	7	0	1	0	1
Ontario	35	N/A		N/A	N/A	N/A

The total number of observations at each location is too limited to allow any assessment. The consistent reporting of a 5.0 ug/l value indicates detection limit problems, but this value is well below standards or objectives.

The major contributions of lead originate from the Detroit, Maumee, Sandusky, Black, Rocky, and Cuyahoga Rivers. In general, 1979 values are greater than those for 1978.

Sufficient data to linearly regress data points through time were recorded at three locations. A significant decreasing trend was calculated for data collected at the Sandusky Water Supply Intake. Stations located in the Maumee and Cuyahoga Rivers showed no significant change during the period of record. Nearshore, tributary and water supply intake databases were screened to determine if any existing records exceeded USEPA published criteria for freshwater aquatic life. Only trend analysis calculations were performed for data from tributaries and water intakes (Table 58).

Manganese. Limits on manganese concentrations in surface waters are imposed primarily for aesthetic reasons for drinking purposes. Concentrations less that 20 ug/l represent minimal risk in aquatic environments (Sawyer and McCarty 1978). Only Ohio and Pennsylvania have imposed manganese standards; 50.0 ug/l for Ohio waters and 1,000 ug/l for Pennsylvania (Table 56). There are no other objectives or standards for this parameter. Potential health problems associated with chronic or massive exposure to manganese are summarized in Table 55.

Statistical summaries of quarterly mean values calculated for four nearshore segments of the U.S. shore are presented in Figure 115. With the exception of eastern basin mean values, 1979 values were generally higher than those in 1978. Of the four nearshore segments, the western central basin mean concentrations generally were highest with manganese concentrations ranging from 0.00 ug/l to 284 ug/l.

Tributary loading estimates indicate that during 1978 and 1979, the Detroit River, the Maumee River and the Rocky River served as major contributors of total manganese.

Significant increasing trends were discerned at two locations, the Sandusky and Niagara Rivers. A significant decreasing trend was calculated for data from the Erie, Pennsylvania water supply intake. No significant increasing or decreasing trends were noted in calculations performed on data from the remaining sites.

Mercury. High levels of mercury in water could be detrimental to aquatic life, and if consumed by humans, large amounts of mercury would endanger their lives (OMOE 1978) (Table 55). The IJC objective for dissolved mercury is 0.2 ug/l, making levels of mercury in Lake Erie water of interest. Although samples for dissolved mercury analyses were not collected, analyses were conducted for total mercury in the water from samples at 253 stations during the two-year interval 1978-1979. The results of analyses are summarized below in Table 62.

TABLE 62

SUMMARY OF MERCURY OBSERVATIONS

Number OBS	Mean (ug/l)	Standard Error	Maximum Value	Minimum Value
1309	0.196	0.119	6.080	0.000

The results of the Intensive Nearshore Survey are summarized as quarterly means for defined segments of the nearshore zone in Figure 115. Generally, the quarterly means for total mercury were below, or near, the IJC objective of 0.2 ug/l for dissolved mercury. The exception was in the Detroit River segment where mean concentrations exceeded 0.3 ug/l during the third quarter of both years. These values were not significantly different from the western basin open lake mean concentrations determined from samples taken in June 1978. In addition, relatively high mean values were reported for the fourth quarter of 1979 for the segment extending between Port Maitland and Buffalo.

Since total mercury values seldom exceed the IJC standards of 0.2 ug/l in water, this was interpreted to mean that mercury in the water column has not been identified as a subject of concern during the intensive study period.

Nickel. Nickel is used extensively in electroplating and occurs in the rinse waters from these operations, constituting the major avenue by which the salt of this metal gains access to the aquatic environment. Nickel is suspected of being oncogenic and for this reason standards and objectives have been formulated (Tables 55 and 56).

Nickel concentrations in excess of criteria occurred rather frequently in the nearshore zone but were seldom found elsewhere in Lake Erie. Table 63 lists the total number of stations in each water where at least one sample exceeds limits.

TABLE 63

SUMMARY OF NICKEL VIOLATIONS

Jurisdiction	Total No. of Stations	Nearshore Stations	Main Lake Stations	Tributary Stations	Intake Stations	Connecting Channel Stations
Ohio	249	127	7	15	5	—
Pennsylvania	57	24	1	2	0	—
New York	38	18	2	0	N/A	0
Michigan	73	22	0	0	0	1
Ontario	35	N/A	1	N/A	N/A	N/A

Figure 115 lists quarterly statistical summaries of intensive nearshore survey data from the U.S. shore of Lake Erie. With the exception of second quarter mean concentrations in the eastern-central basin and second quarter mean concentrations in the eastern basin, quarterly means were higher in 1978 than those in 1979. Except for the samples reported by Ohio EPA, most of the values lie within the limits imposed by respective jurisdictions. The Ohio EPA data set reported all total nickel values as 100.0 ug/l, indicating the reporting of the detection limit.

Loading data for this metal was rather scarce; only two stations were sampled by the USGS in 1978; none in 1979. State agencies sampled two stations in 1978, while ten were sampled in 1979. Major tributary sources of total nickel include the Rocky and Cuyahoga Rivers in 1978 and the Black River, the Cuyahoga River, the Chagrin River and the Grand River in 1979.

Insufficient data existed to perform linear trend analysis at any location throughout the lake. Tributary and water intake data screened for exceptions to USEPA published criteria revealed no records in excess of criteria. These observations (i.e., no trends or violations) reflect a scarcity of data necessary for proper assessment of Lake Erie water quality. However, the frequency of nearshore records in excess of jurisdictional criteria and IJC objectives indicates a potential source of concern (Table 58).

Selenium. Selenium occurs in natural waters in very limited areas of the United States. Its major use is in the manufacture of electrical components: photoelectric cells and rectifiers. Selenium has been implicated as oncogenic but existing evidence is limited. The standards and objectives formulated for this metal are presented in Table 56.

Measurements of total selenium in excess of criteria occurred very rarely. The number of stations where at least one sample exceeded standards and/or objectives are listed below:

TABLE 64

SUMMARY OF SELENIUM VIOLATIONS

Jurisdiction	Total No. of Stations	Nearshore Stations	Main Lake Stations	Tributary Stations	Intake Stations	Connecting Channel Stations
Ohio	249	4	0	1	3	N/A
Pennsylvania	57	1	0	0	0	N/A
New York	38	0	0	0	N/A	0
Michigan	73	0	0	0	0	0
Ontario	35	N/A	0	N/A	N/A	N/A

A summary of quarterly mean values calculated for four nearshore segments of the U.S. shore are listed in Figure 115. Quarterly mean concentrations for 1978 were larger than 1979 values for every quarter and nearshore segment. Mean 1979 eastern basin concentrations were based on consistent records of 2.0 ug/l, indicating a possible instrument limitation problem. Data from municipal intakes were also of limited value since all concentrations recorded at some intakes were either 5.0 ug/l or 10.0 ug/l.

Loading data for total selenium was scarce, especially at stations sampled by state agencies. The Detroit River, Maumee River and Cuyahoga River were large contributors of selenium in 1978. In 1979, the Grand River, Ohio and Cattaraugus Creek, New York were calculated to contribute large amounts of selenium.

Sufficient data were collected only at the Maumee River station near Waterville, to conduct trend analysis. A significant decreasing trend was calculated for the period extending from January 1974 to October 1980.

Vanadium. There are no applicable water quality or drinking water standards for vanadium nor is there an objective stated by the Great Lakes Water Quality Agreement of 1978.

Vanadium data collected for intensive nearshore purposes is summarized by nearshore segment in Figure 115. For the most part, quarterly 1978 mean concentrations were higher than 1979 values. Data were not reported for the third or fourth quarters in 1979 in the western-central basin nearshore segment. In addition, third and fourth quarter data from the western-central and eastern-central basin segments and the entire eastern basin portion were consistently reported as 5.0 ug/l. Thus, the data set was of limited use in assessing Lake Erie water quality in terms of total vanadium concentrations.

Due to the extreme scarcity of vanadium data, it was not possible to calculate loading estimates or linear trend analyses.

Zinc. The toxicity of zinc is very low. Zinc salts gain access to the aquatic environment through mining, electroplating and corrosion of galvanized pipes. Water quality standards and objectives are developed primarily for taste considerations. The standards and objectives have been formulated for Lake Erie waters (Table 56).

Measurements of total zinc concentrations in excess of criteria occur frequently and were most evident in the intensive nearshore surveillance data. The following table summarizes the number of stations where at least one sample exceeded limits during the 1978-1979 intensive surveillance period:

TABLE 65

SUMMARY OF ZINC VIOLATIONS

Jurisdiction	Total No. of Stations	Nearshore Stations	Main Lake Stations	Tributary Stations	Intake Stations	Connecting Channel Stations
Ohio	249	146	5	19	11	N/A
Pennsylvania	57	21	0	5	0	N/A
New York	38	11	1	0	N/A	1
Michigan	73	26	0	3	1	3
Ontario	35	N/A	30	N/A	N/A	N/A

Quarterly mean values of intensive nearshore total zinc data calculated for each of four segments of the U.S. shore are listed in Figure 115. In the eastern-central basin and the entire eastern basin portion, 1979 mean concentrations were generally higher than 1978 mean values. In the western-central basin, 1978 nearshore means were higher than 1979 values.

The western-central basin nearshore was the segment with the highest calculated values. Along the U.S. shoreline, zinc values in the nearshore study area ranged from 0.00 ug/l to 1726.50 ug/l.

During both years of the intensive survey, major inputs of zinc originated from the Detroit River, the River Raisin, the Maumee River, the Sandusky River, the Cuyahoga River, the Grand River in Ohio, the Rocky River, the Chagrin River, Conneaut Creek and Cattaraugus Creek.

Of the five stations where sufficient data existed for trend analysis, none showed a change through time for the period of record (approximately 1974 to 1980). Tributary and water intake data screened for exceptions to USEPA published criteria revealed a very limited number of exceptions to this criteria (Table 58).

Synopsis. In spite of what is indicated by this section, trace metal data for Lake Erie are not complete or very reliable. Numerous serious problems exist with the database making any comprehensive picture of trace metal contamination still subject to further examination at the surveillance level. For example, the entire open lake data collected during 1978-1979 intensive study provides no information that can be used for a long-term database. Consequently, this facet needs to be re-examined. Several data sources reported values only at detection limits; thus, much of this information is of only limited value. Copper, for example, has a violation level of 5 ug/l while the detection limit frequently reported was 30 ug/l; consequently, little can be discerned from this information. In addition, very little, if any, data is available on internal/external quality control, making interpretation of results a problem. In addition to laboratory problems, the actual sampling patterns and sampling schedules employed by the various studies were by no means optimal for data interpretation. Thus, the entire trace metal contaminant program on Lake Erie needs to be re-evaluated in order to establish a reliable database. Careful attention needs to be placed on the station pattern, sample plan, methodologies employed, and what metals are important enough to be considered in the program.

In a recent report, Rossman (1983) presented metals data for the western, central and eastern basins. The report contains information on open lake concentrations of total, dissolved and particulate fractions of 27 trace metals. Table 66 presents the total concentrations for the three basins. In addition, the historical database is presented and summarized with comments as to the quality of the database. In order to estimate the potential toxicity of the mixture of trace metals analyzed, a ratio of the concentrations of each metal (M_i) to its respective IJC objective concentration (0_i) was calculated. The sum of the individual ratios should not exceed 1.0 if all concentrations are at safe levels. The results presented in Table 67 indicate that open lake concentrations of metals may pose a problem to the biota. In particular, selenium was found to exceed objective levels. The Rossmann (1983) report together with a manuscript by Lum and Leslie (1983) have advanced the open lake trace metal database significantly. Future programs involving trace metal analysis in Lake Erie should take these documents into consideration.

Nearshore Water Quality Trends

Improvements or changes in water quality resulting from remedial measures are most likely to first appear in nearshore regions rather than in the open lake. This section deals with analyses of water quality in the nearshore zone of Lake Erie in an attempt to assess changes or trends which may have occurred in the last decade.

Trend analysis of long-term databases has recently attracted the attention of many Great Lakes research groups. Two major problems have arisen in attempting to analyze large databases through time: first, a satisfactory definition of what exactly constitutes a "trend;" secondly, and more importantly, developing an adequate method of removing large variations in raw data resulting from seasonality and climatic conditions such as storm events. Such variation could mask a trend that really exists, or, conversely, it could indicate a trend where none actually exists.

In 1978, the IJC defined "trend" as a linear regression equation having a slope significantly different than zero as determined by a t-test. Recently, the Data Management and Interpretation Work Group (Richardson 1980) recommended the following definition for a trend in Lake Erie water quality:

> "To relieve any ambiguity and to provide a uniform methodology of testing for trends we propose an operational definition of a trend which narrows it to a change at a constant rate, that is, trend will be understood as simple linear trend. Trend can thus be assessed by regressing the characteristic of interest upon time:
>
> $$y = b_o + b_1x + e$$
>
> where b_o is the characteristic of interest and x is time; coefficient b_1 is tested for statistical significance and e = error."

If analysis indicates presence of a trend, the work group expanded this definition somewhat and suggested further analysis of second and third order coefficients of time to determine if the rate of change is itself changing.

Previous investigations of trend analysis on Lake Erie date back to Beeton (1965) whose work can be found cited in almost every paper dealing with changes in Lake Erie. Beeton seems to have collected the only database for long-term trend analysis dating back to the turn of the century. Since the database used by Beeton has not as yet been reassembled and examined in as rigorous a manner as may be necessary to discern a trend, the results he presented should not be considered absolute.

In 1978, the IJC published an analysis of trends of nearshore water quality data throughout the Great Lakes, 1967-1973 (Gregor and Ongley 1978). In this study, the authors adopted an aggregation procedure for each of 140 nearshore geographic regions. The regions were chosen a priori in an attempt to homogenize the effects of limnological processes while retaining large data populations within each subset in order to enhance statistical significance. The aggregation procedure involves separating the data into three time frames and analyzing each by season (spring, summer and fall) and by depth (surface and subsurface). The authors' summary of water quality trends indicates that the following parameters have generally decreased through time in Lake Erie: conductivity, total phosphorus, chloride, chlorophyll a, secchi depth and total coliforms; total nitrogen and oxygen saturation have increased.

Richards (1981b) employed a third method of analyzing long-term databases. This procedure involved removing seasonal variation by averaging monthly residuals of all years and subtracting this average from the linear model. This analysis was performed with the assumption that the seasonal effect remains constant for each year. Using data collected at the City of Cleveland's Water Supply Intake Division over a period of record extending from 1969-1979, Richard's regression analysis with seasonal filtering indicated a significant decrease in total phosphorus, soluble reactive phosphorus, ammonia-nitrogen, specific conductance, and chlorides. No significant trends were found to exist for nitrate plus nitrite, soluble reactive silica, alkalinity, pH or sulfate.

The following analysis is a first-order attempt to discern which parameters are significantly changing in the nearshore region of the lake by applying the Data Management and Work Group's recommendation. Eleven locations consisting of twenty stations comprised the present data set. A general, all-parameter (chemical and physical) retrieval from STORET was reviewed to ascertain which stations showed the greatest sampling frequency, the longest time period for analysis, and contained parameters most conducive for evaluating water quality status. Stations chosen for analysis are depicted in Figure 116. Agencies which sampled the stations, station descriptions and locations are listed in Table 68, with station type defined as tributaries and water intake systems.

A total of 22 parameters were chosen to represent general water quality conditions in Lake Erie. Physical and chemical parameters such as turbidity, conductivity, residue, and total dissolved solids may indicate changes resulting from sediment loading; chloride, which is considered a conservative parameter, may indicate sources of increased or decreased chemical loading and accumulation; while pH and alkalinity are reflective of acid-base conditions and buffering capacities. Dissolved oxygen and biochemical oxygen demand were chosen to reflect changes in biologically oxidizable organic matter.

The nutrient parameters consist of various forms of nitrogenous and phosphorus compounds. Of these two groups, trend analysis of phosphorus compounds may be considered more important since phosphorus has been identified as an important contributor to eutrophication and its loading rates have been of primary concern in recent years.

Statistical analysis of the data consisted of testing a linear regression equation by use of a t-test or F-test ($P < .05$) in order to determine if the slope of the line was significantly different than zero. On all but two of the data sets reviewed, raw data was plotted against time for all parameters using a STORET REG procedure. If the t-value of the slope was greater than the corresponding tabular "t" value for n-1 degrees of freedom, a slope significantly different than zero was indicated (Nie et al. 1975).

The databases used from the C and O Dock and Davis-Besse locations were not obtained from STORET. Raw data was entered on tape and an SAS (79.5) General Linear Models (GLM) procedure was run on monthly means to test for significant trends. Significance of slope was determined using an F-test ($P < .05$). Linearity of trend was attempted by plotting residuals of the regression line for parameters found to have significant trends in the C and O Dock and Davis-Besse databases. A relatively straight band of residuals may be indicative of an actual linear trend during the period of record (Draper and Smith 1966).

A summary of linear regression trends for each parameter and station analyzed can be found in Table 69. For example, trend analysis at tributary station 1 (STORET code 820011) on the U.S. shore of the Detroit River indicated a decreasing trend in alkalinity, dissolved oxygen, conductivity, turbidity, total dissolved solids, residue, biochemical oxygen demand, ammonia plus ammonium, total Kjeldahl nitrogen, total organic carbon, total phosphorus, ortho-phosphorus, phenols, iron and chloride. No trends could be detected by this analysis for silica, organic nitrogen, nitrate plus nitrite, or total and fecal coliforms. The analysis indicated no parameter at this site was increasing significantly through time. Thus, a general increase in the quality of water can be said to be occurring.

The database for the Cuyahoga River presented a situation requiring a combination of station values. The Cuyahoga River near the river mouth was sampled at three different locations, but all within close proximity of each other. One station was sampled between 1963-1974 while the other two were sampled from 1974-1981. For the purposes of this discussion, the stations are considered to be in the same locale and are reported for the two time periods. From 1963-1974, increases were found to occur for pH, alkalinity and iron, while decreases were noted for conductivity and nitrate plus nitrite. No significant trend was noted for total phosphorus, total coliforms or chlorides. In the 1974-1981 time frame, alkalinity continued to increase, while iron, total phosphorus and chloride did not change. Nitrate plus nitrite, pH, conductivity and total coliforms were not sampled after 1974. Total organic carbon was the only parameter sampled from 1974-1981 and not the 1963-1974 time period which showed a significant increase. The remaining parameters did not change significantly through time.

Each of the four water intake systems was also evaluated for changing water quality. Monroe, Michigan water intake data showed only an increasing trend in phenols; all other parameters of interest were either not present in the data set or showed no significant change. Although the data set was limited, the analyses of existing nutrient and principal ion parameters lead to an initial conclusion that water quality at this site may not have changed significantly over the period of record (1967-1979).

Analysis of Sandusky water intake data indicated a significant increase in temperature, conductivity, residue, nitrates and total organic carbon. No change was detected for dissolved oxygen, turbidity, NH_3+NH_4, total Kjeldahl nitrogen, total phosphorus, fecal coliforms or chlorides. Decreasing trends were observed in the regression analysis for pH, alkalinity and ortho-phosphorus data. Conclusions derived from this analysis of Sandusky water intake data must be regarded with skepticism since the period of record is one of the shortest presented (1974-1980). The possibility of detecting a true trend in this database is dubious at best.

Analysis of data collected from the City of Cleveland's Crown water intake (located approximately 4 km offshore) (Figure 116) indicated significant increases in temperature, alkalinity, total organic carbon and fecal coliforms, as well as significant decreases in pH and turbidity. No significant trend was evident in dissolved oxygen, conductivity, nitrates, NH_3+NH_4, total phosphorus or chloride. Thus, the water quality at this location does not appear to be changing over the period of record, 1974-1980. The database retrieved from the Erie, PA water intake revealed a gap from mid-1976 to early 1978. Analyses performed showed a significant decrease in pH, alkalinity, total and fecal coliforms, iron and chloride values. No significant trends were evident for temperature or total phosphorus values. The only parameters for which the analyses indicate an increase through time were dissolved oxygen and turbidity.

The tributaries or connecting channel stations revealed different responses over time. Total phosphorus analyses indicated a decreasing trend throughout most of the stations in the western basin, including all three station locations in the Detroit River, the C and O Dock and the Maumee River at Waterville. Davis-Besse, Sandusky, Crown, Erie, and the Cuyahoga River showed no significant total phosphorus trends. Analyses of orthophosphorus data revealed a decreasing trend in the Detroit River and at Sandusky, while Niagara River, just downstream from the Black Rock Canal, indicated a significant increase.

Organic nitrogen was unchanging at all sites with the exceptions of the Buffalo and the Niagara Rivers where a decreasing trend was noted and the Cuyahoga River where a significant increase was found. Of the remaining nitrogen compounds, nitrate increased at three locations (Toledo, Sandusky and Buffalo Rivers) and decreased at the C and O Dock. NH_3+NH_4 decreased wherever a trend was observed (U.S. shore and Livingstone Channel in the Detroit River, Maumee River at Waterville, and Buffalo River). Total Kjeldahl nitrogen was decreasing at the U.S. shore and Livingstone Channel (Detroit River) and Buffalo River and increasing in the Cuyahoga River. Analyses of nitrate plus nitrite data indicated a significant increasing trend at Davis-Besse and a significant decreasing trend in the Cuyahoga River. Silica was the only parameter sampled which indicated no significant increasing or decreasing trend at any location.

Figures 117 and 118 are representative of STORET retrieval plots and are shown to illustrate various problems encountered in this analysis of trends. Total phosphorus (Figure 117) at the Livingstone Channel station clearly shows a narrowing variation through time; values plotted from 1978 to 1981 show less variability than previous years. This phenomenon is possibly due to refinement of analytical technique and/or sampling stations. Figure 118 depicts monthly mean total phosphorus plotted from 1970 through 1979 at the C and O Dock (mouth of the Maumee River). Visual inspection of total phosphorus data at this site reveals that concentrations may have remained stable until 1975 and then declined. The extreme variation present in the 1974 portion of the phosphorus data could have influenced the regression line. If the variability in the early portions of these data sets is due to factors other than random error (i.e., inadequate sampling and/or analytical technique) the significant trends resulting from the analyses of these data sets reported herein may not be accurately assessing changes in water quality.

Lastly, it was evident that in most cases r^2 values were rather low, i.e. Figure 117, r^2=0.27 for total phosphorus at the Livingstone Channel site. This suggests that not much of the variability may be explained by time. An exception to low r^2 values was found in cyanide trends, however. These high values were not indicative of actual cyanide phenomena. Inspection of the STORET plots revealed that the detection limit was probably lowered during the period of record.

Variability in the data sets is the leading analytic problem. If the variance about the regression line is greater than the estimated population variance (s^2) then the postulated model suffers lack of fit. Several methods for determining lack of fit are outlined by Draper and Smith (1966) and should be pursued in order to test the validity of the regression model.

One of the most obvious methods for removing much of the variability in the data set is to filter the seasonal component. The authors have attempted to separate the months into seasons and regress the seasons on years. This procedure proved ineffective as most parameters showed increases in trends in some seasons and decreases in others, thus making overall trends more difficult to ascertain.

Another method to remove seasonal variability involves averaging monthly residuals and subtracting the average from the regression equation (Richards 1981b). Although the results of Richards' paper indicate very little improvement in significance levels or r^2 values for data taken from the Cleveland municipal water intake, averaging residuals may prove effective in increasing r^2 and significance levels for data sets presented here.

Perhaps the most effective method is to describe the seasonal variability of each parameter by a polynomial and subtract this equation from the linear regression equation. This could be effective in removing the seasonal component of the variability.

Finally, when trends are adequately described according to variability and linearity, further investigation is necessary to discern probable causes for each parameter exhibiting significant change. Loading and flow data of major tributaries, as well as water level data, may be incorporated to illustrate any correlations which may exist between trends and general physical and limnological phenomena. Trends may also be correlated against one another to see if perhaps a trend in one parameter is accounted for by a trend in another.

Water Quality Trends at Cleveland, Ohio

During 1978 and 1979, the nearshore zone of Lake Erie was sampled intensively as part of the monitoring and surveillance program for the Great Lakes (Herdendorf 1978). The Heidelberg College Water Quality Laboratory (HCWQL) was responsible for sampling in the nearshore zone of the central basin between Vermilion, Ohio and Ashtabula, Ohio. Sampling was carried out at 89 stations (Figure 9). Each station was sampled on three successive days during four cruises each year. At most stations, samples were collected one meter below the surface and one meter above the bottom.

One major purpose of this nearshore study was to identify historical trends, especially among parameters that may have changed in concentration due to human impact on Lake Erie. This section addresses that purpose at two levels: comparisons with a long-term but often sketchy database extending back to 1900, and comparisons with a much more detailed but localized database for one station from 1968 to 1979.

The attempt to identify historical trends is often frustrated by the scarcity and inadequate quality of historical data. Changes in methods of analysis affect the data in ways which are hard to identify. The methods of analysis themselves are often not specified. Even when the methods are specified, and are known to be bias-free analytically, the possibility of biases due to different working ranges and other laboratory-level differences is very real, but usually difficult to evaluate. For the nearshore zone, data is scarce even in comparison to the data set for the open lake. Much of the data found in the literature prior to 1950 consists of average values, and often the locations where the data were obtained are not adequately specified. Also, the nearshore zone is much more variable spatially and temporally than is the open lake, making historical trends more difficult to detect.

For all of these reasons, historical analysis is a difficult endeavor, especially in nearshore waters. Even statistically significant changes must be carefully scrutinized to see if they are reasonable in limnological context or if they are better interpreted as artifacts of problems in the data set. The point must be made at the outset, however, that statistical trend analysis can show only a significant change in the numbers in a data set as a function of time. Identification of a historical trend in Lake Erie involves substantial interpretation of the results of the statistical procedure.

Long-Term Historical Trends. One of the most important historical trend studies was that of Beeton (1961 and 1965, Beeton and Chandler 1963). The importance of this study lies in its time span (1902 to 1960) and its concern with chemical parameters of general importance: total dissolved solids, calcium, sodium, potassium, sulfate and chloride. The concentrations of these parameters are great enough that one can have at least cautious confidence that measurements in the early 1900s were not drastically inaccurate.

The data used by Beeton (1961 and 1965) came from a variety of sources: public water intakes, fisheries studies, early research efforts, and a few early studies of pollution in Lake Erie. The data set includes values from all three basins of Lake Erie, and from nearshore regions and open lake waters. Since gradients in concentration are known to exist from onshore to offshore, and from basin to basin, the data set contains sources of systematic difference other than the historical trends. However, the changes in most of the parameters over time are large compared to the magnitude of these spatial gradients, and the mix of data from different areas is reasonably random with respect to time. Thus, spatial factors may serve to obscure historical trends by increasing overall variance, but they probably do not bias the trends in an important way.

Beeton does not list the data sources shown in his figures, and much of it is from sources that are not readily available. Data has been taken from Beeton's figures as precisely as possible; his data is reproduced in Figures 119-121. Since many of the data "points" in Beeton's graphs are actually averages, the distortion of the data due to reading the graphs is probably small compared to the distortion (loss of variance) introduced initially by the averaging process. It would be preferable to begin with the raw data; however, to date it has not been possible to reassemble the data set from the sources that Beeton used.

Also shown in Figures 119-121 are the 1978 and 1979 means and standard deviations for data collected at the 15 HCWQL stations farthest from shore. These stations were chosen as most compatible with Beeton's sources. In general, the HCWQL values are quite comparable to the values reported by Beeton (1965) from the late 1950s; indeed, they seem to be lower than Beeton's 1950s data in the case of calcium and chloride. Within the limitations of the data, it appears that for most parameters the lake is not deteriorating at the rate which typified the first half of the century.

In order to test this conclusion, regression lines were fitted to Beeton's data for each parameter. The slopes of the regression lines were tested for significance using a t-test. The regression equations were then used to extrapolate Beeton's data to best estimates for 1979. A standard error of the estimate was also calculated for a sample size comparable to the HCWQL database for each parameter (Sokol and Rohlf 1969), and these were compared with the HCWQL data using a modified two-tailed t-test, adjusted for unequal variances. Table 70 summarizes the results of this procedure. The statistical procedure reveals that all of Beeton's parameters increased significantly ($p < .01$) from 1900 to 1960. It also shows that, for all parameters except sodium plus potassium, values in 1978-1979 fall significantly below the values extrapolated from the historical data. In some cases, there probably has been an absolute decline in concentration since 1960. In others, especially sulfate and conductivity, there may only be a lessening in the rate of increase. However, had the analysis been done on the original data, the variance would have been greater, and thus the statistical significance of some of the results would have been reduced, perhaps even below the standard acceptable limit of $p < .05$.

The decrease in specific conductance, while highly significant statistically, is strongly dependent on the conversion factor used to convert Beeton's data, expressed as total dissolved solids, to specific conductance. The analysis was done using a conversion factor of:

$$\text{Specific Conductance} = \text{TDS}/.62$$

recommended by Fraser (1978). The analysis was redone with a conversion factor of .65 which has been used elsewhere on Lake Erie. This second analysis yielded no significant deviation of HCWQL data from the trend of Beeton's data. Analysis of specific conductance and total dissolved solids data from the Division Water Intake for the City of Cleveland, measured between 1968 and 1975 by the USEPA (Westlake) and the City of Cleveland lab at Whiskey Island, produced a ratio of 0.66. This ratio is not significantly different from the value of 0.65 discussed above, but is higher ($p < .05$) than the value of 0.62 used initially. However, the rather poor correlation between the two parameters ($r^2 < .15$) makes the data of questionable value in establishing the "true" ratio. There is, at present, no adequate way to be certain which ratio is correct. Until a definitive study of this relationship is made, the long-term history of specific conductance cannot be assessed with certainty.

Short-Term Historical Trends. Because Beeton's data set ends about 1960, a more recent data set was sought to help evaluate the changes in the 20 years falling between Beeton's data and the Lake Erie nearshore study. The best source of information was the records from the Division Water Intake for the City of Cleveland, which include data on alkalinity, specific conductance, pH, total phosphorus, soluble reactive phosphorus, ammonia, nitrate plus nitrite, chloride and sulfate, obtained between 1968 and 1973 by the USEPA office now in Westlake, and between 1974 and 1977 by the Water Quality lab of the City of Cleveland, formerly located at Whiskey Island.

The data set used for this study is less than ideal because it was produced by three different laboratories, using different working ranges and in some cases different analytical techniques. In addition, the USEPA analyses were of samples from the water as it entered the purification plant, while the other samples were of lake water at the site of the water intake. Thus, the EPA samples were of bottom water modified by passage through the intake pipe. By comparison, the City of Cleveland samples were mostly surface water, and the HCWQL samples were both surface and bottom waters. Because of the composite nature of the data set, various techniques were used to evaluate possible biases or inadequacies in the data. The results of this scrutiny and of the earlier analysis are presented below.

The data for each parameter was subjected to regression analysis to detect statistically significant linear trends. Initial analysis used all data in raw form, but subsequent analyses involved various modifications of the data, as described below.

Tests of the regression line slopes for significant deviation from 0 (no trend) indicated no trend for alkalinity or specific conductance, but a significant increase in nitrate plus nitrite ($p < .001$) and sulfate ($p < .001$), and a highly significant decrease in chloride ($p < .001$) in the last decade at this station (Richards 1981b). Total phosphorus showed no significant change, but soluble reactive phosphorus decreased significantly, even though the period of record was shorter (1974-1979). The SRP data contains a number of suspiciously high values early in the record, and when these were removed the trend disappeared.

Removing Seasonal Patterns. Many, if not all, of the parameters studied for historical trends also undergo concentration fluctuations as a result of seasonal fluctuations in supply and, in some cases, as a result of biological activity. The seasonal changes are most pronounced in the nutrients, the extreme case being nitrate plus nitrite, which declines sharply in late summer, with less than 20% of those found in early spring.

These seasonal fluctuations tend to mask longer-term historical trends because they increase the overall variance of the data set. Typically, their effect is to decrease the achieved statistical significance in a test of the regression line slope. Since seasonal fluctuations are a different phenomenon than the one being examined, it would be helpful if these fluctuations could be removed from the data. This can be done in the following way. Assume that the seasonal effect is constant from year to year, and is not linked to the long-term historical pattern. If this is so, the data can be fit by a function of the form:

$$y = mx + s(x) + b$$

where $s(x)$ is a periodic function (perhaps a very irregular one) of period one year.

Under this assumption, the procedure is as follows. A standard regression is performed on the data, in effect ignoring the periodic component. Since it is assumed to repeat exactly each year, it does not change the regression equation except to increase the components of variance associated with it. The regression equation is then used to calculate the values of $\hat{y}$ (the concentration) predicted for the given values of x (time), and the predicted y values are subtracted from the actual values. In statistical terms, the residuals are calculated.

The residuals are then grouped together by some sub-interval period of the postulated period function. The grouping interval should be small enough to capture the essence of the periodic changes, yet large enough to contain enough data to be statistically useful. Some compromise is often necessary. In this study, data was grouped by month, which gave at least 30 data points in a month, with very few exceptions. This grouping gathered January data for all years in one group, February data for all years in another group, etc. The average of the residuals in each of these groups is calculated. If there is no seasonal effect in a data set, the residuals reflect only random error, and these averages should all be very close to zero. Thus, any non-zero group average may be taken as an estimate of the seasonal effect for that interval of time.

These estimates of the seasonal effect are then subtracted from the raw data, and the regression is recalculated. The result should be a regression equation which is very similar to the one calculated from the raw data, but it should have a higher associated r-square, or, alternatively, a t-test comparing the slope with zero should achieve a higher level of significance.

Application of the above procedure to the Division Water Intake data set produced the results summarized in Table 71. Examination shows that most parameters showed improvement in the resolution of their historical trends, as measured by increases in the t value. The greatest increases were among the nutrients, where seasonality is typically most pronounced. In a few cases, the t value decreased. This is to be expected where there was little seasonality, due to the error component of the seasonal effect estimate. There was in most cases no change in the achieved significance level of the slope regression line. Most of the parameters for which this was true either showed no significant change, and the improvement brought about by removing seasonality was not sufficient to give significance at $p < .05$, or they already showed highly significant historical change ($p < .001$) and the computer program did not give significance levels less than .001. In one important instance, seasonal filtering produced a significant trend. Total phosphorus did not show a significant trend before filtering, but showed a decreasing trend significant at $p < .05$ after filtering.

Because the procedure assumes that the seasonal patterns were constant during the period of record, monthly averages were plotted for each year to verify the validity of the assumption. While the averages fluctuated considerably from year to year, no systematic change was seen in any of the parameters.

In general, the seasonal filtering process tended to improve resolution of historical changes, but not sufficiently to have a great impact on the conclusions of this study. It appears that factors other than predictable seasonal changes dominate the variance of this data set. These factors may include laboratory accuracy and precision, and the effects of fluctuating currents, which may alternately expose the sampling site to waters of more nearshore or more offshore character. The following paragraphs highlight the results of the seasonal filtering technique.

The total phosphorus data showed no significant change in concentration during the period of record; however, after seasonal filtering, a downward trend was indicated. Due to problems resulting from high detection limits and the various analytical methodologies the indicated decreasing total phosphorus concentrations require future data in order to make a more definitive statement.

SRP showed a significant decrease with time which improves upon seasonal filtering. Due to similar detection limit problems, as previously discussed, this trend remains questionable.

Nitrate plus nitrite indicates a highly significant increase in concentration over the period of record showing an even greater significance upon seasonal filtering. Most of the increasing values were found in the last three years with little trend evident prior to 1978.

No trend was evident for alkalinity; however, a slight decline was noted for the last five years.

pH indicates a statistically significant but not visibly obvious increase with seasonal filtering improving the analysis. The net apparent change over 11 years is approximately 0.1 pH units. Considering the difference in sampling and instrumentation, this cannot be considered a significant trend limnologically.

Specific conductance showed a non-linear pattern. Problems with the initial nine years of data make this analysis questionable.

Chloride data indicated the most visually obvious (decreasing) trend with seasonal filtering only improving the trend slightly.

Sulfate has a highly significant increasing trend over the period of record with seasonal filtering not improving this trend.

Analysis of the long-term historical data of Beeton documented statistically significant increases in all parameters. By comparison, data from the Cleveland area in 1978-1979 is comparable to or lower than Beeton's data for 1960, indicating a decline in the rate of increase for most parameters, and an actual decline in concentration for some. The only exception was specific conductance, for which the analysis was uncertain because the proper conversion factor between total dissolved solids and specific conductance is not known at this time. Analysis of historical data from the Cleveland Water Intake Division suggests that the concentration of chloride has declined over the period of time 1968-1979, and that sulfate has increased in the same time. Both trends were reasonably linear, and were highly significant statistically.

Some parameters in the short-term data set showed no significant linear trend (e.g. specific conductance), and others showed trends that were significant but data was decidedly non-linear (e.g., nitrate plus nitrite). In some cases, the trends indicated may be partly a result of laboratory bias (phosphorus forms) or sampling of different water masses (surface vs. bottom, e.g., pH) rather than historical change. These parameters require further study to establish adequate historical trend information.

Decade-long historical trends were often comparable in magnitude to the annual scatter in the data, or even to the difference between surface and bottom water concentrations. Biases between labs or between years within a lab, or differences in values obtained with different analytical methodologies, may be sufficient to mask subtle historical trends, or to create "trends" which reflect the history of analytical methodology and bias rather than reflect the history of the body of water under study. The attempt to recognize subtle historical trends, which may nonetheless be of great interest to the public, requires data of the best quality. Wherever possible, the database should be the work of one lab using one set of methodologies and a carefully designed quality control program to guarantee the comparability of data from day to day, month to month, and year to year. At the very least, frequent participation in "round-robin" exercises (such as that carried out the the International Joint Commission) is necessary by all labs contributing to a historical database. The results of these round-robin studies must be made part of the laboratory quality control program, and used to adjust biases, if compatible data sets are to be generated. These results should also be considered in the historical analysis, since they may suggest biases that were not corrected, and that might not otherwise be apparent.

Finally, the researcher who conducts the historical analysis should seek as much background information as possible related to quality control, and should assume that biases will exist in many data sets. In the matter of historical analysis, scientific skepticism must extend to the data itself.

Cladophora

Prior to the 1950s, the abundance of the filamentous green alga *Cladophora glomerata* (L.) Kutz had not presented significant enough problems in the Great Lakes to attract widespread attention. The earliest comprehensive Lake Erie study was reported by Taft and Kishler (1973) documenting the history of *Cladophora* in the western basin as well as seasonal abundance and biomass development from 1965 through 1971. The study specifically examined *Cladophora* populations in and around the South Bass Island region of the western basin. This study was stimulated more by academic interest than as a result of *Cladophora* being considered a nuisance problem. However, with increased nutrient loading and recreational use of the lakes, *Cladophora* became an ever-growing topic of concern.

In response to renewed ecological awareness in the Great Lakes region and the recognition of *Cladophora* as a potential symptom of pollution-related problems, a workshop was sponsored by the International Joint Commission's Research Advisory Board Standing Committee on Eutrophication in order to bring together scientists most knowledgeable of *Cladophora*. The proceedings from the workshop (*Cladophora* in the Great Lakes, ed. H. Shear and D. Konasewich 1975) reviewed the current knowledge and discussed the future research needs concerning *Cladophora*. The workshop members defined seven specific areas in which further research on *Cladophora* was necessary in order to manage the problem effectively and be able to measure whether or not efforts to control *Cladophora* were to be effective:

1. Growth requirements, physiology and life history.
2. Nutritional factors limiting growth.
3. Measurements of present distribution, biomass and production.
4. Measurement and prediction of responses.
5. Significance of *Cladophora* in the ecology of the lake.
6. Mechanical, biological and chemical control.
7. Socio-economic impact on lake activities and uses.

Each of the seven topics was described in greater detail within the text. In addition, nine general conclusions were stated, several of which were similar to the previously listed research concerns:

1. The limnologists participating in the workshop concluded that Cladophora was the most important manifestation of eutrophication in Lake Ontario and a major symptom in Lakes Erie, Michigan and Huron.

2. Cladophora could be used as a general barometer of lake condition if its distribution, biomass and production could be measured quantitatively.

3. Several important measuring techniques are available but have not yet been broadly tested and used, i.e. remote sensing for distribution and assays of nutritional status of Cladophora.

4. The role of Cladophora in the general ecology of the lake is little known and should be included in a biological mapping of major components of the Great Lakes biota.

5. The objectives for fishery production for each lake should be established as Cladophora is believed to play a major role in determining fish species composition and production.

6. Two basic types of in-lake studies are recommended—a detailed continuing investigation of water chemistry, physical and biological conditions from within a limited growth bed in each lake, and synoptic surveys from a number of stations in each lake to obtain comparative nutritional information, data on associated faunal populations, and accumulation of heavy metals, pesticides and radioactivity.

7. As an alternative to control, the development of economic uses for Cladophora offers the potential of changing a liability to an asset.

8. A measurement of the socio-economic impact of Cladophora on the Great Lakes should be made by specialists in this area of endeavor.

9. To direct future Cladophora studies and coordinate activities of various research and funding agencies, a task group should be established and operate under the aegis of the IJC.

In response to this workshop and subsequent smaller Cladophora workshops, the Great Lakes International Surveillance Plan included a program designed to address some of the issues outlined in the 1975 workshop. Three objectives were declared:

1. To determine the growth rate, density and distribution of Cladophora at selective sites in Lake Erie for trends;

2. To determine the relationship(s) between environmental contaminants and Cladophora growth; and,

3. To establish a systematic database.

In order to ensure complete coverage of Lake Erie, USEPA-GLNPO and Ontario Ministry of the Environment (MOE) jointly cooperated in the program. Sites were selected in each of the 3 basins; studies were conducted in the western basin by CLEAR-OSU, central and eastern basins U.S. shoreline by GLL-SUNY and eastern basin north shore by Ontario MOE. The central basin site was actually positioned at the transition between the central and eastern basin and will be considered an eastern basin site in this report. Simultaneous sampling programs were established over the 1979 field season with similar methodologies employed by each of the groups. Details concerning each of these studies can be found in Volume 8, No. 1, 1982, of the Journal of Great Lakes Research (Millner et al., Lorenz and Herdendorf, and Neil and Jackson). This issue of the journal is devoted exclusively to studies involving the ecology of filamentous algae (primarily Cladophora) in the Great Lakes. For further insight into Cladophora ecology and modeling, the reader should take note of the 7-paper series on Lake Huron presented in the same issue.

Lakewide Distribution. The Lake Erie Cladophora study examined seasonal growth patterns and biomass estimates as they related to physical and chemical (nutrient) factors. In addition, the areal distribution of Cladophora throughout the three basins has been reviewed by Auer and Canale (1981). In this report areas of widespread Cladophora occurrence were delineated (Figure 122).

As an additional segment of the western basin study, an attempt was made to determine the extent to which Cladophora colonized the western basin (Lorenz and Herdendorf 1982). From June 27-29, 1981, data on the nearshore region and shoreline structures including reefs, shoals, and submerged shorelines was obtained throughout the basin (Figure 123). Cladophora standing crop, bio-volume, filament length, maximum depth of growth, photosynthetically active radiation (PAR) profiles, Secchi depth and temperature data were also collected at each site.

Although Cladophora is present "throughout the western basin" its total areal extent is not great. Verber (1957) reported that only 3% of the bottom of the western basin is composed of bedrock some of which occurs at depths not capable of supporting Cladophora due to light limitations. A significant portion of the littoral region along the Michigan, Ohio and Canadian shorelines does not provide suitable substrate to support this alga. The largest extent of bedrock suitable for colonization is located in the Island region where exposed bedrock is found along the shorelines of most of the islands as well as isolated tops of the major reefs.

The western basin survey reported Cladophora on the vast majority of all suitable substrate in the western basin including rocky shorelines, submerged shoreline shelves, reefs and man-made structures such as concrete, stone, wood and metal breakwalls, buoys and ships. Occasionally Cladophora was completely absent from substrates, as was the case on the metal navigational buoys at Middle Ground Shoal and Pelee Point. These buoys were exclusively colonized by Ulothrix zonata. Bangia atropurpurea was also frequently observed in the splash zone throughout the basin. Bangia is a recent invader into the Great Lakes, first reported in Lake Erie in 1969 (Kishler and Taft 1970), and is now established in the splash zone throughout the lake.

The depth to which Cladophora was found on the island shelves and reefs varied with location. Maximum colonization depth was generally greater the further north the site was located, corresponding to greater Secchi transparencies and smaller light extinction coefficients (K). Depth distribution of Cladophora was greatest on the isolated reef areas located offshore.

Standing crop varied from 10-229 g/m^2 dry weight (DW). Middle Ground Shoal standing crop was patchy and concentrated in the cracks of the bedrock, possibly the result of scouring action of sand moving across the shoal. The largest DW standing crop collected was from Kelleys Island (229 g/m^2); this site also had the lowest in percent AFW (ash free weight). The percent AFW was greatest (62-78%) in the areas located in the northwest region of the western basin where algal filaments appeared healthier (a bright green color) and were more firmly attached than filaments found in other areas.

A detailed account of Cladophora distribution is not available for the central basin. Only one station west of Erie, Pennsylvania was sampled near the western boundary of the eastern basin; consequently, no information can be extrapolated for the entire basin. In general, the north shore of the central basin is lined with steep erodable clay bluffs with limited rubble/sand beach areas. This unstable substrate is not suitable for any extensive development of Cladophora. The south shore is somewhat similar in topography although some areas are more advantageous for limited Cladophora development with the most noticeable Cladophora colonization associated with man-made structures such as breakwalls. These structures almost without exception support prolific Cladophora growth.

The eastern basin studies also do not provide information pertaining to the extent of basin-wide Cladophora colonization. In general, the south shore substrate characteristics are similar to those in the central basin in that expanses of colonizable bedrock are unavailable for extensive development of Cladophora beds. In contrast, the north shore does provide a bedrock substrate similar to the western basin island region. In particular, the area from Port Maitland to Fort Erie, Ontario supports extensive Cladophora beds. In addition, Cladophora populations are prevalent throughout the basin wherever the appropriate man-made substrate is available.

Specific Study Sites. The Lake Erie Cladophora studies provided information as to the seasonal growth pattern and biomass accumulations for the specific areas studied. At each of the study sites, a bimodal season pattern of biomass accumulation was observed (Figures 124-126). The magnitude of the bimodal peaks varied with sampling depth and from site to site; however, the general pattern was evident. The maximum standing crop recorded at each of the study areas is presented in Figure 127 and Table 72.

The Walnut Creek, Pennsylvania site, located at the central-eastern basin border, supported the smallest standing crop, with slightly larger standing crops measured at Hamburg, New York and Stony Point, Michigan in 1979 and 1980, and South Bass in 1979. Rathfon Point, Ontario (eastern basin) clearly supported the largest maximum standing crop of 980 g/m^2 DW (Figure 127). In comparison, standing crops reported for Lake Huron at Harbor Beach, Michigan were 200-300 g/m^2 DW range (Canale and Auer 1982), and in Lake Ontario maximum standing crops have reached 1062 g/m^2 DW (Neil 1975).

The western and eastern basins presented somewhat different growth limiting conditions. In the western basin ambient levels of nutrients, in particular phosphorus, are sufficient so that a nutrient limiting condition is not created (Lorenz 1981). Light was determined to be the limiting factor inhibiting more extensive Cladophora development in the western basin. The greatest depth of growth was attained during the spring pulse, from late May to late June. At Stony Point, Cladophora generally did not colonize below 2 m, and at South Bass Island the alga extended to approximately 3 m. Cladophora at other locations in the western basin was observed as deep as 7 m. When the variation in depth of colonization at the different sites was compared with light data it was evident that light attenuation was influencing the extent of vertical growth. Temperature and nutrient availability at the deeper depths (3 m) was not appreciably different than at the shallower depths.

The results from routine monitoring, laboratory experiments, and surveys of the western basin all support the theory that Cladophora in western Lake Erie is light-limited at PAR levels below approximately 50 uE/m^2 sec. The depth at which light attenuates to 50 uE/m^2 sec in the western basin varies from less than 2 m to over 7 m. This agrees with a similar concurrent laboratory study utilizing a Lake Huron isolate of Cladophora which reported the minimum PAR value to be 35 uE/m^2 (Auer 1982). The increase in the turbidity of western Lake Erie over the past century that has contributed to the decline of aquatic vascular plants (Stuckey 1971) may also have decreased the total colonizable substrate available to Cladophora. If in the future the turbidity of the basin decreases in response to decreased sediment loadings and total phosphorus concentrations remain above 50 ug/l in the nearshore regions, the quantity of Cladophora is likely to increase due to a greater vertical distribution.

It is evident that the Cladophora growth along the Canadian shore in the eastern basin presents the greatest problem due both to the quantity of biomass produced and to the extent of public shoreline made undesirable. Three factors were considered to be important on governing the extent of Cladophora development in the eastern basin providing the appropriate substrate is present: nutrients (phosphorus), light (turbidity) and temperature.

At all three eastern basin sites, nutrients (phosphorus) appeared to be the controlling factor of the abundance of Cladophora biomass. Millner et al. (1982) point out that Secchi disk depth generally exceeded station depth; thus, light was not considered a critical factor in the basin. Tissue nutrients were found to be at or below critical levels during the summer months indicating possible near-limiting conditions. At the north shore location an experiment was conducted to test if phosphorus additions into an experimental site would further stimulate growth (Neil and Jackson 1982). Cladophora standing crop did in fact increase in response to the additions of phosphorus, indicating a phosphorus dependent condition. It was concluded that Cladophora biomass could be expected to be reduced if local phosphorus concentrations are reduced.

Temperature seemed to influence Cladophora populations similarly in both basins. The combined effects of light and temperature have been extensively investigated by Graham et al. (1982). In general, Cladophora standing crop continues to increase as the temperature increases to 20°C (July). At this point, the photosynthetic/respiration (P/R) ratio is less than 1 leading to senescense, tissue nutrient decline and subsequent detachment of the filaments results. In the fall as temperature and light intensities decline, the P/R ratio is again greater than 1 and the second peak of the bimodal seasonal development begins to appear.

Nuisance Conditions. Frequently contained in the literature is a series of similar statements describing the serious nuisance effects resulting from Cladophora populations (Surveillance Subcommittee 1981, Shear and Konasewich 1975, and Millner et al. 1982). For example, the Great Lakes International Surveillance Plan states:

(1) The odor and water discoloration caused by windrows of decomposing Cladophora that accumulate on beaches can force the closing of recreational areas.

(2) Floating masses of algae foul the nets of commercial fishermen in Lake Erie.

(3) Tastes and odors in drinking water have also been attributed to decomposing masses of Cladophora.

(4) Indications are that the abundance of Cladophora and other attached algae has increased significantly over the past 50 years.

These statements do not represent the situation in Lake Erie. In fact, the last three do not seem to be based on any factual information; commercial fishermen experience minimal problems as a result of Cladophora; for the most part, water intake systems are generally elevated off the bottom and located approximately 2 km offshore, and consequently, Cladophora would rarely interfere with intakes or cause taste and odor problems; and finally, there is no real documentation that would enable one to state whether there has been a quantitative change in the standing crop of Cladophora over the last 50 years in Lake Erie. Cladophora can and does accumulate along shorelines becoming odiferous as it decomposes; thus, only the first statement has any validity concerning the Lake Erie Cladophora community. The significance of Cladophora on a lake-wide distribution basis is certainly over-exaggerated and primarily presents problems to beaches and shorefrontage in localized areas. The problem of washed-up algae and aquatic plants is common to most every marine coastal beach in North America. The approach taken is to routinely remove the accumulated biomass.

The nuisance problems attributed to Cladophora in the Great Lakes result from an over-abundance of nutrients, in this case primarily phosphorus. This is particularly evident by the extensive standing crops in regions of point sources. The most effective way to reduce the levels of Cladophora to "natural concentrations" is to reduce the loading of phosphorus to the lake as shown by Auer (1982) in Lake Huron. This results in a positive response both in the nearshore and offshore regions. Concerning the original objectives of the Surveillance Plan, two components remain unaddressed. First, little information is available as to the relationship(s) between environmental contaminants such as heavy metal and organic compounds and Cladophora growth. Second, a more complete basin-wide database has to be established in order to adequately evaluate phosphorus control programs. Having data from five select study sites provides only a very limited insight into the Cladophora community of the whole lake.

Fish Communities

Fish communities of Lake Erie and their habitats have undergone significant changes over the past 150 years in response to a series of cultural stresses. These have included intensive, selective commercial exploitation of several fish stocks, increased nutrient loading, siltation due to watershed and shore erosion, invasion or introduction of exotic fish species, and loss of important stream and marsh habitats due to diking, filling, damming, channelization, siltation, and industrial pollution. The history and causes of these changes have been extensively reviewed and discussed, particularly during the last 20 years. Much of the discussion regarding causes is and must remain speculative due to a lack of intensive limnological and fish population data during the times when the most significant changes were occurring and to incomparability of such data as a result of changing techniques in limnological measurement and fish stock assessment.

In general, the cultural stresses listed above resulted in drastic declines or extirpations of several endemic commercially and recreationally abundant valuable fish species and the proliferation of a few exotic or adaptable native species with significantly less commercial or recreational value. Declines of certain species were first noticed as early as the 1880s, and some ultimately ineffective attempts were made to stop or reverse the declines by supplemental stocking and regulation. However, during the 1950s a series of major fish population collapses and extirpations occurred and radically altered the composition of both the Lake Erie fish community and the nature of the fisheries exploiting it. Moreover, the deterioration of water quality in the lake accelerated due to population and industrial expansion after World War II lead to fishery population declines. Nationwide trends of a similar nature attracted increasing public attention and eventually resulted in state and national legislation aimed at maintaining environmental quality and managing natural resources. In Lake Erie, measures to regulate commercial and recreational fisheries and to reduce cultural nutrient loading, siltation, industrial pollution and habitat loss were introduced during the 1960s and 1970s.

The purpose of this section is to provide a current assessment of fish stocks, fish community composition, and fisheries in Lake Erie with respect to their actual or potential responses to improving water quality.

Background on Fish Population Changes. Approximately 138 species of fishes have been recorded from Lake Erie and its tributary waters. At least 40 are or have been of significant commercial, recreational or forage value (Table 73). Nineteen of these species have been of major significance in commercial landings since commercial fishing began in Lake Erie over 150 years ago. Lake Erie supports a greater diversity and higher biomass of fish per unit area than any of the other Great Lakes. This has been attributed to the southernmost position of the lake, its relatively warm, shallow, nutrient-rich waters, and its variety of aquatic habitats (Trautman 1957, 1981; Van Meter and Trautman 1970; Hartman 1973).

Commercial fish production in Lake Erie has been high throughout the history of the fishery, averaging approximately 19 million kg/yr and ranging from approximately 11 million kg/yr to 75 million kg/yr since 1915. Annual commercial fish production in Lake Erie has often surpassed total production in the other four Great Lakes combined and has seldom comprised less than one-third of total Great Lakes production. An extensive and valuable recreational fishery has developed largely since 1949 and continues to expand, competing with the commercial fishing industry for several fish stocks (Regier et al. 1969; Applegate and Van Meter 1970; Hartman 1973; Baldwin et al. 1979).

In spite of the traditionally high level of commercial fish production in Lake Erie, significant qualitative changes in the fish communities of the lake have occurred over the last 150 years as a result of exploitation and environmental changes. The following review of fish population changes and their causes is based largely on the accounts and data of Regier et al. (1969), Applegate and Van Meter (1970), Regier and Hartman (1973), and Baldwin et al. (1979) unless otherwise noted.

The intensive settlement, agriculturalization and urbanization of the Lake Erie basin by European-descended Americans and Canadians began around 1815. Native, pre-settlement fish communities in the lake were characterized by a much greater predominance of coldwater and coolwater species, including lake sturgeon, lake trout, lake whitefish, lake herring, northern pike, muskellunge, yellow perch, walleye, sauger, and blue pike (Table 73). Many native warmwater species, including white bass, suckers, ictalurids, and centrarchids, were also apparently more abundant than at present whereas other warmwater species such as gizzard shad and freshwater drum may have been significantly less abundant (Trautman 1957 and 1977; Hartman 1973; Regier and Hartman 1973).

Regular commercial fishing in Lake Erie began around 1815. By 1930, fishing had become an important industry using seines, drag nets, weirs, trotlines, spears, and hook-and-line. Most fishing was concentrated in nearshore areas along the U.S. shore. Around 1850, large, stationary pound nets were introduced in the western basin and gill nets were introduced in the eastern basin. This gear made offshore, deepwater fishing a feasible enterprise. These efficient harvest techniques, in conjunction with improved preservation methods and transportation systems made fishing more profitable (Regier et al. 1969; Applegate and Van Meter 1970).

A precise description of species and quantities of fish harvested between 1815 and 1870 is not possible due to the sparse catch records kept during those years. Based on available records, muskellunge, northern pike, largemouth and smallmouth bass, lake sturgeon, yellow perch and white bass were among the first species to attain commercial importance, especially in the seine fisheries of bays and rivers. Lake herring, lake whitefish and lake trout became commercially important around the mid-1800s as gill nets and pound nets made offshore harvest of these species more efficient. Lake trout had already declined significantly in abundance by 1870 (Regier et al. 1969; Applegate and Van Meter 1970).

By the early 1870s pound nets, gill nets, fyke nets and trap nets were in use on a large scale in Lake Erie, predominantly in U.S. waters. The Ohio fishery was preeminent during this period. The Canadian pound net fishery, which concentrated on lake herring, began to increase significantly after 1880, marking the beginning of increased activity by the Canadian fishery, which had previously lagged far behind the U.S. (Regier et al. 1969; Applegate and Van Meter 1970).

Improved but still fragmentary catch records between 1870 and 1900 indicated generally stable lakewide harvest. Lake herring and lake whitefish stocks supported an intensive, high-profit commercial fishery, but landings of these species peaked during these years and lower-value "coarse fish" such as sauger, walleye, yellow perch, blue pike, channel catfish and white bass increased in commercial importance. Perceived decreases in abundance of lake whitefish and lake herring led to attempts at governmental regulation, management, artificial propogation and stocking, however, these attempts were complicated by jurisdictional divisions. The only significant loss to the fishery during this period was the lake sturgeon (Regier et al. 1969; Applegate and Van Meter 1970).

Steam, gasoline and diesel-powered fishing vessels replaced sailing vessels on Lake Erie after 1899, and the introduction of the steam gill net lifter increased handling efficiency. The use of pound nets declined after 1920 due to the increasing efficiency and portability of gill nets and trap nets, and pound nets were no longer in significant use after 1936 (Regier et al. 1969; Applegate and Van Meter 1970).

Good commercial fishery statistics were available after 1900. Lakewide fish landings declined steadily during the period 1914-29, due largely to a major decline in abundance of lake herring. The lake herring fishery collapsed around 1925. Commercial harvest of northern pike and muskellunge declined after 1915 (Regier et al. 1969; Applegate and Van Meter 1970).

By 1930, the principal commercial fishing method consisted of gill netting throughout the eastern and central basins and shore seining and trap netting in the western basin. Lakewide commercial fish production leveled off between 1930 and 1950 with no new losses to the fishery, although species already declining continued to do so. However, these declines were offset by increased landings of walleye, blue pike, lake whitefish and white bass. This period marked the end of the high-profit fisheries based on high-value coldwater stocks, but fishing effort remained relatively stable lakewide (Regier et al. 1969; Applegate and Van Meter 1970).

Two major changes in fishing technology occurred in the 1950s. First, by 1952 nylon nets had replaced twine as the material used in manufacturing gill nets. The new nylon gill nets could be fished continuously and were two to three times more efficient than the conventional twine nets. Second, trawling for smelt was introduced in 1958 and became a major portion of the Canadian fishing industry (Regier et al. 1969; Applegate and Van Meter 1970).

In the early 1950s a period of great instability in the fisheries began. Lakewide commercial fish landings increased between 1951 and 1960 due largely to use of nylon gill nets and intensified fishing effort, primarily for smelt, in Canada. Canadian landings superseded U.S. landings as the abundance of the higher-value species (lake whitefish, sauger and blue pike) on which the U.S. depended declined. Landings of whitefish, sauger and blue pike had fluctuated cyclically around relatively stable averages between 1915 and 1950, but these fisheries declined steadily and significantly during the 1950s and had all collapsed by 1960. By the 1960s the composition of commercial fish landings from Lake Erie had changed considerably. Canadian fisheries depended almost entirely on intensive production of yellow perch, walleye and smelt, whereas U.S. fisheries depended largely on yellow perch and walleye as "cash species," with supplemental income derived from lower value species (channel catfish, white bass, carp, suckers and freshwater drum). Although stocks of the latter species were substantial, landings were variable and governed by seasonal demand and marketability (Regier et al. 1969; Applegate and Van Meter 1970).

Effects of Cultural Stress on Fish Populations. Natural and culturally induced environmental changes in Lake Erie have been widely reviewed and analyzed (Arnold 1969; Beeton 1961, 1963, 1965; Carr 1962; Carr and Hiltunen 1965; Davis 1964; Hartman 1973; Trautman 1957; Verduin 1964, 1969). Highlights based largely on Hartman (1973) and Regier and Hartman (1973) of the major environmental changes as they affected the lake's fish populations are as follows.

Regier and Hartman (1973) conceded that short-term and long-term natural stresses such as storm surges, seiches, cyclic water level fluctuations and temperature changes could have marked, even persistent effects on the Lake Erie ecosystem, but they argued that no natural stress during the last 200 years could have had more profound, long-term, direct effects on the lake's fish populations than any one of a series of cultural stresses introduced after 1815. Natural stresses were probably not primary causes of any major, long-term changes in fish populations, although the synergistic effects of natural stresses in conjunction with cultural stresses probably contributed to changes (Regier and Hartman 1973).

The original vegetative cover of the Lake Erie drainage basin consisted of dense upland and swamp forest, interspersed with grasslands, and an extensive marsh system bordering the western end of the lake. Because of the dense vegetative cover, soil erosion was limited and runoff waters entering the lake were generally low in dissolved and suspended solids. Tributary and lake waters were clear, their bottoms largely free of silt, and aquatic vegetation was abundant. Most of the forest and grassland was cleared for agricultural by 1870, and most of the marshes were filled and diked by 1900. Loss of the original vegetative land cover and subsequent increased runoff, poor erosion control and inadequate soil management resulted in increased turbidity and silt deposition in the lake and its tributaries. The extensive loss of wetlands, aquatic vegetation, and clean rock, sand and gravel bottoms constituted a significant loss of spawning, nursery and adult habitats for many fish species, especially salmonids, esocids and percids (Trautman 1957, 1977; Hartman 1973; Regier and Hartman 1973).

After 1815, hundreds of mill dams were constructed on tributaries of Lake Erie and during the present century many larger dams were built for purposes of water supply and flood control. Many tributaries were dredged and channelized for navigation and agricultural drainage. Dikes were constructed around marshes at first to protect adjacent farmland and later to preserve the remaining marshes as waterfowl hunting areas. Dams and dikes contributed to the decline or extirpation of many fish populations by making essential marsh and tributary spawning areas inaccessible, whereas dredging and channelization resulted in increased siltation and habitat loss in many areas still accessible (Trautman 1957, 1977; Hartman 1973; Regier and Hartman 1973).

Accelerated nutrient loading, or cultural eutrophication, became a significant stress on Lake Erie's fish populations over the last 50-60 years. Cultural eutrophication was marked by significant increases in all major ions, including apparent three-fold increases in nitrogen and phosphorus. Nutrient loading has been greatest in the western basin, decreasing eastward through the central and eastern basins. Increased nutrient loading resulted in increased production of phytoplankton and zooplankton, increased biomass and deposition of decaying organic material on the bottom, which subsequently increased sediment oxygen demand (Beeton 1965; Hartman 1973; Regier and Hartman 1973).

The principal effect of cultural eutrophication on fish populations was the gradual restriction of suitable spawning, resting, and feeding habitats. For example, due to oxygen depletion of the colder hypolimnetic central basin waters, the cool and cold water species inhabiting this region during the summer months were forced to find alternative habitats. As a consequence, several detrimental effects on certain species were probable, i.e., decreases in the stocks of sensitive populations, increases in year-class strength variability and increases in population mobility, with all factors rendering the affected fish populations more vulnerable to other stresses such as commercial exploitation.Fish populations in the western and eastern basins were less strongly affected by oxygen depletion because the former is too shallow to thermally stratify for long periods and because the latter is subject to less nutrient loading and deep enough to contain a large dissolved oxygen reserve when thermally stratified. Changes in the composition of benthic invertebrate populations caused by siltation and oxygen stress may also have negatively affected certain fish populations by decreasing the availability of forage items such as mayflies and amphipods (Beeton 1965; Hartman 1973; Regier and Hartman 1973).

The long-term effects on Lake Erie fish populations of toxic pollutants, including persistent biocides, metals, other inorganic and organic compounds delivered to the lake via agricultural runoff or industrial discharge, are poorly understood. Although such pollutants have been detected in fish and their negative human health impacts recognized, long-term impacts on growth, reproduction and mortality to the fish require further research. Regier and Hartman (1973) expected such effects to be small in relation to the other cultural stresses discussed.

Eurasion carp and goldfish were widely introduced for pond culture beginning in the 1870s. Escapes and deliberate introductions into tributaries resulted in the establishment of these species in the lake. The increasingly turbid, nutrient-rich condition of the nearshore regions favored their proliferation. The direct competitive effects of carp and goldfish on native fish populations are not known, although their herbivorous, bottom-rooting habits may have had some negative effects on coastal marshes (Trautman 1957; Hartman 1973).

The sea lamprey, first reported in Lake Erie in 1921, invaded the lake via the Welland Canal. Lamprey never became as numerous in Lake Erie as in the upper Great Lakes and have apparently had little effect on native fish populations. The relative scarcity of the lamprey in Lake Erie has been attributed to a lack of suitable spawning tributaries and preferred salmonid prey. The alewife, another marine invader entering via the Welland Canal, was first reported in the lake in 1931. It also never became as numerous in Lake Erie as in the upper Great Lakes and has had apparently little effect on native fish populations. The failure of this species to become well established in Lake Erie has been attributed to an abundance of predators and possible susceptibility to coldwater stress (Dymond 1932; Van Meter and Trautman 1970; Hartman 1973).

Various non-native salmonids have been stocked in Lake Erie since 1870, but no significant naturally reproducing populations became established. At present only steelhead, coho and chinook salmon are stocked annually and exist in significant numbers. The effects of these three species on native fish populations are poorly understood although they are known to prey extensively on the abundant emerald shiners and rainbow smelt (Hartman 1973; Parsons 1973).

Rainbow smelt were first reported in Lake Erie during the 1930s, having evidently originated from a single introduction in the Lake Michigan basin in 1912, and have become increasingly abundant in the central and eastern basins since the 1950s. Their abundance has been attributed to greatly reduced competitive and predatory pressure during the 1940s and 1950s (Van Oosten 1936; Van Meter and Trautman 1970; Regier and Hartman 1973). Regier et al. (1969) hypothesized that predatory stress exerted by abundant smelt on young native salmonids and percids was a significant factor in the decline or extirpation of these populations.

White perch were first reported in Lake Erie in 1953, having apparently invaded the lake via the Welland Canal. This species did not become widely established in the lake until the late 1970s (Busch et al. 1977; Barnes and Reutter 1981; Isbell 1981). The effects of increasing populations of white perch on native fish populations have yet to be assessed.

The combined effects of exploitation and environmental changes in Lake Erie resulted in major changes in several commercial and recreational fish populations. In addition, many fish populations which have not been exploited have also directly or indirectly responded to these factors and have exhibited long-term increases or decreases. Changes in commercial fish populations have been largely documented by continuous monitoring of commercial landings since 1915 and have been summarized by Trautman (1957, 1981), Regier et al. (1969), Applegate and Van Meter (1970), Hartman (1973), Regier and Hartman (1973), and Baldwin et al. (1979). Reliable, quantitative data on changes in populations of other species, including some of significant recreational importance, are largely lacking. Documentation of these changes is primarily found in the results of qualitative or semi-qualitative ichthyological surveys, most of which have been summarized by Trautman (1957, 1977, 1981) and Van Meter and Trautman (1970). Table 74 summarizes the changes in individual populations based on these sources.

A number of unexploited fish species in Lake Erie have also exhibited declines in abundance, largely in response to long-term habitat losses and environmental changes (Table 73). Among the species suffering drastic declines or extirpation were wetland-dependent species such as spotted gar, pugnose shiner, pugnose minnow, blackchin shiner, blacknose shiner, lake chubsucker, tadpole madtom, banded killifish and Iowa darter. Tributary spawners, deep coldwater spawners and generally silt-intolerant species such as longjaw cisco, mooneye, silver chub, longnose dace, eastern sand darter, channel darter, river darter, spoonhead sculpin and fourhorn sculpin were also subject to declines or extirpations (Trautman 1957, 1981; Van Meter and Trautman 1970).

Fish Stock Assessment. Fish stock assessment is "a collective term connoting a group of serially related nonexclusive functions - observation, description, analysis and prediction - focused specifically on the integrity, character, measurement, performance and projection of fish resources" (Kutkuhn 1979). In practice, fish stock assessment can use a full range of fish and fishery data inputs, parameter estimates, functional relationships and analytical outputs. The principal fish stock assessment programs which have or are currently operating in Lake Erie follow. These are the principal sources of long-term, relatively uniform and consistent data concerning fish population abundance on which any analysis of long-term trends in Lake Erie fish populations must be based.

Annual lakewide landing data collected in a roughly uniform manner was not available until around 1914 (Applegate and Van Meter 1970). By the 1930s, a uniform system for collection and analysis of commercial fishery statistics was in use throughout the U.S and Canadian waters of Lake Erie. The basis of this system was the division of the lake into statistical districts and the submission of monthly catch reports by commercial fishermen listing types and amount of gear used, time fished, locations fished and catch of each species (Hile 1962). With certain statistical refinements, this system is still in use today. For heavily exploited fish stocks commercial production is considered a reliable indicator of abundance. Commercial landing statistics are less useful in determining abundance of fish with low market values because the landed catch of such species is related more to dockside price and seasonal marketability rather than the size of the stock available for exploitation.

During drastic fishery changes of the 1950s, the need for more predictive capability in managing the fisheries than could be achieved by monitoring commercial landings became apparent. Consequently, fishery biologists in the U.S. and Canada began sampling both landed and throwaway commercial catches at docksides and on vessels. Data generated included sample age, size, and sex distribution, food habitats, maturity, and fecundity, of imporant commercial and recreational species. Analyses of these data increased the ability of fishery management agencies to estimate future year-class strengths, recruitment, growth rates, mortality rates, and stock size of important species. This provided the information necessary to maintain or increase exploitable stocks by imposing size and catch limits or by regulating the types of gear used or areas fished.

Index sampling of fish populations was a logical and necessary addition to the collection and analysis of commercial fishery statistics. Index sampling in Lake Erie consists of long-term collections by state, provincial or federal fishery biologists at selected sites and times of year using comparable effort and techniques from year-to-year. Index sampling is similar to biological sampling of commercial catches in the types of data acquired and kinds of analyses possible. However, index sampling gear, sites and timing can be selected to maximize catches of target species and age groups, particularly the low-value species, young-of-the-year, and small forage fishes often not included in commercial catches. This program was necessary to maintain uninterrupted time-series data, and to sample populations during critical life-stages not represented in commercial catches. Two types of long-term index sampling programs have been in operation in Lake Erie during the last 20 years.

Stock-specific index sampling is oriented toward predicting future performance on a stock-wide basis important recreational, commercial, or forage species. The purpose of the program is to conserve the stocks by regulating the size and characteristics of the catch over a period of time and evaluating the effectiveness of past and current management strategies. Techniques primarily involve trawling, fyke netting and gill netting at selected index stations with data collected on relative abundance of young-of-the-year fishes, age, size, and sex distribution, food habits, maturity and fecundity. Target species are primarily the heavily exploited yellow perch, walleye, white bass, channel catfish and smallmouth bass, but the relative abundance of all lower-value commercial, recreational and forage species are generally recorded. Index sampling has been largely standardized and integrated over jurisdictional areas via the Great Lakes Fishery Commission so that stocks ranging over several such areas can be managed as units.

Site-specific index sampling on a long-term basis has generally been related to environmental impact assessment, specifically impacts of thermal discharges, impingement and entrainment of adult and larval fishes by water intakes. Most Lake Erie electrical power companies with generating facilities in the U.S. have conducted programs. In general, such surveys employ a variety of sampling methods and the types of data collected include seasonal abundance and distribution of fish species at control and test sites in the vicinity of the plant, size distribution, food habits and numbers of fish impinged or entrained by the intake. Although these studies are not oriented toward stock-wide assessment as previously discussed, they have provided useful, long-term corollary data which can be of some value in analyzing fish populations in general (Reutter et al. 1980; Hamley 1981).

During the 1960s and 1970s exploitation of certain Lake Erie fish populations, notably walleye, yellow perch, freshwater drum, smallmouth bass, white bass and channel catfish, by recreational fisheries increased significantly and approached the intensity of commercial exploitation. It thus became necessary for fish stock assessment programs to record recreational extractions. Sporadic creel censuses, or collection and analysis of recreational fishing statistics, were conducted during the 1950s and 1960s. Regular, annual creel censuses consist of boat counts at access points, direct contact interviews with boat and shore anglers, biological sampling of catches, and submission of monthly reports by licensed charter boat operators and sport fish processors. Quantitative information provided by these methods includes angler harvest by species, success rates, amount and distribution of angling effort, and biological characteristics (age and size distribution) of catches.

Current Status and Potential Population Changes. The potential impacts on fish populations from improving Great Lakes water quality as a result of restoration and enhancement programs instituted since 1970 were reviewed and discussed by Sullivan et al. (1981). The most significant impact of these in terms of effects on fish communities are phosphorus (and dissolved oxygen regimes) and sediment loads.

Nutrient loading from point sources is expected to decrease significantly in the Great Lakes in the next 20 years primarily as a result of treatment of municipal effluents (Sullivan et al. 1981). Little change in total phosphorus loading from non-point sources is anticipated. Phosphorus loading in Lake Erie decreased from approximately 24,000 metric tons in 1970 to 15,000 metric tons in 1980 (Sullivan et al. 1981).

Phosphorus load reductions could result in decreased plankton production, followed by decreased production of planktivorous species such as alewife, gizzard shad and rainbow smelt and of salmonid and percid predators. On the other hand, reductions in phytoplankton production could improve water transparency and favor the growth of submersed macrophytes which could provide valuable cover and spawning habitat to many fish species (Sullivan et al. 1981). The most obvious benefit to fish communities of phosphorus load reductions would be decreased organic decomposition and increased availability of dissolved oxygen. In oxygen-stressed areas like the central basin of Lake Erie, this could be of crucial importance. Availability of summer habitat for coolwater and coldwater species like lake herring, lake whitefish, lake trout, rainbow smelt, alewife, yellow perch and walleye could be increased (Sullivan et al. 1981).

In general, nutrient loading is directly related to primary and secondary production, and ultimately fish production (Ryder 1981). Theoretically, phosphorus load reductions to the Great Lakes could result in decreased fish production and decreased yield to fisheries (Sullivan et al. 1981). Based on a model by Lee and Jones (1979), if planned reductions in phosphorus loading occur between 1990 and 2000, fish yield could decrease 5, 10, and 25 percent in the eastern, central and western basins of Lake Erie, respectively; however, this is highly speculative.

Such models cannot account for secondary, selective effects of nutrient load increases or reductions on individual species, populations or assemblages in complex fish communities such as occur in the Great Lakes. In eutrophic Lake Erie, greatly increased cultural nutrient loading was accompanied by increased plankton biomass and deterioration of dissolved oxygen regimes. This resulted, in combination with over-exploitation, in yield declines of the most desirable and profitable coolwater and coldwater species, notably lake herring, lake whitefish, lake trout and blue pike. Although the total biomass of fish in Lake Erie may have increased, this is more likely reflected in increased stocks of tolerant, warmwater species such as gizzard shad, carp and freshwater drum. Anticipated nutrient load reductions may indeed result in decreased fish biomass, particularly these tolerant, warmwater species. Such decreases may be balanced by increases in more valuable coolwater and coldwater species such as lake whitefish, lake trout, rainbow smelt, walleye and yellow perch. Precise effects are difficult to predict. In the oligotrophic upper Great Lakes, where cultural nutrient loading has been relatively light and has had minimal impact on offshore hypolimnetic oxygen regimes, it has been speculated that nutrient load reductions might result in some decrease in salmonid production (Sullivan et al. 1981).

Reductions in sediment loading could have beneficial effects on fish communities and fisheries throughout the Great Lakes, particularly in harbors and embayments. Loading reductions could result in restoration of clean sand, gravel and rock bottoms needed as spawning substrates by many species, notably salmonids and percids. Decreased amounts of suspended sediments could result in greater water clarity, thereby favoring the growth of submersed macrophytes. This could benefit a number of species using submersed macrophyte beds as spawning and nursery areas. A negative side effect of sediment loading reduction might be an increase in many toxic or persistent contaminants in the water column, since many such contaminants tend to sorb to particulate matter and be deposited on the bottom. A decrease of particulates might increase the amount of time toxics remain in the water column thereby increasing exposure to fishes. On the other hand, sorption on particulate matter is the transport mechanism by which many such contaminants enter a lake, so that decreased sediment loading might be accompanied by decreased contaminant loading (Sullivan et al. 1981).

The elimination of contaminants from industrial discharges and agricultural runoff will certainly have beneficial local effects, particularly in harbors, tributaries and embayments, by reducing fish mortality and restoring habitat quality. The lakewide effects of reductions in dissolved solids and persistent contaminants are difficult to assess because the effects of these substances on fish growth, health and survival are poorly understood. In general, effects of contaminant reductions on fish communities will probably be much less significant than the effects of reductions in nutrient loading and sediment input.

Following the series of major fish population declines, extirpations and community changes in Lake Erie during the 1950s, a period of relative stability ensued during the 1960s and 1970s. No major losses to the fishery occurred. Stock sizes, distributions and commercial landings exhibited no apparent fluctuations or trends on a scale comparable with previous years. Deterioration of water quality in the lake during the 1950s and 1960s was severe, and major water quality restoration and enhancement efforts began in the 1970s. To assess the actual effects of the resulting water quality improvements on fish populations, one must analyze the status and trends in those populations during the period 1970-1980 against the background of their status and trends during the period 1960-1970.

The following results are based on data from the Great Lakes Fishery Commission (1971, 1973, 1974, 1975, 1976, 1978, 1980, 1981) unless otherwise noted.

Lakewide commercial landings of all species from Lake Erie during the period 1970-1980 averaged approximately 20 million kg/yr and ranged from 16 million kg in 1976 to 23 million kg in 1980. This average was consistent with the long-term average of 19 million kg/yr (since 1915), and the variability was quite low compared to the long-term range of 11-75 million kg/yr (since 1915). The estimated average weights of major species during the period were: rainbow smelt (8 million kg/yr), yellow perch (6 million kg/yr), white bass (1.5 million kg/yr), carp (1 million kg/yr), freshwater drum (0.5 million kg/yr), gizzard shad (0.4 million kg/yr), walleye (0.2 million kg/yr) and channel catfish (0.2 million kg/yr). No other species had mean annual lakewide landings that exceeded 0.2 million kg/yr (Baldwin et al. 1979; Great Lakes Fishery Commission 1980, 1981).

Recreational fishing pressure during the period 1970-1980 was concentrated on walleye, yellow perch, channel catfish, white bass, freshwater drum and smallmouth bass. Recreational fishery statistics were not available on a regular basis until 1975 so a thorough long-term analysis of recreational harvest trends is not possible. During 1980 in Ohio waters alone approximately 3.5 million kg of fish were harvested by recreational fishermen. This comprised approximately 16 percent of the lakewide commercial harvest that year and 109 percent of the Ohio commercial harvest, illustrating the current significance of recreational extractions as a factor affecting the lake's fish populations.

After a general decline during the 1950s, walleye stocks remained relatively low through the 1960s. In 1970, Ontario, Ohio and Michigan closed the commercial walleye fishery in the western basin because high concentrations of mercury were detected in walleyes. This moratorium remained in effect through 1975. Ohio and Michigan subsequently banned commercial walleye fishing but it continued in Ontario, Pennsylvania and New York waters. A series of consistently strong year classes occurred almost every year after 1970. Moreover, during the moratorium an international catch quota management plan under the auspices of the Great Lakes Fishery Commission was developed for western basin walleye stocks (Hartman 1980). By 1975, walleye stocks were thought to be at their highest level since the mid-1950s and approaching the carrying capacity of the basin (Figure 128). There also appeared to be a significant expansion of western basin populations into the central basin.

Stocks and commercial landing of yellow perch were high during the 1950s and 1960s. Between 1970 and 1974 a series of poor hatches and weak year-classes occurred. This resulted in drastically declining stocks reflecting in reduced commercial and recreational landings from 1971 to 1976. Michigan, Ohio and Ontario, under the auspices of the Great Lakes Fishery Commission, established a Yellow Perch Technical Committee to develop information required for increasing brood stock size via minimum size limits and catch quotas (Hartman 1980). Tactics for accomplishing this are still under discussion. Good to excellent hatches and year-classes in 1975, 1977 and 1979 resulted in a reversal of the decline. By 1980, yellow perch stocks had increased to near 1971 levels but were still considered dangerously low (Figure 129).

Rainbow smelt stocks and commercial landings in Lake Erie increased steadily during the 1950s and remained relatively stable through the 1960s and early 1970s (Figure 129). There has been evidence of short-term stock size variability due to variable year-class strengths and mass adult mortality. Potential causes of this mortality are spawning stress, oxygen stress in the central basin, the widespread sporidian parasite Gluea hertwigi, or a combination of the three. Nevertheless, long-term smelt production has remained high and commercial landings increased substantially after 1975. This increase was attributed to a shift in Canadian summer fishing pressure from the depleted yellow perch stocks to smelt due to increasing Japanese market demand (Baldwin et al. 1979).

Both lake sturgeon and muskellunge were severely depleted by over-exploitation and habitat loss to the point of near-extirpation by the 1950s (Hartman 1973). Both species, as indicated by their occasional presence in commercial and index sampling catches, are still present in the lake in limited numbers and there is no indication of a significant change in their status since 1960.

Northern pike landings, after a significant decline from over one million kg/yr in 1914, averaged 28,000 kg/yr during the period 1920-1956. In 1957, commercial fishing for pike was banned in Ohio and Michigan waters. Subsequent landings, predominantly Canadian, averaged only 900 kg/yr until 1973, after which they steadily increased through 1980, averaging approximately 11,000 kg/yr (Baldwin et al. 1979; Great Lakes Fishery Commission 1980, 1981).

An effort to re-establish sauger was made by the Ohio Department of Natural Resources. Fry and fingerlings were stocked in upper Sandusky Bay in 1974, 1975 and

1976. Survival was good and growth excellent, with successful natural reproduction documented. Future plantings were proposed, but the natural expansion of the stock and its interactions with walleye are not certain (Rawson and Scholl 1978).

The principal native coldwater species of Lake Erie, lake trout, lake herring, lake whitefish and burbot, have all been commercially extinct in the lake since the 1950s (Hartman 1973). The latter three, as evidenced by their occasional occurrence in commercial landings and index sampling catches, are still present in limited numbers, but there is no evidence of significant increases in stock sizes. Commercial landings of lake whitefish have increased from an average of approximately 750 kg/yr during 1970-1976 to an average of approximately 2,000 kg/yr during 1977-1980. The recent short-term increase in landings cannot be considered highly significant, and it is not certain that it indicates increased stock size.

Lake trout restoration efforts began by stocking in Pennsylvania waters in 1974. Since 1978 the New York State Department of Environmental Conservation and the U.S. Fish and Wildlife Service have cooperated annually in an effort to re-establish a viable population by stocking in the eastern basin. Although it is too early to evaluate the success of the program, survival has been good and growth excellent.

Stocks and commercial landings of the principal commercial and recreational warmwater species in Lake Erie, namely gizzard shad, carp, suckers, channel catfish, bullheads, white bass and freshwater drum, appeared to remain relatively stable throughout the 1960s and 1970s (Figure 130). Except for channel catfish, none of these species exhibited signs of over-exploitation or response to environmental stress. Commercial landings of channel catfish declined steadily from 1960 to 1980 and an apparent decline in stocks was documented. The cause of this decline was thought to be poor year-class strength and over-exploitation of younger, mature females. Length limits on commercially caught catfish in Ohio waters were increased to protect this segment of the stock during the late 1970s.

Although cyclic fluctuations in individual populations occurred, abundance of principal Lake Erie forage species, including spottail shiner, emerald shiner, trout-perch, and young-of-the-year alewife and gizzard shad, generally remained stable throughout the period 1960-1980. By 1980, an apparent general decline in all these populations was noted in index sampling catches and attributed to an over-abundance of predators, primarily walleye. The U.S. Fish and Wildlife Service in 1979 began a study of forage abundance and predator-prey relationships in Lake Erie (Great Lakes Fishery Commission 1981).

Pink salmon (Oncorhynchus gorbuscha) were first reported in both U.S. and Canadian waters of Lake Erie in 1979. This Pacific species was first introduced into Lake Superior in 1956 and has now extended its range throughout the Great Lakes. In the upper Great Lakes it reproduces naturally and has established self-sustaining populations. Successful reproduction in Lake Erie has not yet been documented (Emery 1981).

Although the sea lamprey and white perch invaded Lake Erie in the 1920s and 1950s, respectively, significant changes in the status of each occurred in the 1970s. Several U.S. and Canadian tributaries were classed as "low producers" of lamprey ammocoetes, with Big Creek in Ontario considered the major source of lamprey recruitment to the lake. Surveys documented significantly increased production of ammocoetes in Conneaut Creek, Ohio, during 1977, followed by increased spawning runs and production in Big Creek and Young Creek, Ontario, and Cattaraugus Creek, New York, during 1978-1980. These increases were attributed to improving water quality in the streams (Great Lakes Fishery Commission 1978, 1980, 1981).

Abundance and distribution of the white perch increased suddenly and dramatically in Lake Erie during the late 1970s, particularly in the western basin. This species has now become commercially and recreationally significant. The cause of the sudden population expansion and its potential impact on other fish populations remains unclear and is currently being investigated (Schaeffer 1981).

Fish Population Response to Improving Water Quality. Although changes in status have been documented for several Lake Erie fish populations during the period 1970-1980, it is difficult to specifically relate these changes to documented improvements in water quality during the same period. First, as pointed out by Kutkuhn (1979), "analytical and assessment capabilities have not yet advanced to the point where the relative contribution of pollution abatement to the recovery and improvement of Great Lakes fishery resources can be quantitatively (and reliably) discriminated." In Lake Erie other factors such as tighter regulation of fisheries, more effective and comprehensive fish management programs, artifical replenishment of stocks, regulation of fish losses due to impingement and entrainment at large volume water intakes, and increasingly closer evaluation and modification of habitat-altering construction activities have all probably contributed to the recovery and expansion of certain populations.

Second, Lake Erie fish populations for which an extensive amount of biological data is available are those economically important populations which are most intensively exploited and managed. The relative contribution of improving water quality to the recovery or expansion of such species as walleye, yellow perch and rainbow smelt is difficult to segregate from the contributions of management, regulatory and habitat protection programs. Populations of lake sturgeon, lake herring, lake whitefish, northern pike, muskellunge and burbot suffered major historical declines in abundance and have remained at low levels of abundance due in part to water quality deterioration. These species are not intensively exploited or managed at present and any recovery from depleted status might be construed as due to improving water quality. However, because these potential indicator species are of relatively minor economic importance at present, they are not intensively monitored in stock assessment programs. The biological data necessary to detect and evaluate any recovery is not available.

Third, the life cycles of the majority of economically important Lake Erie fish species currently monitored range from five to ten years. Important indicator species like lake sturgeon and lake trout live as long as 30 years. Even assuming, quite liberally, that significant water quality improvements began in the mid-1970s, the ensuing five years are scarcely an adequate time base for analyses of trends in stocks in which the majority of individuals have not completed a single life cycle. A longer time, on the order of 10-20 years, is necessary to make such analyses.

Four recent cases of fish population recovery and expansion may be related to improving water quality in Lake Erie. Of these, increased production and expansion of sea lamprey populations in certain tributaries is the only sufficiently documented case in which improved water quality is probably a major cause. The expansion of western basin walleye stocks into the central basin is often cited as an indication of improving dissolved oxygen regimes. There is no documentation of expansion into the hypolimnetic region, and it appears to be confined to the nearshore epilimnetic area where oxygen depletion has not been a problem. The expansion is more likely due to population pressure. However, reduction of the degree and extent of dissolved oxygen depletion in the central basin may be important in the restoration of a large endemic walleye population in the basin. Finally, commercial landings of lake whitefish and northern pike have increased markedly in the last several years. However, sufficient data is not available to determine whether these increases are due to expanding stocks or to increased availability and fishing pressure in certain areas. For instance, increased fishing pressure on smelt in the central basin may have resulted in greater incidental catches of whitefish, which are probably sympatric with smelt during all or part of the year.

In general, improving water quality in Lake Erie might result in a shift of trophic status toward improved trophic status. It can be conjectured that in the long-term this would result in the re-emergence of a fish community approximating the composition of the original pre-settlement community. While individual populations of coolwater and coldwater species might indeed expand, it is doubtful that the pre-settlement community can be re-established. Certain native species have been irrecoverably extirpated. If habitat alterations such as dammed and channelized tributaries and diked marshes persist, improving water quality alone will not result in major recoveries of certain tributary and marsh-spawning stocks. Large populations of exotic species such as rainbow smelt, carp and white perch have occupied niches which may have once been occupied by depleted native stocks. For instance, to what extent the large smelt populations will affect the recovery of lake herring or lake whitefish, which occupied similar niches, is difficult to predict. Predatory interactions between populations of exotic species and depleted native species may affect recovery of the latter. Smelt predation on young-of-the-year walleye and blue pike has already been hypothesized as a factor in the decline of these two native species (Regier et al. 1969). Finally, commercial and recreational extractions and management programs will continue to affect the fish community as a whole. To a large extent, the structure of Lake Erie's fish community in the future will depend on a public perception of what structure would be most economically advantageous.

Fish Research

Larval Fish Entrainment. Although not part of the intensive program, a brief summary of a study designed to examine the distribution of larval fish and the effect of power plant entrainment on larval fishes in western and central Lake Erie (Cooper et al. 1981) is considered to be appropriate. By examining larval fish distributions, considerable insight can be gained as to potential effects of construction, industrial water use and new sources of pollution on fish populations. Consideration of the impacts upon major spawning and nursery areas when locating new industry and dredging operations can only benefit fish populations.

Icthyoplankton samples were collected at ten transects (three stations perpendicular to the shoreline) along the Michigan and Ohio shorelines of the Western basin in 1977 and at nine transects along the Ohio shoreline of the central basin in 1978. Additional samples were collected in 1978 immediately adjacent to six power plant intake structures. Figure 131 gives station locations for the western and central basin studies. Samples were collected every ten days beginning in May and ending in mid-August. All samples were collected during the period from one hour after sundown to one hour before sunrise using a 75 cm diameter 550 micron oceanographic plankton net with an attached calibrated flow meter. The net was towed obliquely through the water column behind a small boat at a constant speed between four and five knots for four minutes. Each larval fish was identified to the lowest taxon possible and its developmental stage, as described by Hubbs (1943), was noted. Several species which are morphologically similar during their early development could not be efficiently separated. Gizzard shad (*Dorsoma cepedianum*) and alewife (*Alosa pseudoharengus*) were grouped together as gizzard shad. Carp (*Cyprinus carpio*), goldfish (*Carassius auratus*) and their hybrids were similarly grouped and reported as carp. White bass (*Morone chrysops*) and white perch (*Morone americana*) were reported as white bass. Black crappies (*Pomoxis nigromaculatus*) and white crappies (*Pomoxis annulius*) were reported as crappies, *Pomoxis* spp., and all sunfish specimens were reported as sunfish, *Lepomis* spp. References found useful in the identification procedures included: Fish (1932), Norden (1961a), Mansuiti and Hardy (1967), Nelson (1968) and Nelson and Cole (1975).

The number of ichthyoplankton captured in each sample was converted to larvae per 100 m^3. Four replicate samples at each station were then averaged to give a mean station larvae concentration. Entrainment estimates for each power plant were calculated by multiplying the average larvae concentration at the station closest to the power plant intake by the average pumping rate for that plant per day.

Distribution. Twenty taxa of larval fishes were collected in the nearshore of the western basin in 1977. Sixteen species were identified, representing ten families and comprising 99.90% of the catch. Ten species, gizzard shad, yellow perch (Perca flavescens), emerald shiners (Notropis antherinoides), white bass, carp, freshwater drum (Aplodinotus grunniens), log perch (Percina caprodes), walleye (Stizostedion vitreum vitreum), rainbow smelt (Osmerus mordax), and spottail shiners (Notropis hudsonis) were captured in numbers great enough to be considered abundant (i.e., mean density >.1/100 m^3). Four species, gizzard shad, yellow perch, emerald shiners and white bass made up over 97% of the catch. Gizzard shad alone accounted for 83% of the total catch with the remaining ten taxa represented by a few or often a single specimen. Table 75 lists the average density for each taxon for the entire study area.

In addition, larval whitefish and sauger, although rare, were captured. Both whitefish and sauger were abundant and commercially fished prior to the 1950s; however, populations of these two species have been reduced consequently they were rarely captured. Subsequently, stocking programs have been initiated to re-establish the native sauger population; thus, the capture of larval sauger indicates these efforts may have been successful. The capture of whitefish larvae indicates a small population of whitefish still uses spawning sites in the western basin.

Of the twenty taxa collected in the western basin, yellow perch, white bass and walleye (henceforth referred to as "valuable species") have the highest commercial and sport interest. A detailed description of the spatial and temporal distributions of these "valuable species" will follow.

Yellow perch, the second most abundant larval species captured in the western basin, had a basin-wide mean density of 21.31 larvae per 100 m^3 in 1977. Larvae were first captured on April 20 and were collected during every sampling effort thereafter, reaching a maximum density of 87 per 100 m^3 on May 2. Figure 132 shows the temporal distribution of yellow perch larvae in the western basin in 1977 and Figure 133 displays the yearly mean yellow perch density at each station.

Friedman's rank sum test (Hollander and Wolfe 1973) was used to determine differences between inshore and offshore densities and differences between transects. However, no significant differences were found. The only significant differences occurred ($\alpha = .05$) between the transects where the densities were highest, transects M2 and OH3, and transects M5 and M3 where the densities were lowest. Transects M2 and OH3 accounted for 31 and 23 percent of the total yellow perch catch, respectively. The maximum density of yellow perch larvae sampled was 665 larvae per 100 m^3 at station M2/1 on May 1.

The fourth most abundant species captured in the western basin in 1977, white bass, had a basin-wide mean density of 7.85 larvae per 100 m^3. Figure 134 displays mean white bass densities for each sampling date. White bass were first captured on May 22 and were collected during every sampling effort thereafter with maximum densities reaching 29.5 larvae per 100 m^3 on June 13. Figure 135 shows the mean density of white bass larvae captured at each station for the entire study period. Significantly more white bass larvae were captured in Maumee Bay than along the Michigan or Ohio shorelines. Friedman's rank sum test ($\alpha = .05$) indicated the lowest densities of white bass larvae were captured along transects OH3 and M5 while no significant differences were detected between inshore and offshore concentrations ($\alpha = .05$). The maximum density of white bass sampled was 283.3 larvae per 100 m^3 on June 4 at station MB1/1.

With a basin-wide mean density of 0.99 larvae per 100 m^3, walleye were the ninth most abundant larval species captured in the western basin. Larval walleye were the first larval species captured in this study, first collected on April 20, and were seen only during the next three collection periods (Figure 136). Samples collected indicated larval densities were highest on May 1 with an average basin density of 4.6 larvae per 100 m^3. Figure 137 displays the spatial distribution of walleye larvae in the study area. The Kruskal-Wallis test indicated ($\alpha = .05$) that more larval walleye were captured along the Ohio shoreline than in Maumee Bay or along the Michigan shoreline. The highest densities of walleye larvae were captured along transects OH3 (43% of the total walleye catch) and OH2 (32% of the total catch) with the maximum density of 38 per 100 m^3 captured at station OH3/1 on May 2. The lowest densities were found along transects M3 and M5. The walleye larvae, however, were almost exclusively found along the Ohio shoreline, particularly in the Locust Point area (Davis-Besse Power Plant). This area along the shoreline has many offshore shallow rocky shoals ideal for walleye spawning habitat.

The majority of white bass captured in the western basin were probably spawned over sandy dredge spoil islands on both sides of the Toledo navigation channel or near the Ottawa River in North Maumee Bay. The high yellow perch densities probably were spawned near the shallow sandy shoreline along Woodtick peninsula. Densities of yellow perch larvae were higher off Otter Creek, Michigan (transect M2) than anywhere else in the study area.

Twenty-eight taxa of larval fishes were collected in the nearshore zone of the central basin in 1978. Twenty-two species were identified representing fourteen families comprising 98.98% of the total catch (Table 76). Nine species, emerald shiner, gizzard shad, spottail shiner, freshwater drum, rainbow smelt, carp, yellow perch, trout perch (Percopsis omiscomaycus) and log perch were captured in numbers great enough to be considered abundant (i.e., mean density >.10 per 100 m^3). Johnny darters (Etheostoma nigrum) and mottled sculpins (Cottus bairdi) had average mean densities of .84 and .50 larvae per 100 m^3 respectively, but since the capture was limited to a few stations these species were not considered to be abundant in the central basin in 1978. Table 76 lists the mean densities for the entire sampling period and the percentage of the total catch represented by each taxon for the central basin as a whole.

The bulk of the catch was made up of Cyprinidae with emerald and spottail shiners contributing 32% and 16% of the total catch. Species of commercial and/or sport interest captured were rainbow smelt, carp, white bass, yellow perch, sauger and walleye. The capture of walleye and sauger larvae was limited to only a few specimens at a small number of locations. Only yellow perch and rainbow smelt will be discussed since these two taxa represent the major portion of the commercial/sport/ valued species.

Yellow perch, the seventh most abundant species captured in the central basin, had a mean basin-wide density of 1.25 larvae per 100 m^3 and were first captured on May 11 and subsequently on every sampling effort thereafter. Figure 138 shows the temporal distribution of yellow perch larvae and Figure 139 represents the spatial distribution of yellow perch larvae in the central basin study area. Friedman's rank sum test indicated significantly more larvae were captured at stations immediately adjacent to the shoreline (77 percent) than at either the intermediate or offshore stations. Ohio transects 8, 9 and 10 accounted for 59% of the total yellow perch larvae captured. Collections indicated yellow perch larvae densities were highest on June 19 (100 larvae per 100 m^3) at station OH9/1 and had a mean density of 6.2 larvae per 100 m^3.

Yellow perch larvae were found to be concentrated in the eastern third of the study area. This area has very limited quantities of clean sand and gravel and even less aquatic vegetation (requirements for yellow perch spawning habitat). Yellow perch therefore may be using harbor breakwalls and sand accumulated on the leeward side of these structures as spawning habitat.

Rainbow smelt were the fifth most abundant larval species captured, with a mean basin density of 3.4 larvae per 100 m^3. Smelt larvae were first captured on May 20 and during every sampling effort thereafter. Samples collected indicated smelt densities were highest on July 5 with an average density of 14.6 larvae per 100 m^3. Figure 140 graphically represents smelt densities throughout the sampling period. Seventy-two percent of all smelt larvae were captured at the stations farthest from the shoreline. The majority of smelt were captured west of Cleveland with 68.3% of the catch coming from transects Ohio 1-4. Maximum density of smelt larvae was 100.1 larvae per 100 m^3 on July 5. Figure 141 is the representation of mean smelt densities at each station. Past studies indicate that no rainbow smelt spawning activity had been reported west of Cleveland. Historically it has been believed that any smelt larvae found in this area were probably spawned in the Pelee Island-Pelee Point area and were carried to the south shore area by the dominant surface currents (MacCallum and Regier 1969). The fact that 72% of all smelt larvae were captured well offshore and that over 98% of the smelt larvae were developed beyond the pro-larval stage indicates the majority of the smelt may have been carried into the study area by these currents.

<u>Entrainment</u>. A total of 4.87×10^9 larvae were estimated to have been entrained at the four power stations along the shoreline of the western basin in 1977. Detroit Edison's Monroe Plant accounted for 61% (2.87×10^9 larvae) of the total, Toledo Edison's Bayshore Plant accounted for 27.3%, Consumer's Power's Whitting Plant 11.3% and the Toledo Edison-operated Davis-Besse Plant 0.3% of the total.

Gizzard shad was the most abundant species entrained comprising 90.5% of the total number of larvae entrained (summed over all four plants). Carp larvae were the second most abundant, accounting for 4.48% of the total entrained and yellow perch were third with 2.15% of the total. Entrainment estimates were highest at the Monroe plant where 2.97×10^9 larvae were estimated to have been entrained (60.9% of the total basin entrainment). The lowest number entrained was at the Davis-Besse plant where

1.58×10^7 larvae were estimated to have been entrained. Table 77 lists the number of each species entrained at each power plant.

Although the Monroe power plant entrained two times more larvae than any other power plant, 98.2% of the total entrainment was made up of gizzard shad (91.0%) and carp (7.2%). "Valuable species" accounted for only 1.1% of total entrainment at Monroe. In contrast, the much smaller Toledo Edison Bayshore plant entrained far more larvae of "valuable species." The Bayshore plant was responsible for 48.2% of all yellow perch larvae entrained, 1.6 times that of the Monroe facility, 67.7% of the white bass, 15 times more than Monroe, and 66.3% of the walleye entrained, with no walleye calculated to have been entrained at Monroe. If one would consider the location of the power plant in relationship to spawning and nursery areas, entrainment of valuable species, particularly walleye and yellow perch, would be expected to be high at Davis-Besse. However, comparatively few larvae were entrained here: 6.2% of the total number of walleye, 2.1% of the yellow perch, and .03% of the white bass. This can be attributed to the fact that the Davis-Besse plant has a small water demand compared to the other three plants because it utilizes a cooling tower.

Entrainment estimates were calculated for six power plants along the Ohio portion of the central basin: Avon Lake, Edgewater, Lake Shore, Eastlake, Ashtabula A & B and Ashtabula C Plants (Table 78). Calculations indicate a total of 2.52×10^8 larvae were entrained at the six power stations along the shoreline in 1978. Entrainment losses were highest at the Ashtabula A & B plant where 7.61×10^7 larvae, representing 30.8% of all central basin entrainment, occurred. The Eastlake plant ranked second with 21.4%, third was Ashtabula C plant (20.3%), fourth the Avon Lake plant (14.6%), fifth Lake Shore (6.4%) and the Edgewater plant entrained the fewest larval fishes with 4.7% of the total number entrained.

The power plants in the central basin, unlike those in the western basin, have their cooling water intakes behind man-made structures. Although these man-made structures are designed to reduce the accumulation of storm-driven debris in the canal; they may also reduce larval entrainment. Entrainment of larval fishes in the central basin appears to be more dependent upon location of the power plant than to the amount of water used by the plant.

Emerald shiners were calculated to be the most abundant species entrained, accounting for 37.2% of the total entrainment in the basin. Gizzard shad (25.0%) and rainbow smelt (13.0%) ranked second and third. Table 78 lists the number of each taxon estimated to have been entrained at each power plant.

Densities of yellow perch larvae were higest along the transects east of Cleveland. The Ashtabula A & B plant and the Ashtabula C plant, the easternmost power plants in the study area, accounted for 54.22% of the total number of yellow perch entrained (36.96% at A & B and 17.26% at the C plant). Yellow perch entrainment was lowest at the Edgewater plant where 4.83×10^4 larvae were estimated to have been entrained (1.05% of total central basin yellow perch entrainment).

Larval smelt entrainment was highest at the Eastlake plant where 2.19×10^7 smelt larvae (68.7% of total smelt entrainment) were estimated to have been entrained. It is hypothesized that this plant entrained such a high percentage of smelt because of the design of the protective breakwall. At this plant the breakwall is open to the west to minimize inflow of warm water and debris from the Chagrin River. All other power plants are located inside harbors or have their intakes open and to the east. If one assumes smelt larvae are spawned in the Point Pelee area and are carried into the study area by the dominant currents, smelt larvae would be carried directly into the water intake.

In an effort to determine the effects of entrainment upon larval fish populations, the total number of larval fish estimated to have been entrained was compared to a volume-weighted estimate of nearshore larval fish abundance. Table 79 gives the percentage of the volume-weighted estimate of nearshore larvae abundance for the valuable species that were entrained. One cannot assume, however, that yellow perch populations in the western basin are almost eight percent lower than they would be if power plants were not present.

The number of larval fish entrained by a power plant is largely determined by two factors: (1) the location of the power plant or more specifically the location of its water intake structure, and (2) the amount of cooling water pumped from the lake. Entrainment losses are therefore lower at power plants which are built in an area not utilized as spawning or nursery areas or in which measures have been taken to minimize lake water usage.

Fish Contaminants. The second current research effort deals with the assessment of toxic substances found in the fish of Lake Erie. Since Lake Erie is heavily exploited by sport and commercial fisheries, it is imperative that the toxic burden of the fish be known. Surveys of organochlorine contaminant concentrations in Lake Erie fishes have not been extensive and have been largely limited to samples from the open lake. Moreover, uptake rates of such contaminants have primarily been investigated under laboratory rather than field conditions.

In order to determine some watershed sources of organochlorine contaminants in Lake Erie, Burby et al. (1980) determined concentrations of 27 major contaminants (aldrin, α-BHC, b-BHC, y-BHC, chlordane, o,p'-DDT, p,p'-DDT, o,p'-DDD, pp'DDD, o,p'-DDE, p,p'-DDE, dieldrin, α-endosulfon, b-endosulfon, endrin, heptachlor, heptachlor epoxide, hexachlorobenzene, 2, 4-D, methoxychlor, mirex, arochlors 1016, 1254 and 1260, total PCBs, toxaphene and trifluralin) in whole fish samples from 11 Lake Erie tributary mouths (River Raisin, Maumee River, Toussaint River, Sandusky River, Black River, Cuyahoga River, Chagrin River, Grand River, Ashtabula River, Walnut Creek and Cattaraugus Creek). Twelve common species of recreational, commercial or forage importance, gizzard shad (Dorosoma cepedianum), rainbow smelt (Osmerus mordax), northern pike (Esox lucius), carp (Cyprinus carpia), emerald shiner (Notropis atherinoides), channel catfish (Ictalurus punctatus), brown bullhead (Ictalurus nebulosus), white bass (Morone chrysops), yellow perch (Perca flavescens) and freshwater drum (Aplodinotus grunniens) were tested. Age groups within each species were tested separately. In order to make field determinations of uptake rates, hatchery-raised young-of-the-year bluegill (Lepomis macrochirus) and channel catfish were held in the mouths of the Maumee, Cuyahoga and Ashtabula Rivers for six weeks during summer, 1980. Fish were removed and tested for the 27 contaminants at the end of the holding period in 1979, whereas weekly sub-samples were removed and tested during the 1980 holding period.

Of the 27 contaminants tested, α-endosulfan, b-endosulfan, and toxaphene were not detected in any of the samples from the tributary mouths. Arochlors 1016, 1254, 1260 and total PCBs exceeded 1.0 ppm in fish samples from the Raisin, Maumee, Toussaint, Sandusky, Black, Cuyahoga and Chagrin Rivers and a concentration of γBHC in excess of 1.0 ppm was found in the Ashtabula River. All other contaminants were found in concentrations less than 1.0 ppm. Significant differences were found in concentrations of contaminants in fish of the same species and age groups from different tributaries. In particular, total PCB concentrations exhibited large differences among same age groups of white bass, carp and spottail shiners in different tributaries. One Age Group IV channel catfish from the Sandusky River and one Age Group IX channel catfish from the Black River contained concentrations of DDT and metabolites in excess of IJC limits. The same channel catfish contained total PCBs and mirex concentrations in excess of FDA and IJC limits, respectively Age Group IV carp, Age Group I spottail shiner, and Age Group II brown bullhead from the River Raisin also contained total PCBs concentrations in excess of FDA limits. Gizzard shad, carp, spottail shiner, emerald shiner, white bass and freshwater drum representing a number of age groups in the Raisin, Maumee, Sandusky, Black, Cuyahoga, Chagrin, Grand and Ashtabula Rivers contained mirex concentrations in excess of IJC limits.

Yellow perch recovered from the Maumee River at the conclusion of the 1979 uptake rate experiment showed a slight increase in concentration of 7 contaminants. White perch recovered from the Cuyahoga River indicated a slight increase of 15 contaminants. Two of the contaminants, hexachlorobenzene and trifluralin, increased markedly. In the channel catfish recovered from the Cuyahoga River, 10 contaminants increased slightly. Again, hexachlorobenzene and trifluralin increased markedly. No living channel catfish were recovered from the Maumee River. No uptake of the majority of the 27 contaminants was observed during the 1980 experiment. Only p,p'-DDD, p,p'-DDE, dieldrin, heptachlor epoxide, 2,4-D, trifluralin and arochlor 1254 exhibited increases, generally at low concentrations, in either bluegill or channel catfish from the Maumee, Cuyahoga and Ashtabula river mouths.

Clark et al. (1982) reported results of comprehensive organochlorine and mercury analyses of coho salmon (Oncorhynchus kisutch) in each of the Great Lakes. Analysis by a single laboratory produced a set of tissue residue data on over 30 pesticides and industrial chemicals including those currently in use in the Great Lakes and those whose use has been banned or severely restricted. The data also demonstrated the extent of accumulation for compounds currently applied to control various pests in the Great Lakes Basin. Coho salmon from Lake Superior contained only trace amounts or low concentrations of most contaminants. Lake Erie coho contained low levels of a number of pesticides and industrial compounds with relatively higher residue levels in coho from Lake Huron and Lake Michigan. The highest residue levels for a number of compounds were found in coho from Lake Ontario, but this may reflect a faster growth rate for fish in that lake and not present a true picture of the relative magnitude of contaminant inputs. Because of their open water habitat preferences, contaminant concentrations in coho salmon demonstrate whole lake contaminant problems rather than point-source or nearshore conditions. The data reported generally agreed with recent findings from individual state contaminant monitoring programs, although the problems with varying analytical and sampling techniques precluded direct comparisons. Current tissue residue levels were usually less than historical levels for PCBs, DDTs and mercury, indicating some decreases in these contaminants have occurred since the 1960s and early 1970s. Only residue levels of mirex in coho collected from Lake Ontario exceeded the Food and Drug action level of 0.1 ug/g.

The differences in study design of toxics in fish far outweight the similarities making it evident that standardization of techniques should be resolved before any future studies are initiated. A summarization of recent studies (Table 80) shows the variation in study areas sampled, tissue types analyzed (whole body vs. fillet), fish species utilized, parameters analyzed, and the application of data correction methods for recoveries. The few guidelines concerning toxic substances in fish established by the Federal Drug Administration refer only to edible portions (fillets) yet studies on whole bodied fish have been undertaken (Table 81) with no certainty as to how the data collected would apply to these guidelines. The scientific evidence points to the fact that organochlorines are concentrated in fatty portions of fishes, very little of which is associated with fillets (Reinert 1969; Hamelink et al. 1971). If one wishes to examine the potential toxic burden to humans it is best to measure concentrations in edible portions only; however, if total bio-accumulation in fishes is the desired information the measure of whole fishes or possibly just the fatty portions is appropriate.

With the number of utilized industrial chemicals increasing, and with their potential health effects singularly or synergistically uncertain, we are forced to begin a more realistic approach to a toxic program.

The following list presents suggestions compiled from the authors of the most recent Lake Erie toxics programs in order to aid in the coordination of future programs.

1. To optimize the dollars spent on analysis an attempt should be made to select tributaries which appear to be sites of organochlorine contamination based on the recent survey information (i.e., Ashtabula, Raisin, Maumee and Sandusky Rivers).

2. Select only parameters that result in health problems.

3. Limit collections to a few species.

4. **Standardization in sampling design and methodology.**

   a. **Whole body versus fillets**

   b. **Definition of whole body should be established**

   c. **Total PCBs (the sum of arochlors 1260, 1254, 1248 and 1242) should be reported to comply with the Federal Drug Administration guidelines as well as the individual components.**

   d. **Reported data should not be corrected for recoveries; however, the recovery data must be presented along with additional quality control information.**

   e. **Most importantly, the extraction and analytical procedures need to be agreed upon.**

RECOMMENDATIONS

The recommendations that have ensued during the preparation of this document are classified in two categories: (1) scientific investigations and (2) future management programs. Further studies on Lake Erie should involve a thorough analysis of past programs and a firm committment to future programs. New programs must be more efficient in design in order to acquire information pertinent to the goals of the investigation. In addition, more attention must be paid to information already available pertaining to the scientific problem being addressed.

Scientific Investigations

1. The U.S. alone has accumulated a preponderance of historical data collected from the turn of the century until present. Many of the questions we are being confronted with today cannot be answered without the proper evaluation of past data records. The subjects that need to be examined in light of historical data include both biological and chemical parameters. For example, the issue of changes in the biota of the lake, specifically phytoplankton and benthic communities, needs to be thoroughly appraised in this manner. This type of approach is also applicable to chemical parameters such as phosphorus, nitrogen and ions.

2. In conjunction with the previous recommendation, an in-depth evaluation of the statistical techniques applicable to trend analysis needs to be examined in order to adequately evalute historical data. This is a complex problem dealing with numerous sources of variability, i.e., changes in sampling locations and methods, missing data, and natural variability within a field season and between years. If we are to utilize this valuable historical resource, proper consideration to these problems must be given, resulting in a valuable contribution to the analysis of the entire Great Lakes database. Statistical evaluation of historic data sets would be useful in planning future programs.

3. The continuation of the open lake monitoring program is required by international agreement and must be maintained in order to evaluate the response of the lake to remedial programs. The major effort should be concentrated on the western and central basins with a reduced effort maintained on the eastern basin. Primary

consideration should center around total phosphorus, nitrate plus nitrite, chlorophyll, phytoplankton and benthic organisms. This effort requires survey data pre- and post-stratification as well as data throughout the stratified period. This will ensure adequate information for modeling efforts as well as nutrient budget calculations. The current program should be stringently reviewed in light of present and future priorities in order to avoid problems of incomplete and/or inadequate data sets.

4. The nearshore region primarily along the U.S. coast of the western and central basins needs special consideration. Site and parameter specific studies should be implemented in many of the nearshore regions to evaluate contaminants known or suspected to be important within a region. Each of the site specific studies should involve a pilot study to evaluate current data records, to inventory potential or anticipated contaminants, to scientifically determine optimal sampling schedules and locations and to define objectives for the study. Careful consideration of these points must be made in order to follow contaminant loads into the lake and follow their interaction with the open lake and biota.

5. Databases on heavy metals and organic contamination are extremely weak and need to be updated and upgraded. This is particularly important in the western and central basins of the open lake and at localized nearshore regions suspected to be problem areas. In many cases, the information is either incomplete or not existent. Also, recommended methods and detection limits need to be upgraded to reflect current technology. Accessability and usability of the STORET system should be improved:

   a. Reorganization of STORET codes

   b. Addition of codes for pesticide parameters

   c. Correction of data already in system

   d. Simplification of user's manual

6. Biological indicators should be better utilized to examine contaminant loadings and subsequent effects. It is recommended that benthic and Cladophora populations be examined for this purpose. Due to the sedentary nature of these organisms, and their reduced variability to exposure, they could provide a better indication of biotic levels of contamination than transient fish populations. For example, benthic and Cladophora populations located at or near point sources or transects extending from

such sources may prove to be an effective monitor of contaminant loads as mixing with the open lake occurs.

Future Management Programs

The second group of recommendations is put forward in hopes that future programs on the lake will be more effective and efficient. They specifically are designed to upgrade the management of future programs.

1. The IJC should assume a dominant role in the prioritizing and coordination of the studies to be undertaken. This requires overseeing a project from inception to completion in order to ensure that programs are implemented in accordance with the original study plan. This is particularly important for quality control programs and statistical analysis of the data.

2. The overseeing IJC committee should consist of U.S. and Canadian managers and scientific staff who are currently active in lake research. This is to ensure a proper balance and perspective of studies at both planning and implementation phases.

3. A stronger effort needs to be applied to the active cooperation of scientists from both U.S. and Canadian research institutions. Not since "Project Hypo" in 1970 have the U.S. and Canada formally been involved at a research level concerning problems on Lake Erie.

4. Future studies should be more focused on site-specific and parameter-specific objectives. This will allow the research effort to be more thorough and allow an intensive effort if deemed necessary. In addition, it is more likely that the project will be brought to completion with a thorough analysis of the data and a complete manuscript.

5. The open lake annual surveillance/monitoring program should be combined with specific research efforts in order to take better advantage of the current database and sampling program. Since the major expense in supporting a whole lake program originates from boat and field staff expenditures, a combined effort is both economical and utilizes current facilities and expertise. Future programs should be

designed with this consideration in mind as such combined efforts generally lead to a better surveillance/monitoring program.

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TABLE 1

EPA CRUISE SCHEDULE

Year	Cruise No.	Julian Date	Calendar Date
1978	1		no cruise
	2	138-147	May 18-May 27
	3	156-166	June 5- June 15
	4	174-182	June 23-July 1
	5	200-210	July 19-July 29
	6	220-228	August 8-August 16
	7	241-249	August 29-September 6
	8	276-285	October 3-October 12
	9	297-305	October 24-November 1
	10	314-323	November 10-November 19
1979	W1	016-018	January 16-January 18
	W2	058-060	February 27-March 1
	W3	086-088	March 27-March 29
	2	107-110	April 17-April 20
	3	135-146	May 15-May 26
	4	163-172	June 12-June 21
	5	192-200	July 11-July 19
	6	212-216	July 31-August 4
	7	235-247	August 23-September 4
	8	254-264	September 11-September 21
	9	275-287	October 2-October 14
	10	311-320	November 7-November 16

TABLE 2

CCIW CRUISE SCHEDULE

Year	Cruise No.	Julian Date	Calendar Date
1978			
	103	149-157	May 29-June 2
	104	170-175	June 19-June 24
	106	194-199	July 13-July 18
	108	212-216	July 31-August 4
	110	231-235	August 19-August 23
	111	256-262	September 13-September 19
	114	273-277	September 30-October 4
1979	101	114-116	April 24-April 26
	103	135-138	May 15-May 18
	104	161-165	June 10-June 14
	106	184-187	July 3-July 6
	109	204-208	July 23-July 27
	112	235-237	August 23-August 25
	114	267-271	September 24-September 28
	116	289-291	October 16-October 18

TABLE 3

NEARSHORE CRUISE SCHEDULES FOR LAKE ERIE INTENSIVE
(JULIAN DATES/JULIAN MID POINT)

	U.S. Western Basin	U.S. Central Basin	U.S. Eastern Basin
1978			
Cruise 1	Apr 14 - Apr 29 104-119/112	May 18 - Jun 2 138-153/146	May 24 - Jun 17 144-168/156
Cruise 2	Jun 26 - Jul 12 177-193/185	Jun 15 - Jun 29 166-180/173	Jun 21 - Jul 13 172-194/183
Cruise 3	Aug 23 - Sep 11 235-254/245	Aug 28 - Sep 11 240-254/247	Aug 14 - Sep 1 226-244/235
Cruise 4	Oct 3 - Oct 17 276-290/283	Oct 8 - Oct 22 281-295/288	Sep 14 - Oct 5 262-278/270

	Canadian Western Basin	Canadian Central Basin	Canadian Eastern Basin
1978			
Cruise 1	Apr 16 - Apr 29 106-119/113	May 1 - May 24 121-144/133	May 22 - May 30 142-150/146
Cruise 2	Aug 17 - Aug 23 229-235/232	Aug 26 - Sep 5 238-248/244	Aug 18 - Aug 29 230-241/236
Cruise 3	Oct 12 - Oct 20 285-293/289	Oct 23 - Nov 3 296-307/302	Nov 1 - Nov 6 305-310/308

TABLE 3 CONTINUED

NEARSHORE CRUISE SCHEDULES FOR LAKE ERIE INTENSIVE
(JULIAN DATES/JULIAN MID POINT)

	U.S. Western Basin	U.S. Central Basin	U.S. Eastern Basin
1979			
Cruise 1	Mar 29 - Apr 15 088-105/097	Apr 11 - Apr 25 101-115/108	May 15 - Jun 1 134-152/143
Cruise 2	Jul 25 - Aug 5 206-217/212	Jul 11 - Jul 25 192-206/199	Jul 2 - Jul 18 183-199/191
Cruise 3	Sep 9 - Sep 23 252-266/259	Aug 18 - Sep 1 230-244/237	Aug 20 - Sep 6 232-249/241
Cruise 4	Oct 9 - Oct 23 282-296/289	Oct 2 - Oct 18 275-291/283	Oct 1 - Oct 31 274-304/289

	Canadian Western Basin	Canadian Central Basin	Canadian Eastern Basin
1979			
Cruise 1	Apr 17 - Apr 19 107-109/108	Apr 20 - Apr 23 110-113/111	Apr 27 - May 16 117-136/126
Cruise 2	May 18 - May 30 138-150/144	Aug 20 - Aug 23 232-235/233	Jun 16 - Jun 28 167-179/172
Cruise 3	Jul 4 - Jul 9 185-190/187	Oct 28 - Nov 3 301-307/303	Jul 19 - Aug 5 200-217/209
Cruise 4	Aug 9 - Aug 19 219-231/226		Aug 27 - Sep 15 239-258/249
Cruise 5	Sep 23 - Sep 25 266-268/267		Sep 29 - Oct 19 272-292/282
Cruise 6	Oct 14 - Oct 16 287-289/288		Nov 5 - Nov 19 309-232/316
Cruise 7	Nov 22 - Nov 24 326-328/327		

TABLE 4

NEARSHORE REACH DESIGN

No.	Name	Description
1	Colborne	Port Maitland to Buffalo
2	Port Maitland	Port Maitland
3	Nanticoke	Nanticoke to Port Maitland
4	Long Point Bay	Long Point to Nanticoke
5	Port Burwell	Port Burwell to Long Point
6	Port Stanley	Rondeau to Port Burwell
7	Wheatley	Point Pelee to Rondeau
8	Leamington	Kingsville to Point Pelee
9	Colchester	Amherstburg to Kingsville
10	Monroe	Detroit River to Maumee Bay
11	Maumee Bay	Maumee Bay
12	Locust Point	Cedar Point to Marblehead
13	Sandusky Bay	Sandusky Bay
14	Huron	Sandusky Sub Basin
15	Lorain	Huron to Rocky River
16	Cleveland	Rocky River to Euclid
17	Fairport	Euclid to Ashtabula
18	Conneaut	Conneaut to Erie Harbor
19	Erie Harbor	Erie Harbor
20	Dunkirk	Erie to Buffalo

TABLE 5

PRECISION ANALYSIS, BASED ON SPLIT SAMPLES
Units for concentration are mg/l except as noted.

WBNS: Western Basin Nearshore, CBNS: Central Basin Nearshore,
EBNS: Eastern Basin Nearshore, CNS: Canadian Nearshore,
USOL U.S. Open Lake, COL: Canadian Open Lake

1978

Parameter	Estimated Standard Deviation					
	WBNS	CBNS	EBNS	CNS	USOL	COL
Temperature	.20	.11		----	0.0	----
pH	.058	.024		.089	.023	----
Conductance	7.1	2.84		10.0	.75	----
Alkalinity	1.26	.68		3.0	.31	.30
Dissolved Oxygen	.17	.10		----	.07	----
Turbidity	.54	.20		.66	.12	----
Chlorophyll a	.0034	.0006		----	.0004	----
Pheophytin	ND	.0003		----	.0005	----
Tot. Sol. Phos.	.0006	.0015		----	----	----
Total Phosphorus	.001	.0022		.011	.0015	.0003
Sol. React. Phos.	.0005	.0005		.004	.0002	.001
Tot. Kjeldahl N	.011	.073		.097	.041	----
Ammonia N	.0012	.007		.011	.002	.0004
Nitrate + Nitrite	.008	.006		.04	.002	.003
Dis. React. Silica	.014	.022		.38	.003	.005
Chloride	.11	.48		.53	.12	.12
Fluoride	.0172	.0008		.075	----	----
Sulfate	.32	.95		1.2	.36	.18
Calcium	NA	1.56		2.0	----	.05
Magnesium	NA	.17		.40	----	----
Sodium	NA	.23		.83	----	.1
Potassium	NA	.11		.23	----	.04

TABLE 5 CONTINUED

PRECISION ANALYSIS, BASED ON SPLIT SAMPLES
Units for concentration are mg/l except as noted.

1978

Parameter	Estimated Standard Deviation					
	WBNS	CBNS	EBNS	CNS	USOL	COL
Total Metals (in ug/l)						
Aluminum	63.44	282		----	----	1
Cadmium	1.40	2.4		----	----	.1
Chromium	16.57	7.2		----	----	.1
Copper	8.05	8.1		----	----	.2
Iron	78.39	21		89	----	.5
Lead	1.38	17.4		----	----	.3
Manganese	11.14	3.4		----	----	.1
Nickel	18.12	5.8		----	----	.5
Vanadium	1.50	39		----	----	.1
Silver	0.19					
Zinc	6.21	77		----	----	.3
Arsenic	0.75	.71		----	----	----
Mercury	0.05	.13		----	.15	----
Selenium	9.26	.28		----	----	----
Dissolved Metals (in ug/l)						
Aluminum	26.63	77		----	----	----
Cadmium	0.11	0.0		----	----	----
Chromium	0.07	8.9		----	----	----
Copper	0.73	2.5		----	----	----
Iron	3.41	2.9		----	----	.2
Lead	0.88	17		----	----	----
Manganese	0.50	.2		----	----	----
Nickel	0.45	3.6		----	----	----
Vanadium	2.74	48		----	----	----
Zinc	7.46	5.1		----	----	----
Silver	0.02					

TABLE 5 CONTINUED

PRECISION ANALYSIS, BASED ON SPLIT SAMPLES
Units for concentration are mg/l except as noted.

1979

Parameter	Estimated Standard Deviation					
	WBNS	CBNS	EBNS	CNS	USOL	COL
Temperature	.03	0		—	.006	—
pH	.078	.012		.089	.02	—
Conductance	3.07	.68		10.0	.464	—
Alkalinity	2.15	.68		3.0	.26	.30
Dissolved Oxygen	.14	.00		—	.13	—
Turbidity	1.38	.11		.66	.12	—
Chlorophyll a	.0030	.0003		—	.0003	—
Pheophytin	ND	.00016		—	.00012	—
Tot. Sol. Phos.	ND	.0014		—	—	—
Total Phosphorus	.0010	.0018		.011	.0024	.0003
Sol. React. Phos.	.0004	.0003		.004	.0004	.001
Tot. Kjeldahl N.	.039	.122		.097	—	—
Ammonia N	.0017	.005		.011	.0015	.0004
Nitrate + Nitrite	.0040	.0034		.04	.0026	.003
Dis. React. Silica	.010	.026		.38	.0064	.005
Chloride	ND	.17		.53	.13	.12
Sulfate	ND	.55		1.2	—	.18
Calcium	6.66	.38		2.0	—	.05
Magnesium	7.27	.12		.40	—	—
Sodium	0.11	.12		.83	—	.1
Potassium	0.01	.03		.23	—	.04
Total Metals (in ug/l)[d]						
Aluminum		18.2		—	—	1
Cadmium		.55		—	—	.1

TABLE 5 CONTINUED

PRECISION ANALYSIS, BASED ON SPLIT SAMPLES
Units for concentration are mg/l except as noted.

1979

Parameter	Estimated Standard Deviation					
	WBNS	CBNS	EBNS	CNS	USOL	COL
Chromium		8.0		----	----	.1
Copper		4.4		----	----	.2
Iron		29.7		89	----	.5
Lead		1.6		----	----	.3
Manganese		4.9		----	----	.1
Nickel		3.7		----	----	.5
Vanadium		6.7		----	----	.1
Zinc		7.4		----	----	.3
Arsenic		.05		----	----	----
Mercury		.06		----	----	----
Selenium		0.0		----	----	----
Silver		.321		----	----	----
Dissolved Metals (in ug/l)						
Aluminum		4.8		----	----	----
Cadmium		.10		----	----	----
Chromium		1.7		----	----	----
Copper		4.3		----	----	----
Iron		8.7		----	----	.2
Lead		2.2		----	----	----
Manganese		2.6		----	----	----
Nickel		2.7		----	----	----
Vanadium		2.1		----	----	----
Zinc		5.9		----	----	----

TABLE 5 CONTINUED

a. Data as published in MOE Data Quality Summary 1975, but appropriate to their Lake Erie work, according to Don King. Data is the 95 within run precision, and may be expected to be higher than data generated for this paper by a factor of about 2.7

b. Data screened in advance by the agency for large differences between values. This has probably led to lower standard deviations for some parameters, but it is not possible to say which parameters have been affected.

c. Precision data as supplied by the agency. Method based on analytical or reagent blanks. This method will tend to give smaller standard deviations than the method used by TAT.

d. Metals data for the western basin is combined for 1978 and 1979.

TABLE 6

PERFORMANCE OF THE LAKE ERIE LABS ON IJC ROUND-ROBIN STUDIES 21 THROUGH 29, ORGANIZED BY PARAMETER

Region codes:
WBNS: Western Basin Nearshore, CBNS: Central Basin Nearshore,
EBNS: Eastern Basin Nearshore, CNS: Canadian Nearshore,
USOL: U.S. Open Lake, COL: Canadian Open Lake

Key to symbols used in chart:
ok: performance showed no serious deficiencies,
ERR: performance erratic: some analyses high and others low,
B-H: performance suggests high bias relative to other labs,
B-L: performance suggests low bias relative to other labs.
Labs that did not participate, or did not analyze enough samples to permit evaluation, have a blank entered for that parameter.

Parameter	Study Number	Lake Erie Region					
		WBNS	CBNS	EBNS	CNS	USOL	COL
pH	21			ok	ok	ok	ok
	22	ok		ERR	B-H	ok	ok
	27	ERR	B-H	ok	B-H	ERR	ok
Conductance	21			ok	ok	ok	ok
	27	ERR	B-H	B-L		B-H	
Alkalinity	21			ok	ok	ok	ok
	22	B-L			ok	ok	ok
	27	B-H		ok	ok	ok	B-L
Dissolved Oxygen	No studies						
Suspended Solids	No studies						
Chlorophyll a	No studies						
Pheophytin	No studies						

TABLE 6 CONTINUED

PERFORMANCE OF THE LAKE ERIE LABS ON IJC ROUND-ROBIN STUDIES 21 THROUGH 29, ORGANIZED BY PARAMETER

Parameter	Study Number	WBNS	CBNS	Lake Erie Region EBNS	CNS	USOL	COL
Tot. Sol. Phos.	No studies						
Total Phosphorus	24	ERR	ok		ok	ok	
	27		ok	B-H		B-L	ok
	28		ok	ERR		ok	B-L
Sol. React. Phos.	No studies						
Tot. Kjeldahl N.	22				ok	B-L	ok
	27		ERR	ok	ok	B-H	ok
Ammonia N	27	ok	B-H	B-L		B-H	ok
Nitrate+Nitrite	22	B-L		B-H	B-L	B-H	B-H
	27	ok	ERR	ok	ok	ok	ok
Dis. React. Silica	22	B-H	B-H		ok	ERR	B-L
	25	ok	B-H	ERR		ok	ok
	27	B-L	B-H	B-H		ok	ok
Tot. Org. Carbon	21			ok			
	27		B-H	B-H	B-H	ok	ok
Chloride	22		ok		ok	ok	ok
	27		ok	ok	ok	ok	ok
Fluoride	27					ok	
Sulfate	22		B-L		B-H	ok	ok
	27		ok			ok	ok
Calcium	22				ok	ok	ok
	27		ok	ok	ok	ok	ok
Magnesium	22				ok	ok	ok
	27		B-L	ok	ok	ok	ok
Sodium	22			ERR	ok	B-H	ok
	27		ERR	ERR	ok	B-H	ok

TABLE 6 CONTINUED

PERFORMANCE OF THE LAKE ERIE LABS ON IJC ROUND-ROBIN STUDIES 21 THROUGH 29, ORGANIZED BY PARAMETER

Parameter	Study Number	WBNS	CBNS	Lake Erie Region EBNS	CNS	USOL	COL
Potassium	22			B-L	B-L	ERR	ok
	27		ERR	B-L	ok	ERR	ok
Total Metals:							
Aluminum	21				ok	ok	ok
	23	B-H				ok	ok
Cadmium	21			ok	ERR	ok	ok
	23	ok		B-H	ok	ok	ok
Chromium	21				ok	ok	ok
	23	B-H		ERR	ok	B-H	B-L
Copper	21				ok	ERR	ok
	23	ERR		ERR	ERR	B-H	ok
Iron	21			ok	ok	ok	ok
	23	B-H		B-L	ok	B-H	ok
Lead	21				ok	ok	ok
	23	B-H		ERR	ok	B-H	ok
Manganese	21			ok	ok	B-L	ok
	23	B-H		ERR	ok	B-H	ok
Nickel	21			ok	ok	B-L	ok
	23	B-H		ERR	ok	B-L	B-L
Vanadium	21				B-L	B-L	ok
	23	B-L			ok	B-H	ok
Zinc	21			ok	ok	ok	ok
	23	ERR		ok	ok	B-L	ERR
Arsenic	21				ok	ok	
	26			ERR	ok	ERR	ok

TABLE 6 CONTINUED

PERFORMANCE OF THE LAKE ERIE LABS ON IJC ROUND-ROBIN STUDIES 21 THROUGH 29, ORGANIZED BY PARAMETER

	Study			Lake Erie Region			
Parameter	Number	WBNS	CBNS	EBNS	CNS	USOL	COL
Selenium	Inadequate data						
Mercury	No studies						
Silver	No studies						
Dissolved Metals:	No study for any dissolved metals except major ions						

TABLE 7

BIASES SUGGESTED BY ACROSS-BOUNDARY COMPARISONS OF FIELD DATA

Although comparisons are made pair-wise, the final determination of who is biased can only be made when all pair-wise comparisons have been made. For now, the following information is offered.

1. Comparisons between USEPA-GLNPO and CLEAR

   EPA data for conductance and pheophytin are consistently higher than CLEAR data for these parameters.

   EPA Total Soluble Phosphorus is consistently lower than CLEAR data.

   EPA Total Phosphorus, Soluble Reactive Phosphorus, and TKN tend to be lower, but these patterns are less clear-cut than the above.

   There is a considerable amount of missing data for many parameters, with much of the missing data being USEPA-GLNPO.

2. Comparisons between Heidelberg College and CLEAR

   HC has higher specific conductance, lower Total Phosphorus, Total Soluble Phosphorus, and turbidity than CLEAR. The last three differences are only apparent at the station at the outer edge of the nearshore zone, because they are not pronounced enough to overcome the great scatter in the very nearshore data.

   HC tends to have higher TKN, nitrate plus nitrite, DO, and Secchi depth values. These tendencies are less clear-cut than the ones above.

   The day-to-day variability in the data is considerable, and no dates of sampling by the two agencies were closer than 1 week. These facts make bias discrimination rather hazy.

3. Comparisons between USEPA-GLNPO and Heidelberg College

   EPA Alkalinity is higher both years about 60% of the time. It is never lower.

   In 1979, 4 of 6 USEPA-GLNPO pH values are <u>higher</u> (see below), and 4 of 6 USEPA-GLNPO Nitrate plus Nitrite values are higher (but the other 2 are lower).

   In 1978, 8 of 14 USEPA-GLNPO pH values are <u>lower</u>, as are 4 of 4 Total Phosphorus, and 3 of 4 Total Soluble Phosphorus. Five of 10 EPA chloride values are higher.

   Much of the USEPA-GLNPO data is missing.

TABLE 8

WESTERN BASIN THERMAL STRUCTURE DATA BY CRUISE FOR 1978-1979

DATE	LIMNION	VOLUME km^3	THICKNESS (m)	PERCENT OF TOTAL VOLUME	TEMPERATURE (°C)
1978/USEPA					
5/18-5/27	total	25.1	8.3	100	16.4
6/5-6/15	total	25.1	8.1	100	17.5
6/23-7/1	epi	22.4	7.3	89.2	21.4
	meso	2.6	2.5	10.4	21.0
	hypo	0.1	0.6	0.4	N
	total	25.1		100	
7/19-7/29	epi	23.7	7.7	97.1	23.4
	meso	0.7	1.4	2.9	22.8
	hypo	0.0	0.0	0.0	N
	total	24.4		100	
8/8-8/16	total	24.3	7.9	100	24.3
8/29-9/6	total	24.1	7.8	100	23.5
10/3-10/12	total	23.9	7.7	100	17.7
10/24-11/1	total	23.8	7.7	100	10.8
11/10-11/19	total	23.9	7.7	100	8.0
1979/USEPA					
4/17-4/20	total	24.8	8.1	100	5.5
5/15-5/26	total	25.0	8.1	100	12.8
6/12-6/21	total	24.8	8.1	100	19.4
7/11-7/19	total	25.0	8.1	100	21.8
7/31-8/4	total	25.1	8.2	100	23.6
8/23-9/4	total	25.1	8.2	100	21.3
9/11-9/21	total	24.8	8.1	100	21.4
10/2-10/14	total	24.4	8.0	100	18.5
11/7-11/16	total	24.2	7.9	100	8.2

TABLE 9

CENTRAL BASIN THERMAL STRUCTURE DATA BY CRUISE
FOR 1978-1979

DATE	LIMNION	VOLUME (km^3)	THICKNESS (m)	PERCENT OF TOTAL VOLUME	TEMPERATURE
1978/CCIW					
5/29-6/2	epi	93.8	5.7	29.6	15.39
	meso	101.2	6.6	31.9	10.60
	hypo	121.9	8.6	38.5	7.04
	total	316.9		100.0	
6/19-6/24	epi	179.5	10.9	56.9	16.80
	meso	69.9	4.5	22.2	12.23
	hypo	65.9	4.7	20.9	7.70
	total	315.3		100.0	
7/13-7/18	epi	191.6	11.7	61.4	20.85
	meso	59.4	4.0	19.0	14.27
	hypo	61.0	4.8	19.6	8.76
	total	312.0		100.0	
7/31-8/4	epi	213.1	13.2	69.1	22.00
	meso	41.5	2.9	13.5	13.18
	hypo	53.5	4.4	17.4	9.41
	total	308.1		100.0	
8/19-8/23	epi	220.7	13.5	70.7	22.92
	meso	37.5	2.6	12.0	13.76
	hypo	53.8	4.1	17.3	9.85
	total	312.0		100.0	
9/13-9/19	epi	266.9	16.3	86.1	20.37
	meso	18.2	1.8	5.9	14.12
	hypo	24.7	3.4	8.0	10.75
	total	309.8		100.0	
9/30-10/4	epi	280.3	17.1	90.8	18.53
	meso	16.4	1.8	5.3	14.63
	hypo	12.1	2.7	3.9	10.72
	total	308.8		100.0	

TABLE 9 CONTINUED

CENTRAL BASIN THERMAL STRUCTURE DATA BY CRUISE
FOR 1978-1979

DATE	LIMNION	VOLUME (km^3)	THICKNESS (m)	PERCENT OF TOTAL VOLUME	TEMPERATURE
1979/CCIW					
4/24-4/26	total	313.7	19.2	100.0	3.83
5/15-5/18	epi	190.7	11.7	60.5	8.83
	meso	56.1	4.0	17.8	6.73
	hypo	68.6	6.0	21.7	5.03
	total	315.4		100.0	
6/10-6/14	epi	266.2	16.3	84.4	12.87
	meso	21.7	1.9	6.9	11.11
	hypo	27.4	3.0	8.7	8.83
	total	315.3		100.0	
7/3-7/6	epi	247.7	15.2	78.8	16.51
	meso	28.9	2.4	9.2	13.87
	hypo	37.7	4.3	12.0	10.00
	total	314.3		100.0	
7/23-7/27	epi	162.8	10.0	51.6	22.36
	meso	125.9	8.1	39.9	16.07
	hypo	26.6	2.9	8.5	9.66
	total	315.3		100.0	
8/23-8/25	epi	266.7	16.3	84.6	20.40
	meso	27.8	2.5	8.8	17.75
	hypo	20.9	2.5	6.6	11.70
	total	315.4		100.0	
9/24-9/28	epi	309.4	18.9	98.6	18.57
	meso	3.1	1.3	1.0	17.77
	hypo	1.2	2.9	0.4	16.60
	total	313.7		100.0	
10/16-10/18	total	312.0	19.1	100.0	10.21

TABLE 10

EASTERN BASIN THERMAL STRUCTURE DATA BY CRUISE FOR 1978-1979

DATE	LIMNION	VOLUME (km^3)	THICKNESS (m)	PERCENT OF TOTAL VOLUME	TEMPERATURE (°C)
1978/CCIW					
5/29-6/2	epi	15.6	2.6	9.7	16.63
	meso	92.6	15.8	57.5	6.73
	hypo	52.8	13.3	32.8	4.15
	total	161.0		100.0	
6/19-6/24	epi	67.6	11.5	42.2	14.89
	meso	42.0	8.7	26.2	9.00
	hypo	50.7	14.0	31.6	4.85
	total	160.3		100.0	
7/13-7/18	epi	68.7	11.6	43.2	20.18
	meso	44.6	9.1	28.0	10.98
	hypo	45.9	12.1	28.8	5.35
	total	159.2		100.0	
7/31-8/4	epi	82.5	14.0	51.8	21.42
	meso	35.3	8.0	22.6	10.63
	hypo	41.5	12.3	25.6	5.07
	total	159.3		100.0	
8/19-8/23	epi	94.6	16.0	59.4	22.36
	meso	29.1	7.2	18.2	11.40
	hypo	35.6	11.3	22.4	5.74
	total	159.3		100.0	
9/13-9/19	epi	105.8	18.1	67.5	19.66
	meso	16.8	4.8	10.7	11.85
	hypo	34.1	12.1	21.8	5.67
	total	156.7		100.0	
9/30-10/4	epi	109.4	18.5	69.2	18.00
	meso	17.6	5.4	11.1	10.34
	hypo	31.2	12.4	19.7	5.89
	total	158.2		100.0	

TABLE 10 CONTINUED

EASTERN BASIN THERMAL STRUCTURE DATA BY CRUISE FOR 1978-1979

DATE	LIMNION	VOLUME (km^3)	THICKNESS (m)	PERCENT OF TOTAL VOLUME	TEMPERATURE (°C)
1979/CCIW					
4/24-4/26	total	159.8	27.1	100.0	1.79
5/15-5/18	epi	158.1	26.8	98.5	4.15
	meso	1.2	3.4	.8	6.57
	hypo	1.1	5.6	.7	4.30
	total	160.4		100.0	
6/10-6/14	epi	28.4	4.8	17.7	13.30
	meso	71.9	12.8	44.8	9.04
	hypo	60.1	15.0	37.5	4.84
	total	160.4		100.0	
7/3-7/6	epi	73.9	12.5	46.1	16.23
	meso	56.9	12.6	35.5	10.49
	hypo	29.6	11.5	18.4	5.33
	total	160.4		100.0	
7/23-7/27	epi	43.6	7.4	27.2	23.26
	meso	91.3	17.1	56.9	14.08
	hypo	25.5	10.5	15.9	5.32
	total	160.4		100.0	
8/23-8/25	epi	91.8	15.6	57.2	20.40
	meso	50.9	12.1	31.7	12.22
	hypo	17.7	9.6	11.1	5.53
	total	160.4		100.0	
9/24-9/28	epi	122.6	20.8	76.8	18.33
	meso	20.2	7.4	12.6	14.21
	hypo	16.9	9.0	10.6	6.88
	total	159.7		100.0	
10/16-10/18	epi	139.9	23.7	88.0	13.62
	meso	14.3	8.1	9.0	10.64
	hypo	5.0	7.1	3.0	6.14
	total	159.2		100.0	

TABLE 11

WESTERN BASIN VOLUME WEIGHTED TOTAL PHOSPHORUS,
SOLUBLE REACTIVE PHOSPHORUS
TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	TOTAL PHOSPHORUS		REACTIVE PHOSPHORUS	
		METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1978/USEPA					
5/18-5/27	total	367.72	14.65	19.08	.76
6/5-6/15	total	588.34	23.44	86.60	3.45
6/23-7/1	epi	663.26	29.61	79.74	3.56
	meso	83.64	32.17	20.37	7.83
	hypo	ND	ND	ND	ND
	total	746.90	29.88	100.10	4.00
7/19-7/29	epi	ND	ND	206.66	8.72
	meso	ND	ND	6.17	8.81
	hypo	ND	ND	ND	ND
	total	ND		212.83	8.79
8/8-8/16	total	ND	ND	43.98	1.81
8/29-9/6	total	ND	ND	51.33	2.13
10/3-10/12	total	ND	ND	163.24	6.83
10/24-11/1	total	ND	ND	45.22	1.90
11/10-11/19	total	536.32	22.44	70.98	2.97

TABLE 11 CONTINUED

WESTERN BASIN VOLUME WEIGHTED TOTAL PHOSPHORUS,
SOLUBLE REACTIVE PHOSPHORUS
TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	TOTAL PHOSPHORUS		REACTIVE PHOSPHORUS	
		METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1979/USEPA					
4/17-4/20	total	2537.78	102.33	171.37	6.91
5/15-5/26	total	504.50	20.18	64.00	2.56
6/12-6/21	total	649.51	26.19	ND	ND
7/11-7/19	total	468.75	18.75	55.75	2.23
7/31-8/4	total	664.65	26.48	51.96	2.07
8/23-9/4	total	882.52	35.16	45.43	1.81
9/11-9/21	total	992.00	40.00	62.00	2.50
10/2-10/14	total	746.40	30.59	50.51	2.07
11/7-11/16	total	795.21	32.86	50.34	2.08

TABLE 12

CENTRAL BASIN VOLUME WEIGHTED TOTAL PHOSPHORUS, SOLUBLE REACTIVE PHOSPHORUS, TONNAGES AND CONCENTRATION, 1978-1979

DATE	LIMNION	TOTAL PHOSPHORUS		REACTIVE PHOSPHORUS	
		METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1978 (CCIW)					
5/29-6/2	epi	1245.2	13.3	89.2	0.95
	meso	1479.6	14.6	96.2	0.95
	hypo	1754.5	14.4	133.8	1.09
	total	4479.3	14.1	319.2	1.01
6/19-6/24	epi	1975.9	11.0	168.5	0.94
	meso	913.5	13.0	81.2	1.16
	hypo	904.4	13.7	70.4	1.07
	total	3793.8	12.0	320.1	1.02
7/13-7/18	epi	2281.8	11.9	201.1	1.05
	meso	915.3	15.3	63.8	1.07
	hypo	1146.1	18.8	74.3	1.22
	total	4343.2	13.9	339.2	1.09
7/31-8/4	epi	ND	ND	239.6	1.12
	meso	ND	ND	55.1	1.29
	hypo	ND	ND	82.9	1.52
	total	ND	ND	377.6	1.21
8/19-8/23	epi	2847.5	12.8	288.3	1.31
	meso	686.9	18.3	67.9	1.81
	hypo	1095.6	20.3	113.1	2.10
	total	4630.0	14.8	469.3	1.50
9/13-9/19	epi	3752.2	14.2	639.2	2.38
	meso	304.6	16.7	53.4	3.02
	hypo	412.6	16.6	81.5	3.32
	total	4469.4	14.4	774.1	2.50
9/30-10/4	epi	4254.5	15.1	607.8	2.17
	meso	331.9	20.2	95.6	5.83
	hypo	257.7	21.3	130.4	10.78
	total	4844.1	15.7	833.8	2.70

TABLE 12 CONTINUED

CENTRAL BASIN VOLUME WEIGHTED TOTAL PHOSPHORUS, SOLUBLE REACTIVE PHOSPHORUS, TONNAGES AND CONCENTRATION, 1978-1979

	DATE	LIMNION	TOTAL PHOSPHORUS METRIC TONS	TOTAL PHOSPHORUS CONC. (ug/l)		REACTIVE PHOSPHORUS METRIC TONS	REACTIVE PHOSPHORUS CONC. (ug/l)	
EPA	1979/CCIW							
4/17-20	4/24-4/26	total	5776.5	18.41	18.36	1002.9	3.19	1.62
5/15-5/26	5/15-5/18	epi	2759.7	14.47		313.4	1.64	
		meso	803.1	14.31		84.0	1.51	
		hypo	973.7	14.20		104.3	1.52	
		total	4536.5	14.38	11.89	501.7	1.59	1.65 $\bar{X}_{TP} = 13.13$ ±
6/12-6/21	6/10-6/14	epi	3351.8	12.59		260.1	0.98	$\bar{X}_{DRP} = 1.62$ ±
		meso	341.2	15.69		25.5	1.17	
		hypo	416.4	15.21		37.4	1.37	
		total	4109.4	13.03	10.72	323.0	1.02	1.50 $\bar{X}_{TP} = 11.88$ ±
	7/3-7/6	epi	2618.2	10.54		393.9	1.58	$\bar{X}_{DRP} = 1.26$ ± 1
		meso	447.3	15.39		86.6	2.98	
		hypo	778.3	20.54		226.8	5.98	
7/11-7/19		total	3843.8	12.23	9.96	707.3	2.25	
	7/23-7/27	epi	1684.8	10.35		103.5	0.64	
		meso	1540.9	12.24		97.6	0.77	
		hypo	428.1	16.08		26.3	0.99	
		total	3653.8	11.59		227.4	0.72	
7/31-8/4	8/23-8/25	epi	2827.5	10.66	13.12	196.6	0.74	
		meso	379.4	13.85		42.5	1.53	
		hypo	295.7	15.29		58.9	2.83	
		total	3502.6	11.10		298.0	0.94	
9/11-9/21	9/24-9/28	epi	4436.2	14.34	13.15	704.7	2.28	2.17
		meso	30.7	9.84		4.2	1.35	
		hypo	22.6	18.68		3.4	2.80	
		total	4489.5	14.31		712.3	2.27	
10/2-10/14	10/16-10/18	total	5827.0	18.67	14.49	2536.5	8.12	2.71
11/7-11/10					15.06			3.53

TABLE 13

EASTERN BASIN VOLUME WEIGHTED TOTAL PHOSPHORUS, SOLUBLE REACTIVE PHOSPHORUS, TONNAGES AND CONCENTRATION, 1978-1979

DATE	LIMNION	TOTAL PHOSPHORUS		REACTIVE PHOSPHORUS	
		METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1978 (CCIW)					
5/29-6/2	epi	234.4	15.1	21.3	1.37
	meso	1578.2	17.0	171.4	1.85
	hypo	840.5	15.9	227.5	4.30
	total	2653.1	16.5	420.2	2.61
6/19-6/24	epi	998.4	14.7	106.5	1.57
	meso	571.6	13.6	42.9	1.02
	hypo	726.3	14.3	113.8	2.24
	total	2296.3	14.3	263.2	1.64
7/13-7/18	epi	863.5	12.5	97.4	1.42
	meso	635.9	14.2	62.3	1.39
	hypo	744.7	16.2	92.5	2.01
	total	2244.1	14.1	252.2	1.58
7/30-8/4	epi	ND	ND	87.5	1.06
	meso	ND	ND	42.9	1.21
	hypo	ND	ND	75.6	1.82
	total	ND	ND	206.0	1.29
8/19-8/23	epi	1177.5	12.4	175.3	1.85
	meso	384.3	13.2	46.7	1.61
	hypo	527.9	14.8	83.5	2.35
	total	2089.7	13.1	305.5	1.92
9/13-9/19	epi	1110.0	10.5	168.4	1.57
	meso	166.7	9.9	31.1	1.87
	hypo	347.7	10.2	97.8	2.80
	total	1624.4	10.4	297.3	1.90
9/30-10/4	epi	1103.7	10.1	128.7	1.18
	meso	159.6	9.0	23.7	1.34
	hypo	302.1	9.7	56.5	1.81
	total	1565.4	9.9	208.9	1.32

TABLE 13 CONTINUED

EASTERN BASIN VOLUME WEIGHTED TOTAL PHOSPHORUS, SOLUBLE REACTIVE PHOSPHORUS, TONNAGES AND CONCENTRATION, 1978-1979

DATE	LIMNION	TOTAL PHOSPHORUS		REACTIVE PHOSPHORUS	
		METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1979 (CHARLTON)					
4/24-4/26	total	2720.9	17.02	829.3	5.19
5/15-5/18	epi	2554.2	16.16	315.2	1.99
	meso	16.4	13.39	1.8	1.49
	hypo	17.0	15.52	1.6	1.50
	total	2587.6	16.13	318.6	1.99
6/10-6/14	epi	354.9	12.51	35.0	1.23
	meso	1148.5	15.96	74.7	1.04
	hypo	674.2	11.23	145.1	2.42
	total	2177.6	13.58	254.8	1.59
7/3-7/6	epi	881.4	11.92	113.2	1.80
	meso	638.4	11.22	107.9	1.89
	hypo	330.2	11.15	75.6	2.55
	total	1850.0	11.53	296.7	1.85
7/23-7/27	epi	477.0	10.94	41.8	0.96
	meso	924.6	10.13	80.0	0.88
	hypo	334.1	13.10	50.8	1.99
	total	1735.7	10.82	172.6	1.08
8/23-8/25	epi	887.6	9.70	67.6	0.74
	meso	476.3	9.44	62.1	1.22
	hypo	192.1	11.13	47.5	2.69
	total	1556.0	9.70	177.2	1.10
9/24-9/28	epi	1027.9	8.38	213.4	1.74
	meso	168.3	8.32	36.2	1.79
	hypo	147.2	8.66	43.6	2.57
	total	1343.4	8.41	293.2	1.84
10/16-10/18	epi	1255.9	8.97	428.2	3.06
	meso	188.8	13.21	49.1	3.40
	hypo	54.6	10.93	18.8	3.77
	total	1499.3	9.42	496.1	3.12

TABLE 14

WESTERN BASIN VOLUME WEIGHTED NITRATE PLUS NITRITE AND AMMONIA TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	NITRATE + NITRITE		AMMONIA	
		METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1978/USEPA					
5/18-5/27	total	18426.91	734.14	331.57	13.21
6/5-6/15	total	15562.00	620.00	ND	ND
6/23-7/1	epi	4626.05	206.52	153.09	33.62
	meso	1144.00	440.00	180.91	69.58
	hypo	ND	ND	ND	ND
	total	5770.05	229.88	934.00	37.21
7/19-7/29	epi	908.42	38.33	634.69	26.78
	meso	21.70	31.00	37.86	54.09
	hypo	ND	ND	ND	ND
	total	930.12	38.12	672.55	27.56
8/8-8/16	total	4214.59	173.44	516.13	21.24
8/29-9/6	total	2284.92	94.81	392.83	16.30
10/3-10/12	total	3107.00	130.00	827.90	34.64
10/24-11/1	total	3862.98	162.31	257.28	10.81
11/10-11/19	total	4237.71	177.31	661.79	27.69

TABLE 14 CONTINUED

WESTERN BASIN VOLUME WEIGHTED NITRATE PLUS NITRITE AND AMMONIA TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	NITRATE + NITRITE		AMMONIA	
		METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1979/USEPA					
4/17-4/20	total	19780.23	797.59	3332.13	134.36
5/15-5/26	total	19708.25	788.33	666.75	26.67
6/12-6/21	total	ND	ND	ND	ND
7/11-7/19	total	8193.50	327.74	1065.25	42.61
7/31-8/4	total	10814.59	430.86	785.88	31.31
8/23-9/4	total	6486.09	258.41	ND	ND
9/11-9/21	total	2378.07	95.89	523.03	21.09
10/2-10/14	total	2430.97	99.63	741.52	30.39
11/7-11/16	total	3543.61	146.43	653.40	27.00

TABLE 15

CENTRAL BASIN VOLUME WEIGHTED NITRATE PLUS NITRITE AND AMMONIA TONNAGES AND CONCENTRATIONS, 1978-1979

		NITRATE PLUS NITRITE		AMMONIA	
DATE	LIMNION	METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1978/CCIW					
5/29-6/2	epi	26086.7	278.04	458.6	4.89
	meso	24232.3	239.39	474.4	4.69
	hypo	25311.3	207.58	1637.6	13.43
	total	75630.3	238.66	2570.6	8.11
6/19-6/24	epi	39347.9	219.19	1274.9	7.10
	meso	16317.4	233.27	1051.9	15.04
	hypo	14511.5	220.25	1091.0	16.56
	total	70176.8	222.57	3417.8	10.84
7/13-7/18	epi	42036.4	219.48	1296.9	6.77
	meso	12393.1	208.34	973.7	16.37
	hypo	12139.1	198.99	1339.5	21.96
	total	66568.6	213.36	3610.1	11.57
7/31-8/4	epi	33661.5	156.67	591.5	2.75
	meso	7629.9	179.77	450.4	10.61
	hypo	11111.5	202.85	789.2	14.41
	total	52402.9	167.96	1831.1	5.86
8/19-8/23	epi	24643.8	111.63	803.5	3.64
	meso	6805.4	181.53	972.8	25.95
	hypo	10820.4	201.07	1525.9	28.36
	total	42269.6	135.48	3302.2	10.58
9/13-9/19	epi	24969.4	93.09	3087.1	11.51
	meso	2659.8	150.69	398.7	22.59
	hypo	6142.7	250.32	456.7	18.61
	total	33771.9	109.01	3942.5	12.73
9/30-10/4	epi	23339.2	83.30	2950.7	10.53
	meso	1647.7	100.50	525.7	32.06
	hypo	2130.2	176.00	473.6	39.14
	total	27117.1	87.80	3950.0	12.79

TABLE 15 CONTINUED

CENTRAL BASIN VOLUME WEIGHTED NITRATE PLUS NITRITE AND AMMONIA TONNAGES AND CONCENTRATIONS, 1978-1979

		NITRATE PLUS NITRITE		AMMONIA	
DATE	LIMNION	METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
1979/CCIW					
4/24-4/26	total	51081.0	162.83	3277.8	10.45
5/15-5/18	epi	24071.9	126.24	611.9	3.21
	meso	8258.4	147.20	142.6	2.54
	hypo	11602.9	169.25	550.8	8.03
	total	43933.2	139.29	1305.3	4.14
6/10-6/14	epi	31613.8	118.75	4280.6	16.08
	meso	3347.9	153.99	534.5	24.59
	hypo	4537.6	165.69	917.8	33.51
	total	39499.3	125.28	5732.9	18.18
7/3-7/6	epi	33843.8	136.25	2753.6	11.09
	meso	4859.2	167.25	985.2	33.91
	hypo	8068.6	212.89	1733.6	45.74
	total	46771.6	148.81	5472.4	17.41
7/23-7/27	epi	12679.7	77.86	987.9	6.07
	meso	16725.4	132.88	1591.9	12.65
	hypo	6698.1	251.61	686.6	25.79
	total	36103.2	114.50	3266.4	10.36
8/23-8/25	epi	28872.8	108.27	2539.1	9.52
	meso	6412.1	230.59	662.5	23.82
	hypo	5479.6	262.71	517.4	24.80
	total	40764.5	129.25	3719.0	11.79
9/24-9/28	epi	21294.3	68.83	9506.0	30.73
	meso	110.9	35.49	70.1	22.45
	hypo	68.9	56.85	130.5	107.64
	total	21474.1	68.45	9706.6	30.94
10/16-10/18	total	23526.7	75.39	7057.5	22.61

TABLE 16

EASTERN BASIN VOLUME WEIGHTED NITRATE PLUS NITRITE AND AMMONIA, TONNAGES AND CONCENTRATIONS, 1978-1979

		NITRATE PLUS NITRITE		AMMONIA	
DATE	LIMNION	METRIC TONS	CONC. (ug/l)	METRIC TONS	CONC. (ug/l)
CCIW/1979					
5/29-6/2	epi	2823.3	181.47	40.9	2.63
	meso	21797.8	235.38	593.4	6.41
	hypo	12763.5	241.49	500.5	9.47
	total	37384.6	232.20	1134.8	7.05
6/19-6/24	epi	13182.8	194.90	541.9	8.01
	meso	7739.6	184.13	559.8	13.32
	hypo	12302.2	242.67	1052.4	20.76
	total	33224.6	207.26	2154.1	13.44
7/13-7/18	epi	10000.9	145.58	530.4	7.70
	meso	8434.5	189.99	1438.6	32.24
	hypo	11205.3	244.10	1274.6	27.77
	total	29640.7	186.19	3243.6	20.37
7/31-8/4	epi	7546.3	91.51	753.8	9.14
	meso	6585.8	186.53	903.0	25.58
	hypo	11216.3	270.51	478.9	11.55
	total	25348.4	159.12	1400.1	8.79
8/19-8/23	epi	7600.7	80.36	1006.5	10.64
	meso	7138.6	245.50	157.5	5.42
	hypo	10788.3	303.39	106.8	3.00
	total	25527.6	160.25	1270.8	7.98
9/13-9/19	epi	9797.7	91.44	881.9	8.24
	meso	3706.2	222.98	91.7	5.52
	hypo	10955.9	314.16	140.1	4.03
	total	24459.8	156.09	1113.7	7.11
9/30-10/4	epi	10811.2	98.9	613.3	5.61
	meso	4253.4	241.1	82.6	4.68
	hypo	10222.0	328.0	99.7	3.19
	total	25286.6	159.8	795.6	5.03

TABLE 16 CONTINUED

EASTERN BASIN VOLUME WEIGHTED NITRATE PLUS NITRITE AND AMMONIA, TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	NITRATE PLUS NITRITE METRIC TONS	NITRATE PLUS NITRITE CONC. (ug/l)	AMMONIA METRIC TONS	AMMONIA CONC. (ug/l)
CCIW/1979					
4/24-4/26	total	33655.0	210.58	1269.5	7.94
5/15-5/18	epi	32354.6	204.65	363.2	2.29
	meso	238.0	194.91	1.2	1.00
	hypo	243.6	223.25	1.1	1.00
	total	23836.2	204.71	365.5	2.28
6/10-6/14	epi	2759.8	97.28	150.9	5.32
	meso	10562.2	146.74	404.4	5.62
	hypo	13369.6	222.61	877.7	14.61
	total	26691.6	166.41	1433.0	8.93
7/3-7/6	epi	10480.4	141.79	817.9	11.07
	meso	11119.1	195.49	1262.9	22.20
	hypo	6739.3	227.53	557.4	18.82
	total	28338.8	176.68	2638.2	16.45
7/23-7/27	epi	4776.8	109.55	170.9	3.92
	meso	12621.2	138.23	1567.5	17.17
	hypo	5653.4	221.70	55.4	2.17
	total	23051.4	143.71	1793.8	11.18
8/23-8/25	epi	10369.9	112.93	560.9	6.11
	meso	11811.5	232.04	243.4	4.78
	hypo	4879.5	276.06	52.9	2.99
	total	27060.9	168.71	857.2	5.34
9/24-9/28	epi	11546.0	94.18	717.4	5.85
	meso	3519.8	173.97	196.9	9.74
	hypo	4338.2	255.33	72.3	4.25
	total	19404.0	121.50	986.6	6.18
10/16-10/18	epi	15272.1	109.13	1393.9	9.96
	meso	2310.3	161.63	99.1	6.93
	hypo	1117.3	223.74	20.9	4.18
	total	18699.7	117.46	1513.9	9.51

TABLE 17

CORRECTED CHLOROPHYLL a VOLUME WEIGHTED TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	CORRECTED CHLOROPHYLL a METRIC TONS	CORRECTED CHLOROPHYLL a CONC. (ug/l)
		WESTERN BASIN	
1978/USEPA			
5/18-5/27	total	261.54	10.42
6/5-6/25	total	174.95	6.97
6/23-7/1	epi	340.70	15.21
	meso	12.51	4.81
	hypo	ND	ND
	total	353.21	14.07
7/19-7/29	epi	352.89	14.89
	meso	3.30	4.7
	hypo	ND	ND
	total	356.19	14.60
8/8-8/16	total	455.87	18.76
8/29-9/6	total	377.89	15.68
10/3-10/12	total	233.98	9.79
10/24-11/1	total	316.30	13.29
11/10-11/19	total	239.00	10.00

TABLE 17 CONTINUED

CORRECTED CHLOROPHYLL a VOLUME WEIGHTED TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	CORRECTED CHLOROPHYLL a	
		METRIC TONS	CONC. (ug/l)
		WESTERN BASIN	
1979/USEPA			
4/17-4/20	total	109.86	4.43
5/15-5/26	total	265.50	10.62
6/12-6/21	total	ND	ND
7/11-7/19	total	209.00	18.36
7/31-8/4	total	454.81	18.12
8/23-9/4	total	ND	ND
9/11-9/21	total	455.58	18.37
10/2-10/14	total	316.22	12.96
11/7-11/16	total	279.51	11.55

TABLE 17 CONTINUED

CORRECTED CHLOROPHYLL a VOLUME WEIGHTED TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	CORRECTED CHLOROPHYLL a	
		METRIC TONS	CONC. (ug/l)
	CENTRAL BASIN		
1978/USEPA			
5/18-5/27	total	2720.16	8.61
6/5-6/15	total	1334.90	4.37
6/23-7/1	epi	319.73	2.46
	hypo	398.80	5.00
	meso	333.80	3.17
	total	1052.33	3.34
7/19-7/29	epi	346.14	2.92
	hypo	433.30	4.32
	meso	323.30	3.47
	total	1102.64	3.53
8/8-8/16	epi	805.29	4.68
	hypo	292.57	4.20
	meso	387.31	5.56
	total	1485.17	4.77
8/29-9/6	epi	779.57	3.86
	hypo	271.52	5.26
	meso	238.18	4.20
	total	1289.27	4.16
10/3-10/12	total	2254.31	7.30
10/24-11/1	total	2479.74	8.03
11/10-11/19	total	1917.06	6.40

TABLE 17 CONTINUED

CORRECTED CHLOROPHYLL a VOLUME WEIGHTED TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	CORRECTED CHLOROPHYLL a	
		METRIC TONS	CONC. (ug/l)
	CENTRAL BASIN		
1979/USEPA			
4/17-4/20	total	1776.40	5.67
5/15-5/26	epi	962.59	4.97
	hypo	303.22	3.88
	meso	193.42	4.47
	total	1459.23	4.63
6/12-6/21	total	ND	ND
7/11-7/19	epi	822.21	3.53
	hypo	100.43	2.04
	meso	74.01	2.31
	total	996.65	3.17
7/31-8/4	epi	1499.05	6.84
	hypo	306.12	4.67
	meso	196.17	6.47
	total	2001.34	6.35
8/23-9/4	total	ND	ND
8/11-9/21	epi	1964.95	7.20
	hypo	65.22	2.78
	meso	66.13	3.92
	total	2096.30	6.69
10/2-10/14	total	1871.30	6.17
11/7-11/16	total	2548.77	8.45

TABLE 17 CONTINUED

CORRECTED CHLOROPHYLL a VOLUME WEIGHTED TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	CORRECTED CHLOROPHYLL a	
		METRIC TONS	CONC. (ug/l)
		EASTERN BASIN	
1978 (USEPA)			
5/18-5/27	total	860.7	5.35
6/5-6/15	total	660.7	4.12
6/23-7/1	epi	102.2	2.10
	meso	152.5	3.54
	hypo	146.9	2.14
	total	401.6	2.51
7/19-7/29	epi	210.6	3.30
	meso	71.8	1.72
	hypo	116.3	2.16
	total	398.7	2.51
8/8-8/16	epi	178.3	2.08
	meso	52.9	1.81
	hypo	44.5	1.01
	total	275.7	1.74
8/29-9/6	epi	197.0	2.32
	meso	49.9	1.92
	hypo	38.3	0.81
	total	285.2	1.81
10/3-10/12		ND	ND
10/24-11/1	total	580.8	3.67
11/10-11/19	total	592.8	3.75

TABLE 17 CONTINUED

CORRECTED CHLOROPHYLL a VOLUME WEIGHTED TONNAGES AND CONCENTRATIONS, 1978-1979

DATE	LIMNION	CORRECTED CHLOROPHYLL a	
		METRIC TONS	CONC. (ug/l)
	EASTERN BASIN		
1979 (USEPA)			
5/15-5/26	epi	408.0	3.22
	meso	34.8	3.89
	hypo	64.5	2.60
	total	507.3	3.17
6/12-6/21		ND	ND
7/11-7/19	epi	167.0	1.92
	meso	20.2	0.86
	hypo	38.2	0.79
	total	225.4	1.41
7/31-8/4	ND	ND	ND
8/23-9/4	ND	ND	ND
9/11-9/21	epi	312.0	2.86
	meso	46.5	2.53
	hypo	43.1	1.34
	total	401.6	2.52
10/2-10/14	epi	333.6	2.59
	meso	26.1	2.01
	hypo	22.0	1.28
	total	381.7	2.40
11/7-11/16	total	621.4	3.92

TABLE 18

VOLUME WEIGHTED PARTICULATE ORGANIC CARBON, TONNAGES AND CONCENTRATION, 1978-1979

DATE	LIMNION	PARTICULATE ORGANIC CARBON METRIC TONS	CONC. (ug/l)
		CENTRAL BASIN	
1978 (CCIW)			
5/29-6/2	epi	49803.6	530.9
	meso	57213.0	565.2
	hypo	57659.2	472.9
	total	164675.6	519.6
6/19-6/24	epi	59731.0	332.7
	meso	27818.0	397.7
	hypo	30941.0	469.6
	total	118490.0	375.8
7/13-7/18	epi	72655.0	379.2
	meso	29300.3	492.6
	hypo	37590.0	616.2
	total	139545.3	447.3
7/31-8/4	epi	91604.6	426.4
	meso	19649.1	462.9
	hypo	26749.4	488.3
	total	138003.1	442.3
8/19-8/23	epi	113789.0	515.4
	meso	22807.2	608.4
	hypo	31018.4	576.4
	total	167614.6	537.2
9/13-9/19	epi	152463.0	568.4
	meso	9901.1	560.9
	hypo	13918.0	567.2
	total	176281.1	569.0
9/30-10/4	epi	158873.0	566.8
	meso	8669.8	528.8
	hypo	3708.1	306.4
	total	171250.9	554.6

TABLE 18 CONTINUED

VOLUME WEIGHTED PARTICULATE ORGANIC CARBON, TONNAGES AND CONCENTRATION, 1978-1979

DATE	LIMNION	PARTICULATE ORGANIC CARBON METRIC TONS	CONC. (ug/l)
		CENTRAL BASIN	
1979/CCIW			
4/24-4/26	total	113980.0	363.3
5/15-5/18	epi	98151.0	514.7
	meso	26768.0	477.1
	hypo	26392.0	384.9
	total	151311.0	479.7
6/10-6/14	epi	112707.0	423.4
	meso	9258.0	425.8
	hypo	10665.0	389.4
	total	132630.0	420.7
7/3-7/6	epi	63669.0	256.3
	meso	9287.0	319.7
	hypo	11522.0	304.0
	total	84478.0	268.8
7/23-7/27	epi	42114.0	258.6
	meso	34426.0	273.5
	hypo	8171.0	306.9
	total	84711.0	268.7
8/23-8/25	epi	100720.0	377.7
	meso	9029.0	324.7
	hypo	7456.0	357.5
	total	117205.0	371.6
9/24-9/28	epi	121733.0	393.5
	meso	898.0	287.6
	hypo	489.0	403.5
	total	123120.0	392.5
10/16-10/18	total	107459.0	344.3

TABLE 18 CONTINUED

VOLUME WEIGHTED PARTICULATE ORGANIC CARBON, TONNAGES AND CONCENTRATION, 1978-1979

DATE	LIMNION	PARTICULATE ORGANIC CARBON METRIC TONS	CONC. (ug/l)
		EASTERN BASIN	
1978 (CCIW)			
5/29-6/2	epi	8616.6	553.8
	meso	49100.4	530.2
	hypo	14486.5	274.1
	total	72203.5	448.5
6/19-6/24	epi	33517.9	495.6
	meso	18321.5	435.9
	hypo	17920.7	353.5
	total	69760.1	435.2
7/13-7/18	epi	23619.1	343.9
	meso	14515.1	323.8
	hypo	16284.3	356.2
	total	54418.5	341.8
7/30-8/4	epi	35681.6	432.7
	meso	12036.0	340.9
	hypo	12456.8	300.4
	total	60174.4	377.7
8/19-8/23	epi	45918.7	485.5
	meso	10284.0	353.7
	hypo	10973.6	308.6
	total	67176.3	421.7
9/13-9/19	epi	47794.1	446.1
	meso	6269.5	377.2
	hypo	8874.5	254.5
	total	62938.1	401.6
9/30-10/4	epi	44755.8	409.3
	meso	5243.1	297.2
	hypo	7472.9	239.8
	total	57471.8	363.3

TABLE 18 CONTINUED

VOLUME WEIGHTED PARTICULATE ORGANIC CARBON,
TONNAGES AND CONCENTRATION, 1978-1979

DATE	LIMNION	PARTICULATE ORGANIC CARBON METRIC TONS	CONC. (ug/l)
		EASTERN BASIN	
1979 (CHARLTON)			
4/24-4/26	total	33995.0	212.7
5/15-5/18	epi	39818.0	251.9
	meso	330.7	270.8
	hypo	225.3	205.6
	total	40374.0	251.7
6/10-6/14	14639.0	516.0	
	meso	40712.0	565.6
	hypo	14589.0	242.9
	total	69940.0	436.0
7/3-7/6	epi	15860.0	214.6
	meso	11405.0	200.5
	hypo	6215.0	209.8
	total	33480.0	208.7
7/23-7/27	epi	13359.0	306.4
	meso	19959.0	218.6
	hypo	4842.0	189.9
	total	38160.0	237.9
8/23-8/25	epi	25036.0	272.6
	meso	8819.8	173.3
	hypo	2491.0	140.9
	total	36346.8	226.6
9/24-9/28	epi	32605.0	265.9
	meso	4881.0	241.2
	hypo	3162.0	186.1
	total	40648.0	254.5
10/16-10/18	epi	39593.0	211.5
	meso	3329.0	232.9
	hypo	861.0	172.4
	total	33783.0	212.2

TABLE 19

MEAN TOTAL SUSPENDED SOLIDS CONCENTRATIONS (mg/l) for 1978 (USEPA)

YEAR/CRUISE		LIMNION	BASIN WB	CB	EB
1978	2	epi	4.05	2.42	1.74
	3	epi	8.77	1.39	1.44
		hypo	7.63	1.74	1.93
	4	epi	9.36	1.36	1.03
		hypo	ND	1.61	1.81
	5	epi	6.09	1.05	1.33
		hypo	ND	2.10	2.35
	6	epi	7.16	1.46	1.08
		hypo	ND	2.48	2.56
	7	epi	9.52	2.50	2.20
		hypo	ND	2.23	2.82
	8	epi	19.31	5.32	4.60
		hypo	ND	ND	2.78
	9	epi	8.87	5.35	4.47
		hypo	ND	ND	3.89
	10	epi	23.16	4.82	3.87

TABLE 20

LAKE ERIE BASIN CONCENTRATIONS OF AREA WEIGHTED TRANSPARENCY MEASUREMENTS BY CRUISE

Date	Year	Cruise No.	Area-Weighted Transparency, Secchi Disk (m) Western	Central	Eastern
	1978	1	N.A.	N.A.	N.A.
5/18-5/27		2	2.50	3.87	3.96
6/5-6/15		3	2.02	4.31	4.22
6/23-7/1		4	2.00	4.22	6.87
7/19-7/29		5	2.06	6.93	5.95
8/8-8/16		6	2.68	6.60	7.03
8/29-9/6		7	1.94	5.16	4.65
10/3-10/12		8	1.58	4.31	3.20
10/24-11/1		9	2.08	2.93	3.63
11/10-11/19		10	0.65	3.42	3.16
mean of means	n=9		1.95 .58	4.64 1.36	4.74 1.51
	1979	1	N.A.	N.A.	N.A.
4/17-4/20		2	0.67	1.28	N.A.
5/15-5/26		3	1.81	2.82	3.16
6/12-6/21		4	1.44	3.49	3.07
7/11-7/19		5	3.03	5.80	6.91
7/31-8/4		6	2.38	5.78	N.A.
8/23-9/4		7	1.91	N.A.	N.A.
9/11-9/21		8	1.29	3.92	5.82
10/2-10/14		9	1.59	3.50	4.26
11/7-11/16		10	0.96	5.03	3.67
mean of means	n=9		1.68	3.95	4.48

TABLE 22

LAKE ERIE BASIN RATIOS OF AREA WEIGHTED TRANSPARENCY MEASUREMENTS (M) BY CRUISE

Date	Year	Cruise No.	Western	Central	Eastern
	1978	1	N.A.	N.A.	N.A.
5/18-5/27		2	1.00	1.55	1.58
6/5-6/15		3	1.00	2.13	2.09
6/23-7/1		4	1.00	2.11	3.44
7/19-7/29		5	1.00	3.36	2.89
8/8-8/16		6	1.00	2.46	2.62
8/29-9/6		7	1.00	2.66	2.40
10/3-10/12		8	1.00	2.73	2.03
10/24-11/1		9	1.00	1.41	1.75
11/10-11/19		10	1.00	5.26	4.86
	1979	1	N.A.	N.A.	N.A.
4/17-4/20		2	1.00	1.91	N.A.
5/15-5/26		3	1.00	1.56	1.75
6/12-6/21		4	1.00	2.42	2.13
7/11-7/19		5	1.00	1.91	2.28
7/31-8/4		6	1.00	2.43	N.A.
8/23-9/4		7	1.00	N.A.	N.A.
9/11-9/21		8	1.00	3.04	4.51
10/2-10/14		9	1.00	2.20	2.68
11/7-11/16		10	1.00	5.24	3.82

TABLE 23

PRINCIPAL ION CONCENTRATIONS FOR THE OPEN LAKE CRUISES 1978-1979 (USEPA)

Year	Cruise	WB	CB	EB	WB	CB	EB	WB	CB	EB
			Chloride			Sulfate			Bicarbonate	
1978	2	19.0	20.2	20.9	22.4	23.8	24.6	91.0	94.8	94.8
	3	17.4	20.2	20.8	21.6	23.3	24.5	94.4	93.1	94.5
	4	17.2	20.0	20.9	22.1	23.0	24.6	90.0	93.3	93.3
	5	16.2	20.0	20.6	20.7	22.8	23.8	91.3	93.6	94.8
	6	16.4	20.2	21.5	25.2	23.8	24.6	88.4	93.6	96.2
	7	17.0	20.5	21.1	18.3	24.4	----	88.6	93.0	94.1
	8	14.9	19.9	19.9	19.9	22.8	23.4	85.6	94.0	94.6
	9	14.4	20.2	20.8	----	----	----	85.1	93.3	96.2
	10	12.8	20.2	20.5	18.9	23.6	25.5	85.0	93.7	96.2
1979	2	24.0	20.0	----	23.7	23.7	----	87.8	91.8	----
	3	17.9	19.5	20.5	29.5	23.9	25.8	89.3	93.6	94.2
	4	----	----	----	----	----	----	87.8	91.0	94.3
	5	----	19.4	----	----	21.5	----	89.2	90.7	92.8
	6	15.3	18.6	----	20.1	22.8	----	87.0	91.3	----
	7	15.9	----	----	----	----	----	88.7	----	----
	8	13.0	18.8	19.7	----	23.3	24.2	86.8	94.2	96.2
	9	13.9	18.0	19.6	19.9	22.7	25.3	86.1	92.4	96.1
	10	12.6	16.9	19.4	19.3	22.5	24.2	86.5	92.1	95.6
			Sodium			Magnesium			Calcium	
1978	4	10.0	9.6	10.0	8.7	7.6	7.3	36.2	35.9	34.4
1979	5	7.8	9.6	9.1	7.4	7.2	7.5	31.9	33.8	34.1

TABLE 24

LAKE ERIE 1979 SEDIMENT SURVEY (USEPA)
CLUSTER MEANS (mg/kg dry weight)

CLUSTER NO.	AL	BA	CR	CU	FE	MN	HG	TI	VA
1	10,391	65	44	25	14,091	639	0.01	287	40
2	10,113	54	39	26	21,125	498	0.03	111	28
3	15,303	83	46	34	28,970	601	0.04	123	35
4	22,556	121	48	36	38,778	762	0.03	173	49

TABLE 26

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE WESTERN BASIN 1978

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
May 18-25	Melosira spp.	34.43
	Tabellaria fenestrata	16.28
	Closterium lunula	15.11
	Unidentified pennate diatom	7.57
June 6-15	Cryptomonas erosa	32.74
	Cryptomonas ovata	12.63
	Tabellaria fenestrata	9.20
	Cosmarium spp.	7.16
	Unidentified non-green flagellate	6.11
	Rhodomonas minuta	5.41
June 23-July 2	Cryptomonas ovata	14.57
	Cryptomonas erosa	12.89
	Mougeotia spp.	12.84
	Ceratium hinrundinella*	10.03
	Aphanizomenon flos-aquae*	7.30
July 19-29	Ceratium hinrundinella*	53.79
	Cosmarium sp.	11.99
	Aphanizomenon flos-aquae*	7.99
	Cryptomonas erosa	7.11
	Cryptomonas ovata	6.07
August 8-16	Aphanizomenon flos-aquae*	49.50
	Coscinodiscus rothii*	14.38
	Melosira spp.	11.88
August 29-September 6	Cosinodiscus rothii*	28.62
	Aphanizomenon flos-aquae	14.13
	Melosira spp.	11.58
	Stephanodiscus niagarae	9.28
	Oscillatoria spp.*	6.58
	Anabaena spp.*	5.14

TABLE 26 CONTINUED

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE WESTERN BASIN 1978

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
October 3-12	Oscillatoria sp*	18.60
	Melosira spp.	17.82
	Coscinodiscus rothii*	12.32
	Anabaena spp.*	6.85
	Stephanodiscus niagarae*	6.40
	Pediastrum simplex*	6.16
October 24-November 1	Oscillatoria spp.*	31.04
	Melosira spp.	16.40
	Anabaena spp.*	8.32
	Mougeotia spp.	5.68
November 7-16	Oscillatoria spp.*	26.73
	Melosira spp.	15.04
	Coscinodiscus rothii*	6.42
	Mougeotia spp.	5.88
	Tabellaria fenestrata	5.73
	Dinobryon spp.	5.06

*Eutrophic species

TABLE 27

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE WESTERN BASIN - 1979

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
March 27-29	Fragilaria spp.	17.02
	Tabellaria fenestrata	9.71
	Stephanodiscus niagarae*	9.59
	Melosira spp.	8.51
	Stephanodiscus binderana	7.92
	unidentified centric diatom	7.54
	unidentified non-green flagellate	6.90
	Diatoma tenue var. elongatum*	6.00
	Asterionella formosa	5.77
	Fragilaria crotonensis	5.01
April 17-20	Melosira spp.	29.54
	Diatoma tenue var. elonatum*	15.49
	Stephanodiscus binderana*	14.18
	Tabellaria fenestrata	7.49
	Stephanodiscus niagarae*	6.24
May 15-26	No data	
July 11-19	Aphanizomenon flos-aquae*	18.43
	Ceratium hirundinella*	16.82
	Cryptomonas erosa	11.57
	Coscinodiscus rothii*	6.70
	Cryptomonas ovata	6.14
July 31-August 4	Aphanizomenon flos-aquae*	23.10
	Coscinodiscus rothii*	19.48
	Anabaena spp.*	9.95
	Melosira spp.	8.18
	Anabaena spiroides*	7.49

TABLE 27 CONTINUED

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES IN THE WESTERN BASIN - 1979

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
September 11-21	Melosira spp.	16.71
	Stephanodiscus niagarae*	12.54
	Coscinodiscus rothii*	12.21
	Aphanizomenon flos-aquae*	10.93
	Anabaena spiroides*	7.66
	Anabaena spp.*	6.38
October 4-10	Stephanodiscus niagarae*	22.73
	Melosira spp.	12.93
	Aphanizomenon flos-aquae*	11.96
	Gryosigma spp.	8.10
	Pediastrum simplex*	5.32
	Stephanodiscus binderana*	5.13
November 7-16	Melosira spp.	38.45
	Stephanodiscus binderana*	17.82
	Stephanodiscus niagarae*	14.59
	Aphanizomenon flos-aquae*	6.01
	Diatoma tenue var. elongatum*	5.07

*Eutrophic species

TABLE 28

SEASONAL RELATIVE ABUNDANCE OF COMMON (≥5%) SPECIES
IN THE CENTRAL BASIN - 1978

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
May 18-25	Asterionella formosa	31.92
	Melosira spp.	18.08
	Fragilaria crotonensis	6.44
	Stephanodiscus niagarae*	6.40
	Stephanodiscus binderana*	6.39
June 6-15	Unidentified non-green flagellate	27.95
	Unidentified pennate diatom	13.06
	Rhodomonas minuta	9.48
	Tabellaria fenestrata	8.70
	Cryptomonas erosa	8.54
	Fragilaria crotonensis	7.25
June 23-July 2	Fragilaria crotonensis	15.72
	Cryptomonas erosa	11.42
	Unidentified non-green flagellate	12.21
	Stephanodiscus niagarae*	9.64
	Rhodomonas minuta	8.37
	Cryptomonas ovata	7.32
	Tabellaria fenestrata	6.77
July 19-29	Ceratium hirundinella*	29.34
	Aphanizomenon flos-aquae*	8.00
	Stephanodiscus niagarae*	7.59
	Cosmarium spp.	5.10
August 8-16	Ceratium hirundinella*	21.93
	Aphanizomenon flos-aquae*	13.30
	Oedogonium spp.	9.61
	Unidentified coccoid green	5.49
	Scenedesmus bijuga*	5.13

TABLE 28 CONTINUED

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE CENTRAL BASIN - 1978

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
August 29-September 6	Oocystis borgei*	17.68
	Aphanizomenon flos-aque*	11.53
	Unidentified coccoid green	8.79
	Scenedesmus bijuga*	8.79
	Oocystis spp.	7.60
	Oocystis pusilla	5.75
October 3-13	Stephanodiscus niagarae*	12.53
	Cryptomonas erosa	6.56
	Aphanizomenon flos-aque*	5.81
	Unidentified pennate diatom	5.71
	Oocystis borgei*	5.60
	Oocystis spp.	5.22
October 24-November 1	Cryptomonas erosa	13.85
	Oscillatoria spp.*	11.44
	Cryptomonas ovata	9.74
	Oocystis borgei*	7.80
	Stephanodiscus niagarae*	6.55
	Unidentified coccoid green	5.53
November 7-16	Cryptomonas erosa	17.10
	Cryptomona ovata	12.21
	Oscillatoria spp.*	11.79
	Stephanodiscus niagarae*	6.22

*Eutrophic species

TABLE 29

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE CENTRAL BASIN - 1979

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
March 27-29	Stephanodiscus niagarae*	36.03
	Fragilaria spp.	10.81
	Stephanodiscus binderana*	8.89
	Unidentified centric diatom	7.59
	Gryrosigma spp.	7.32
April 17-20	No data	
May 15-26	Stephanodiscus niagarae*	15.55
	Melosira spp.	12.29
	Tabellaria fenestrata	11.26
	Diatoma tenue var. elongatum*	10.65
	Rhodomonas minuta	10.47
	Unidentified non-green flagellate	7.09
	Fragilaria crotonensis	5.99
July 11-19	Ceratium hirundinella*	28.53
	Coelastrum reticulatum	14.67
	Staurastrum paradoxium*	7.21
	Cryptomonas erosa	5.81
	Rhodomonas minuta	5.53
	Oocystis borgei*	5.08
July 31-August 4	Represents only the western portion of the basin	
	Ceratium hirundinella*	25.30
	Aphanizomenon flos-aque*	22.98
	Fragilaria crotonensis	19.28
	Coscinodiscus rothii*	8.19
September 11-21	Stephanodiscus niagarae*	28.05
	Aphanizomenon flos-aque*	8.36
	Pediastrum simplex*	7.39
	Ceratium hirundinella*	7.28

TABLE 29 CONTINUED

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE CENTRAL BASIN - 1979

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
October 4-10	Stephanodiscus niagarae*	30.63
	Melosira spp.	18.40
	Aphanizomenon flos-aquae*	8.23
November 7-16	Melosira spp.	41.76
	Stephanodiscus niagarae*	29.97
	Stephanodiscus binderana*	14.69

*Eutrophic species

TABLE 30

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE EASTERN BASIN - 1978

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
May 18-25	Stephanodiscus binderana*	20.45
	Asterionella Formosa	17.8
	Melosira spp.	9.6
	Stephanodiscus niagarae*	9.6
	Fragilaria crotonensis	9.2
June 6-15	Unidentified pennate diatom	15.7
	Cryptomonas erosa	14.0
	Tabellaria fenestrata	11.5
	Closterium lunula	5.3
June 23-July 2	Cryptomonas erosa	16.4
	Fragilaria crotonensis	14.4
	Rhodomonus minuta	11.7
	Unidentified flagellate	11.2
	Asterionella formosa	9.8
	Tabellaria fenestrata	6.6
July 19-29	Anabaena flos-aquae*	18.7
	Oocystis borgei*	17.0
	Ceratium hirundinella*	13.0
	Staurastrum paradoxum	7.4
	Cryptomonas ovata	5.1
August 8-16	Scenedesmus bijuga*	28.4
	Oocystis borgei*	15.1
	Ceratium hirundinella*	8.3
	Unidentified coccoid green	5.5
August 29-September 6	Oocystis borgei*	24.9
	Oocystis sp.*	16.7
	Scenedesmus bijuga*	11.1
	Unidentified coccoid green	8.0

TABLE 30 CONTINUED

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE EASTERN BASIN - 1978

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
October 3-12	Oocystis borgei*	13.9
	Oocystis sp.	11.1
	Tabellaria fenestrata	10.4
	Staurastrum paradoxum*	8.6
	Unidentified coccoid green	6.3
	Unidentified pennate diatom	5.8
October 24-November 1	Tabellaria fenestrata	21.9
	Stephanodiscus niagarae*	14.7
	Cryptomonos erosa	13.3
	Oocystis borgei*	7.2
	Cryptomonas ovata	7.0
	Staurastrum paradoxum*	5.1
November 7-16	Cryptomonas erosa	18.1
	Tabellaria fenestrata	15.2
	Staurastrum paradoxum*	12.8
	Cryptomonas ovata	10.6
	Cosmarium sp.	5.2

*Eutrophic species

TABLE 31

SEASONAL RELATIVE ABUNDANCE OF COMMON (>5%) SPECIES
IN THE EASTERN BASIN - 1979

CRUISE	SPECIES	% OF TOTAL BIOVOLUME
March 27-29	Stephanodiscus niagarae*	78.33
	Unidentified centric diatom	8.17
April 17-20	No data	
May 15-26	No data	
July 11-19	Oocystis borgei*	19.31
	Ceratium hirundinella*	17.49
	Rhodomonas minuta	11.06
	Fragilaria crotonensis	7.30
	Cryptonoma erosa	5.70
July 31-August 4	No data	
September 11-12	Ceratium hirundinella*	27.78
	Staurastrum paradoxum*	10.02
	Oocystis spp.	8.72
	Cosmarium spp.	7.50
	Coelastrum microporum*	6.78
October 4-10	Stephanodiscus niagarae*	35.73
	Ceratium hirundinella*	10.54
	Microcystis aeruginosa	10.49
	Staurastrum paradoxum*	5.02
November 7-16	Stephanodiscus niagarae*	66.87
	Cryptomonas erosa	5.24

*Eutrophic species

TABLE 34

RATIONALE FOR MONITORING DISSOLVED SUBSTANCES*

Parameter	Sources	Harmful/Beneficial Effects
TDS	Carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates of calcium, sodium, magnesium, potassium, iron and manganese	Concentrations exceeding 500 mg/l are reported to be unpalatable, not capable of quenching thirst, having possible laxative action on new users, causing foam in boilers, interfering with clearness, color or taste of a finished food or beverage product, accelerating corrosion, causing hindrance to crop production and most importantly influencing the toxicity of heavy metals and organic compounds to fish and other aquatic life.
Conductivity	Major ionic species present in the water	At higher concentrations can be harmful to living organisms due to the increase in osmotic pressure, causing water to be drawn from the gills and other delicate external organs, resulting in cell damage or death.
Chlorides	Widely used in water treatment, deicing highways, agricultural salts, human and animal sewage and industrial effluents (paper works, galvanizing plants, water softening, oil wells and petroleum refineries)	In drinking water may be injurious to people suffering from heart or kidney diseases. The USPHS drinking water standards of 1962 recommended that chloride levels not exceed 250 mg/l. Appear to exert a significant effect on the rate of corrosion of steel (45 mg/l), aluminum (5-300 mg/l) and stainless steel (10.0 mg/l).
Sulfate	Leachings from gypsum and abandoned coal mines, as well as numerous industrial wastes (tanneries, sulfate-pulp mills, textile mills, etc.)	Appear to increase corrosiveness of water on concrete. Less toxic to plants than chloride.

TABLE 34 CONTINUED

RATIONALE FOR MONITORING DISSOLVED SUBSTANCES*

Parameter	Sources	Harmful/Beneficial Effects
Sodium	Very common element of the earth's crust (2.83%). Leached from the soils or from industrial wastes	May be harmful to people with cardio-vascular, renal and circulatory diseases at levels of approximately 200 mg/l.
Magnesium	Very common element of the earth's crust (2.1%). Also a constituent of light alloys, used frequently for metallurgy and in the manufacturing of electrical and optical apparatus	At high concentrations, Mg has a laxative effect but it has such an unpleasant taste that people would stop drinking it before it reached toxic levels.
Potassium	Constitutes 2.4% of the earth's crust, is extremely soluble and one of the most active metals	If the total concentration of potassium and sodium exceeds 50 mg/l there may be foaming in boilers. Critical levels of potassium must be 5-10 times higher than the sodium critical level for people with heart and renal problems. Potassium on the other hand is more toxic to fish and shellfish than calcium, magnesium and sodium.
Calcium	Among the most commonly encountered substances in water. Originates from the earth's crust, soil leachates, sewage, and industrial wastes	High concentrations of Ca are associated with low incidence of heart attacks, inhibits corrosion of cast iron and steel and is desirable in irrigation water, essential for normal plant growth and reduces the toxicity of lead, zinc and aluminum to fish. Ca in excess can result in formation of body, kidney or bladder stones, be a disadvantage for washing, bathing, laundrying, form incrustations on cooking utensils and water heaters, result in precipitation and curds when using soaps, and upset certain fermentation processes.

TABLE 34 CONTINUED

RATIONALE FOR MONITORING DISSOLVED SUBSTANCES*

Parameter	Sources	Harmful/Beneficial Effects
Alkalinity	Alkalinity is caused by the presence of carbonates, bicarbonates, hydroxides and to a lesser extent by borates, silicates, phosphates and organic substances. The alkalinity of water can be increased by the addition of municipal sewage and many industrial wastes	Alkalinity in itself is not considered harmful to humans but it is generally associated with high pH values, hardness and excessive solids, all of which may be deleterious. High alkalinities are not desired in the production of food and beverages and may be detrimental for irrigation water. It is desirable to have high alkalinities to inhibit corrosion.
pH	Hydrogen ions, industrial acid and alkaline wastes.	pH of the water affects taste (sour 3.9), corrosivity (dissolves lead pH 8.0), efficiency of chlorination, (diminishes with increasing pH, advantageous if pH 7), and efficiency of treatment processes such as coagulation and industrial applications. PH controls the degree of dissociation of many substances (ammonia, etc.) and since undissociated compounds are frequently more toxic than the ionic forms, pH may be important in areas with effluents of toxic materials.

*From McKee and Wolf, 1974

TABLE 35

LAKE ERIE 1978-1979 NEARSHORE PRINCIPLE ION REACH CONCENTRATIONS (mg/l) AND STATISTICS

Reach number/name	Cl	SO_4	Alk	Na	Mg	K	Ca	Cond umhos/cm	pH
1. Colborne	19.9		106.2					299	8.3
2. Port Maitland	23.2		118.9					359	8.2
3. Nanticoke	20.1		109.6					303	8.2
4. Long Point Bay	20.0		113.5					304	8.2
5. Port Burwell	19.8		113.7					286	8.5
6. Port Stanley	18.9		105.1					285	8.3
7. Wheatley	18.4		99.6					282	8.2
8. Leamington	21.4		89.5					278	8.0
9. Colchester	23.3		89.0					281	7.9
10. Monroe	18.6	29.4	88.4	11.3	8.9	1.0	33.5	282	8.5
11. Maumee	27.5	45.4	101.5	15.9	12.3	2.1	38.9	387	8.5
12. Locust Point	17.8	28.2	92.3	9.9	8.63	1.2	33.0	296	8.4
13. Sandusky Bay	24.4	95.8	95.4	12.3	12.8	2.1	51.3	436	8.6
14. Huron	19.6	27.8	86.8	10.6	7.9	1.1	32.9	286	8.3
15. Lorain	18.9	29.0	88.9	10.3	8.0	1.6	36.5	304	8.3
16. Cleveland	26.3	30.1	89.7	15.4	8.3	2.0	37.8	328	8.2
17. Fairport	25.4	26.0	87.9	13.5	7.8	1.6	37.9	314	8.4
18. Conneaut	20.7	25.8	87.0	8.7	8.2	2.0	27.0	294	8.4
19. Erie Harbor	24.6	26.4	89.5	9.6	8.2	2.0	27.4	303	8.4
20. Dunkirk	20.8	26.7	88.7	8.0	8.4	1.8	28.4	293	8.4
$\bar{x}$ 21.48	35.51	97.06	11.41	9.04	1.68	34.96	310		
SD 2.88	20.74	10.55	2.60	1.77	0.41	6.89	40		
SE 0.64	6.25	2.36	0.78	0.53	0.12	2.07	9		
%SE 3.0	17.61	2.43	6.87	5.86	7.14	5.95	2.9		
n 20	11	20	11	11	11	11	20		

TABLE 36

PRINCIPAL ION COMPARISON OF 1970 OPEN LAKE DATA (CCIW) WITH 1978-1979 OPEN LAKE AND NEARSHORE DATA

	K	Mg	Ca	Na	SO_4	HCO_3	Cl
				1970 ANNUAL MEANS			
$\bar{x}$	1.28	7.59	37.19	11.82	24.01	111.56	23.60
SD	0.09	0.20	0.94	0.25	0.61	1.68	0.61
SE	0.03	0.08	0.36	0.09	0.23	0.63	0.23
%SE	2.6	1.0	1.0	0.8	1.0	0.6	1.0
N	7	7	7	7	7	7	7
				1978-1979 STUDY MEANS			
$\bar{x}$		7.63	34.4	9.37	23.25		18.84
SD					1.34		1.38
SE					0.42		0.36
%SE					1.8		1.9
N	NA	2	2	2	10	NA	15
				1978-1979 MEAN OF STUDY NEARSHORE REACH MEANS			
$\bar{x}$	1.68	9.04	34.96	11.41	35.51	97.06	21.48
SD	0.41	1.77	6.89	2.60	20.74	10.55	2.88
SE	0.12	0.53	2.07	0.78	6.25	2.36	0.64
%SE	7.14	5.86	5.95	6.87	17.61	2.43	3.0
N	11	11	11	11	11	20	20

TABLE 40

COMPARISON OF TROPHIC STATUS OF LAKE ERIE'S NEARSHORE ZONE USING ANNUAL REACH MEANS, 1978-1979

REACH NO.	GROUP*	SECCHI (m)	CHL a ug/l	TP ug/l	CTI**	TROPHIC STATUS***
1	A	3.2	2.4	12.3	4.3	O/M
2	A	2.0	5.0	51.3	11.6	E
3	A	2.2	2.2	14.7	5.8	M
4	A	2.7	2.0	12.7	4.7	M
5	A	2.8	2.8	18.2	5.6	M
6	A	1.6	4.2	18.8	8.9	M
7	A	2.1	6.6	22.2	9.2	E/M
8	B	1.0	6.0	27.5	10.7	E/M
9	C	0.7	2.9	24.6	7.8	M
10	A	0.7	27.3	100.7	37.9	E
11	A	0.5	36.1	179.6	56.4	E
12	A	0.7	18.4	97.1	32.6	E
13	A	0.3	61.7	158.3	81.1	E
14	A	1.1	13.1	77.9	22.2	E
15	A	1.9	6.9	55.7	13.3	E
16	A	2.3	6.8	54.7	12.3	E
17	A	2.1	6.8	40.3	11.2	E
18	A	2.8	4.0	23.6	6.8	M
19	A	1.7	19.5	64.2	21.8	E
20	A	2.7	4.0	23.6	6.9	M

*A High chlorophyll a and low secchi depth
B Low chlorophyll a and high secchi depth
C High inorganic turbidity

**Composite Trophic Index (Gregor and Rast 1979)

***E = Eutrophic
E/M = Eutrophic/Mesotrophic
M = Mesotrophic
O/M = Oligotrophic/Mesotrophic
O = Oligotrophic

TABLE 41

SUMMARY OF TROPHIC STATUS DATA FOR LAKE ERIE NEARSHORE WATERS, SUMMER 1972-1973*

REACH NO.	GROUP**	SECCHI (m)	CHL a ug/l	TP ug/l	CTI***	TROPHIC STATUS****
1	A	3.7	2.3	18	4.5	O/M
2	A	3.6	2.4	23	5.1	M
3	A	4.0	2.6	19	4.5	O/M
4	A	3.0	3.7	34	7.5	M
5	A	3.5	2.2	17	4.5	O/M
6	A	4.0	2.0	20	4.3	O/M
7	A	3.9	1.9	21	4.4	O/M
8	C	2.9	1.7	15	3.2	O/M
9	C	2.7	1.7	17	3.6	O/M
10	C	2.3	2.3	21	4.5	O/M
11	C	1.6	2.2	19	4.7	M
12	C	1.6	3.3	28	6.3	M
13	C	1.1	3.6	24	6.9	M
14	A	2.6	3.4	19	6.2	M
15	A	2.8	3.9	20	6.3	M
16	A	2.9	4.8	19	6.6	M
17	A	2.0	5.6	32	9.9	E/M
18	A	1.4	10.3	48	16.2	E
19	A	1.8	7.2	42	12.3	E
20	C	1.4	2.8	34	6.8	M
21	-	-	-	-	-	
22	A	2.0	7.5	42	11.9	E
23	-	-	-	60	-	
24	-	-	-	30	-	
25	-	-	-	40-100	-	
26	-	-	-	30	-	
27	-	-	-	INSF	-	
28	-	-	-	INSF	-	
29	-	-	-	INSF	-	
30	-	-	-	INSF	-	
31	-	-	-	INSF	-	
32	-	-	-	INSF	-	
33	-	-	-	23	-	

*Taken from Gregor and Rast, 1979

**A High chlorophyll a and low secchi depth
B Low chlorophyll a and high secchi depth
C High inorganic turbidity

***Composite Trophic Index
(Gregor and Rast 1979)

****E = Eutrophic
E/M = Eutrophic/Mesotrophic
M = Mesotrophic
O/M = Oligotrophic/Mesotrophic
O = Oligotrophic

INSF = Insufficient Data

TABLE 42

STEINHART WATER QUALITY INDEX VALUES FOR THE LAKE ERIE 1978-1979 NEARSHORE REACHES

Reach	1978	1979
1	*69.24	*67.56
2	*$54.14_{P_1C_1}$	*56.53
3	*67.80	*67.03
4	*69.38	*69.47_{P_1}
5	*65.95	N.D.
6	*64.84	N.D.
7	*69.23	*60.56_{C_1}
8	*61.11_{C_1}	*62.48_{C_1}
9	*63.67_{C_1}	ND
10	$31.80_{C_1B_2T_3}$	$36.61_{C_1P_1B_1T_3}$
11	$34.66_{C_2P_2B_2T_2}$	$38.55_{C_1P_2B_1T_2}$
12	$31.52_{C_1P_1B_1T_2}$	$51.27_{C_1P_1B_1T_2}$
13	$25.28_{C_1P_2B_2T_3}$	$29.22_{C_1P_2B_2T_3}$
14	$48.95_{C_1B_2T_2}$	$38.16_{P_1C_1B_1T_3}$
15	$42.46_{C_1T_5}$	*$57.58_{C_1T_2}$
16	$40.57_{C_2B_1T_4}$	*$55.95_{P_1C_2T_2}$
17	$44.43_{P_1C_1T_4}$	*$40.23_{P_1C_2T_3}$
18	$44.08_{B_1C_1T_4}$	*$58.97_{C_2T_1}$
19	$41.08_{C_1T_3}$	*67.7_{C_2}
20	$46.83_{C_1T_4}$	*$70.44_{C_1T_1}$

B = Biological (fecal coliforms and chlorophyll a)

C = Chemical (chloride and total phosphorus)

T = Toxics (inorganic and organic)

*incomplete data set (either B, C, P or T missing)

TABLE 43

COMPARISON OF THE NEARSHORE COMPOSITE TROPHIC INDEX (CTI) AND STEINHART'S INDEX USING 1978-1979 LAKE ERIE DATA

Reach #	Name	1978-1979 CTI*	Rank	1978 Steinhart	Rank	Sum of Ranks	Rank of Sums
1	Colborne	4.3	1	69.24*	2	3	1
2	Maitland	11.6	12	54.14*	9	21	11
3	Nanticoke	5.8	4	67.80*	4	8	3
4	Long Pt. Bay	4.7	2	69.38*	1	3	1
5	Pt. Burwell	5.6	3	65.95*	5	8	3
6	Pt. Stanley	8.9	8	64.84*	6	14	6
7	Wheatley	9.2	9	69.23*	3	12	5
8	Leamington	10.7	10	61.11*	8	18	9
9	Colchester	7.8	7	63.67*	7	14	7
10	Monroe	37.9	18	31.80	18	36	17
11	Maumee Bay	56.4	19	34.66	17	36	17
12	Locust Point	32.6	17	31.52	19	36	17
13	Sandusky Bay	81.1	20	25.28	20	40	20
14	Huron	22.2	16	48.95	10	26	13
15	Lorain	13.3	14	42.46	14	28	14
16	Cleveland	12.3	13	40.57	16	29	15
17	Fairport	11.2	11	44.43	12	23	12
18	Conneaut	6.8	5	44.08	13	18	9
19	Erie	21.8	15	41.08	15	30	16
20	Dunkirk	6.9	6	46.83	11	17	8

*Gregor and Rast's Composite Trophic Index (1979)

TABLE 46

CENTRAL BASIN SOD RATES (g $O_2 m^{-2} d^{-1}$) OF SEVERAL INVESTIGATORS

(Taken from Davis et al. 1981)

Data Source	June	July	August	Sept.
Davis et al. (1981)	--	1.45 0.55	0.94 0.43	0.48 0.24
Lucas & Thomas (1971)	1.45 (1.60[1])	--	0.43	1.3
Blanton & Winklhofer (1972)	--	--	0.32	--
Snodgrass & Fay (1979)	mean summer rate of 0.35			
Lasenby (1979)	0.44	--	0.27	0.32

[1] A June mean value of 1.6 g $O_2 m^{-2} d^{-1}$ was reported by Lucas and Thomas in which they included several observations when the sediments within the chamber were slightly to moderately resuspended.

TABLE 47

COMPONENTS OF HYPOLIMNETIC OXYGEN DEMAND (HOD) IN CENTRAL LAKE ERIE - 1979

(Taken from Davis et al. 1981)

Cruise	Month	Station	Hypo Thick.	SOD (Areal)*	WOD (Areal)	SOD (Vol.)**	WOD (Vol.)	HOD (Vol.)	SOD % HOD	WOD % HOD
1	JUNE	A1	2.5m	1.28	---	0.51	---	---	---	---
		A2	4.5m	1.56	0.36	0.35	0.08	0.43	81	19
2	JULY	A1	6.2m	1.19	0.43	0.19	0.07	0.26	73	27
		A2	3.5m	0.82	0.42	0.23	0.12	0.35	66	34
3	AUG.	A1	5.5m	0.56	1.10	0.10	0.20	0.30	33	67
		A2	3.8m	0.38	1.22	0.10	0.32	0.42	24	76

*Areal Rate: g m^{-2} day^{-1}

**Volumetric Rate: mg/l/day

TABLE 48

LAKE ERIE CENTRAL BASIN HOMOGENEOUS AREA OXYGEN DEPLETION RATES
(Taken from Rosa 1982)

	RATES		($gm\ m^{-3}\ mo.^{-1}$)	FINAL
YEAR	S	S+V	S+V+Q	S+V+Q+THKS
1929	2.1	2.3	2.1	2.1
1949	2.6	2.7	2.4	2.4
1950	2.4	2.7	2.9	2.9
1951	2.4	2.6	2.8	2.8
1961	3.2	3.8	3.1	2.9
1962	2.9	3.9	4.0	3.5
1963	3.2	3.7	3.6	3.5
1969	2.7	3.5	3.4	3.1
1970	3.0	3.5	3.6	3.4
1974	3.9	4.8	4.2	4.1
1975	2.4	2.9	3.3	3.5
1977	3.2	4.1	3.7	3.6
1978	3.1	3.3	3.7	3.7
1980	2.9	3.7	3.3	3.5

S: Simple Rate.

S+V: Simple, corrected for Vertical Mixing.

S+V+Q: Simple, corrected for Vertical Mixing, and adjusted to 10°C using Q_{10} = 2.0.

S+V+Q+THKS: Simple, corrected for Vertical Mixing, adjusted to 10°C, and Standardized to a mean thickness of 4.15 m.

TABLE 49

MICHIGAN STANDARDS AND IJC OBJECTIVES
FOR LAKE ERIE WATER QUALITY

Parameter	IJC Objective	Michigan Standards
Dissolved O_2 (mg/l)	6.00*	6.00*
pH (std. units)	6.50-9.00**	6.70-8.50**
Dissolved solids (mg/l)	200	
Specific conductance (umhos/cm)	308.0	
Fluoride (ug/l)	1200	
Chloride (mg/l)		50[1]
Cadmium - total (ug/l)	0.200	12[2]
Chromium - total (ug/l)	50	100[2]
Copper - total (ug/l)	5	
Iron - total (ug/l)	300.0	300[2]
Lead - total (ug/l)	25	30[2]
Nickel - total (ug/l)	25	
Arsenic - total (ug/l)	50	100[2]
Mercury - total (ug/l)		50[2]
Mercury - dissolved (ug/l)	0.200	
Selenium - total (ug/l)	10.00	
Phenols (ug/l)	1.00	
PCB's (ug/l)	0.100 - fish, wet weight	
Zinc - total (ug/l)	30	
Ammonia - total (ug/l)	500 (NH_3)	
Fecal Coliform (no./100 ml)		200[3]
Cyanide (ug/l)		5

[1]Monthly average

[2]Proposed

[3]Total body contact

*Minimum

**Permissible range

TABLE 50

OHIO STANDARDS AND IJC OBJECTIVES FOR LAKE ERIE WATER QUALITY

	IJC OBJECTIVE		OHIO STANDARD	
PARAMETER	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
Dissolved O_2	6.00	xxxx	6.00	xxxx
pH	6.50	9.00	6.50	9.00
Conductivity	xxxx	308.00	xxxx	320.0
Phosphorus	xxxx	0.500	xxxx	1.00
Fluoride	xxxx	1.20	xxxx	1.80
Cadmium	xxxx	0.200	xxxx	1.200
Chromium	xxxx	50.00	xxxx	50.00
Copper	xxxx	5.00	xxxx	xxxx
Iron	xxxx	300.00	xxxx	1000.00
Lead	xxxx	25.00	xxxx	30.00
Nickel	xxxx	25.00	xxxx	25.00
Arsenic	xxxx	50.00	xxxx	50.00
Mercury	xxxx	0.200	xxxx	.200
Selenium	xxxx	10.00	xxxx	10.00
Phenols	xxxx	1.00	xxxx	1.00
Zinc	xxxx	30.00	xxxx	30.00
NH_3-NH_4	xxxx	xxxx	xxxx	6.500
NO_3-N	xxxx	xxxx	xxxx	100.00
Manganese	xxxx	xxxx	xxxx	50.00
Cyanide	xxxx	xxxx	xxxx	.0250
Fecal Coliform	xxxx	xxxx	xxxx	200.00
PCB's	xxxx	0.100	xxxx	xxxx

TABLE 51

COMMONWEALTH OF PENNSYLVANIA AND IJC OBJECTIVES STANDARDS FOR LAKE ERIE WATER QUALITY

Parameter	IJC Objective	Pennsylvania[1]
Alkalinity-total (mg/l)		20*
Ammonia (mg/l)	0.020 (NH_3)	0.500
Arsenic (mg/l)	0.050	0.050
Fecal Coliforms (no/100 ml)		200[2]
Total Coliforms (no/100 ml)		1000[2]
Cadmium (mg/l)	0.002	0.010 (96 RLC 50)
Chromium-total (mg/l)	0.050	0.05 (hexavalent)
Copper-total (mg/l)	0.005	0.1 (96 RLC 50)
Cyanide (mg/l)		0.005 ($HCN+CN^-$)
Dissolved Oxygen (mg/l)	6.0*	6.0*
Fluoride (mg/l)	1.200	2.0
Hardness		150 (monthly mean)
Iron-total (mg/l)	0.300	0.300
Iron-dissolved (mg/l)		0.30
Lead-total (mg/l)	0.025	0.050
Manganese-total (mg/l)		1.0
Nickel-total (mg/l)	0.025	0.01 (96 RLC 50)
Nitrite+Nitrate (mg/l - nitrogen)		10.0
pH (std. units)	6.5-9.0**	6.5-9.0**
Phenolics (mg/l)	0.001	0.001
Selenium (mg/l)	0.010	0.010
Sulfate		250.0
Specific Conductance (umhos at 25°C)	308	3400
Total dissolved solids (mg/l)	200	200[3]
Zinc (mg/l)	0.030	
Aldrin/dieldrin (ug/l)	0.001	0.001
	0.300 (mg/kg-fish, wet wgt.)	0.3 (mg/kg-fish, wet wgt.)
Chlordane (ug/l)	0.060	0.060
DDT+metabolites (ug/l)	0.003	0.003
	1 ug/g - fish, wet wgt.	1 ug/g - fish, wet wgt.
Endrin (ug/l)	0.002	0.002
	0.3 ug/g - fish, wet wgt.	0.3 ug/g - fish, wet wgt.

TABLE 51 CONTINUED

COMMONWEALTH OF PENNSYLVANIA AND IJC OBJECTIVES
STANDARDS FOR LAKE ERIE WATER QUALITY

Parameter	IJC Objective	Pennsylvania[1]
Heptachlor (ug/l)	0.001 0.300 ug/g-fish, wet wgt.	0.001 0.300 ug/g-fish, wet wgt.
Lindane (ug/l)	0.010 0.300 ug/g - fish, wet wgt.	0.010 0.300 ug/g - fish, wet wgt.
Methoxychlor (ug/l)	0.040	0.040
Toxaphene (ug/l)	0.008	0.008
Phthalic Acid Esters (ug/l)		
dibutyl-	4.0	4.0
di (2-ethyl hexyl)-	0.6	0.6
other phthalates	0.2	0.2
Polychlorinated biphenyls (PCBs)	0.001 0.1 ug/g - fish, wet wgt.	0.001 0.1 ug/g - fish, wet wgt.
Mercury-total (mg/l)	0.005 - fish, wet wgt.	
Mercury-dissolved (mg/l)	0.002	

[1]Commonwealth of Pennsylvania Public Law 1987. Title 25. Rules and Regulations. Part I. Dept. of Environmental Resources. Article II. Water Resources. Chapter 93. Water Quality Standards.

[2]Geometric mean taken over not more than a thirty-day period.

[3]Average annual average based on representative lake-wide sampling.

*Minimum

**Permissible range

TABLE 52

NEW YORK STATE STANDARDS AND IJC OBJECTIVES
FOR LAKE ERIE WATER QUALITY

Parameter	IJC Objective[1]	New York State Standard[2]
Fecal coliform bacteria (no/100 m)		200[3]
Total coliform bacteria (no/100 ml)		1000[3]
Dissolved oxygen (mg/l)	6.0*	6.0*
Total dissolved solids (mg/l)	200	200
Specific conductance (umhos/cm)	308	
pH (std. units)	6.5-9.0**	6.7-8.5**
Iron, as Fe (mg/l)	0.3	0.3
Ammonia or ammonium compounds (mg/l)	0.020 (NH_3) 0.500 (NH_3) - water supply	2.0, at pH 8.0
Cyanide (mg/l-CN)		0.100
Ferrocyanide (mg/l-Ferricyanide Fe(CN)6)		0.400
Cadmium total (ug/l)	0.2	300.0
Copper-total (ug/l)	5.0	200.0
Zinc-total (ug/l)	30.0	300.0
Arsenic-total (ug/l)	50.0	
Chromium-total (ug/l)	50.0	
Lead-total (ug/l)	25.0	
Mercury-dissolved (ug/l)	0.2	
Mercury-total (ug/l)	0.5 - fish, wet wgt.	
Nickel-total (ug/l)	25	
Selenium-total (ug/l)	10	
Fluoride-total (ug/l)	1200	
Phenolic compounds (ug/l)	1.0	

[1]Great Lakes Water Quality Agreement of 1978.

[2]Environmental Conservation Law 15-0313, 17-0301. Part 702.1 Class A - Special (International Boundary Waters).

[3]Geometric mean of not less than five samples taken over not more than a 30-day period.

*Minimum

**Permissible range

TABLE 53

ONTARIO PROVINCIAL OBJECTIVES FOR LAKE ERIE WATER QUALITY

PARAMETER	UNIT	OBJECTIVE MIN.	OBJECTIVE MAX.
Chlorine - tot resd	mg/l	xxx	.005
Cyanide = CN - tot	mg/l	xxx	.005
pH	s.u.	6.50	8.50
Phenols - total	ug/l	xxx	1.0
Phosphorus - total	mg/l	xxx	0.020
Beta - total	pc/l	xxx	1000
Radium 226 - dissolved	pc/l	xxx	3.0
Arsenic = As - total	ug/l	xxx	100.0
Beryllium = Be - total	ug/l	xxx	11.0
Cadmium = Cd - total	ug/l	xxx	0.20
Chromium = Cr - total	ug/l	xxx	100.0
Copper	ug/l	xxx	5.0
Iron = Fe - total	ug/l	xxx	5.0
Lead = Pb - total	ug/l	xxx	(25.0) 20.0
Nickel = Ni - total	ug/l	xxx	25.0
Selenium = Se - total	ug/l	xxx	100.0
Mercury = Hg - Dissolved	ug/l	xxx	10.0
Silver = Ag - total	ug/l	xxx	0.10
Zinc = Zn - total	ug/l	xxx	0.30
Endrin	tot ug/l	xxx	0.30
Lindane - whole sample	ug/l	xxx	0.01
Toxaphene	tot ug/l	xxx	0.01
Parathion - whole sample	ug/l	xxx	0.008
Aldrin	tot ug/l	xxx	0.001
Dieldrin	tot ug/l	xxx	0.001

TABLE 54

SUMMARY OF LOCATIONS AND PARAMETERS IDENTIFIED AS AREAS OF CONCERN

Local	Parameter	Status
Michigan		
Detroit River	Fe, Cu, Cd, Hg, phenolic compounds, pH, specific conductance, fecal coliforms	Problem Area
Ohio		
Ottawa and Lucas Counties		
Tributaries		
Maumee River	Cd, Cu, Fe, Pb, Hg, Zn, Mn, P, pH, specific conductance	Problem Area
Nearshore Zone	Cd, Cr, Cu, Fe, Ni, Zn, Mn, P, pH, specific conductance, fecal coliforms	Problem Area (Toledo, Port Clinton)
Water Intakes		
Marblehead	Cd, Cu	
Port Clinton	Cd, Cu, fecal coliform	
Put-in-Bay	Cd, Cu, Zn	
Catawba	Cd, Cu, Zn, Pb	
Oregon	Cd, Cu, Ni, Se, phenolic compounds, P, fecal coliform	
Toledo	Cd, Cu	
Erie and Sandusky Counties		
Tributaries		
Sandusky River	Cu , Cd*, Pb, Fe, P, specific conductance	Problem Area
Huron River	Cu*, Cd*, DO, TP, specific conductance	Problem Area
Vermilion River	Cu*, Cd*, Zn	Problem Area

TABLE 54 CONTINUED

SUMMARY OF LOCATIONS AND PARAMETERS IDENTIFIED AS AREAS OF CONCERN

Local	Parameter	Status
Nearshore	Cd, Cu, Ni, Zn, Fe, pH, fecal coliforms specific conductance	Area of Concern (Sandusky Bay)
Water Intakes		
Kelleys Island	Cd*, Zn	
Milan	Cd*, Zn	
Vermilion	Cd*, Zn	
Huron	Cd*, Zn	
Sandusky	Cd*, Zn	
Ohio		
Lorain County		
Tributaries		
Black River	Cd, Cu, Ni, Mn, Fe, phenolic compounds, Cyanide, P, NO_3, DO, specific conductance, fecal coliforms	Problem Area
Vermilion River	Cu*, Cd*, Ni*, Cr, Pb, Fe, Zn, phenolic compounds, P, NO_3, specific conductance , fecal coliforms	Problem Area
Nearshore	Cd, Cu, Zn, Ni, Mn, Hg, DO, specific conductance	Problem Area (Lorain)
Water Intakes		
Avon	Cd*, Cu*, Pb*, Fe*	
Lorain	Cd*, Cu*, specific conductance, fecal coliforms	

TABLE 54 CONTINUED

SUMMARY OF LOCATIONS AND PARAMETERS IDENTIFIED AS AREAS OF CONCERN

Local	Parameter	Status
Cuyahoga County		
Tributary		
Cuyahoga	Cd, Cu*, Ni*, Zn, Pb, Fe, phenolic compounds, TP, DO, specific conductance, fecal coliforms - rare occurrence Se, Cr, Mn, N, NH_3	Area of Concern
Euclid Creek	Cd*, Cu*, Pb, Ni*, Fe , Zn, specific conductance , pH, fecal coliforms	Problem Area
Rocky River	Cd, Cu, Pb, Zn, Pb, Mn, Hg, DO, specific conductance	Problem Area
Lake and Ashtabula		
Tributaries		
Grand River	Cd* , Cu* , Fe , Pb, Ni, Zn, Mn, Hg, phenolic compounds, DO, specific conductance , fecal coliforms	Area of Concern
Chagrin River	Cd*, Cu*, Ni*, Pb, Zn, Mn, Fe , phenolic compounds, fecal coliforms	Area of Concern
Ashtabula River	Cd*, Cu*, Fe, phenolic compounds , P, DO, specific conductance	Problem Area
Conneaut Creek	Cd*, Ni*, Pb, Fe, Zn, phenolic compounds , P, specific conductance, fecal coliforms	Area of Concern
Ohio		
Lake and Ashtabula		
Nearshore	Cd , Cu , Ni , Zn , Hg, Mn, DO - rare F, Se Cyanide, phenolic compounds, pH, specific conductance	Area of Concern (Fairport, Ashtabula, Conneaut)

TABLE 54 CONTINUED

SUMMARY OF LOCATIONS AND PARAMETERS IDENTIFIED AS AREAS OF CONCERN

Local	Parameter	Status
Water Intakes		
Mentor	P, DO, specific conductance, fecal coliforms	
Conneaut	Fe, P, phenolic compounds	
Open Lake	Cd*, Cu, Cr, Ni, Zn, Pb, Fe, Hg, DO	
Pennsylvania	DO, specific conductance, fecal coliforms	
New York	DO, specific conductance, Cd, Cu, Ni, Zn	
Ontario, Canada		
Nearshore	Cd, Cr, Pb, Ni, Zn , Fe, Ag, Be, phenolic compounds, TP , pH	
Open Lake	Cd, Zn, Fe, Ag, Be, Pb	

*Data of questionable quality for reliable interpretation
High frequency of violation

TABLE 55

NEUROTOXIC AND ONCOGENIC HUMAN HEALTH PROBLEMS ASSOCIATED WITH CHRONIC EXPOSURE TO SELECTED TRACE METALS

TRACE METAL	EFFECT
Aluminum	Mental deterioration; aphasia; convulsions
Arsenic	Oncogenic* - eye,larynx, myeloid leukemia; ischaemic disease of the extremeties
Cadmium	Franconi's syndrome, loss or impairment of sense of smell
Lead, inorganic	Child development; disoreientation; blindness; nerve damage to hands and feet; mental retardation
Mercury, inorganic	Tremors in hands, face and legs
Mercury, organic	Minamata disease; visual field constriction; nerve damage in hands and feet
Manganese	Psychosis; impaired speech; tremors; loss of coordination; muscular weakness
Nickel	Oncogenic* - mouth, intestine

*Selected studies have identified a correlation with cancer; however, a causal relationship has not been found.

Data from National Institute for Occupational Safety and Health.

TABLE 56

OBJECTIVES AND/OR STANDARDS FOR METAL CONCENTRATIONS IN LAKE ERIE

AUTHORITY	OBJECTIVE STANDARD (ug/l)										
	Ar	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Zn
International Joint Commission	50.0	0.2	50.0	5.0	300.0	25.0		0.2	25.0	10.0	30.0
Ontario Ministry of the Environment	100.0	0.2	100.0	5.0	300.0	25.0			25.0	100.0	30.0
Commonwealth of Pennsylvania	50.0	10.0		100.0	1500.0	50.0	1000.0		10.0	10.0	
State of New York		300.0		200.0	300.0						
State of Ohio					1000.0		50.0				
Lake Erie	50.0	1.2	50.0	5.0		30.0			25.0	10.0	30.0
excepted areas		12.0	100.0	10.0		30.0			200.0	50.0	55.0
State of Michigan		12.0	100.0		300.0	30.0					

96 RLC 50

proposed

TABLE 58

NUMBER OF TOTAL CADMIUM, TOTAL COPPER, TOTAL LEAD, TOTAL NICKEL, TOTAL SILVER AND TOTAL ZINC OBSERVATIONS CALCULATED TO EXCEED USEPA PUBLISHED CRITERIA FOR WATER QUALITY, 1978-1979 PERIOD OF RECORD.

STATION NUMBER	PARAMETER	OBSERVATIONS EXCEEDING CRITERION/ TOTAL OBS. (N)	STATION LOCATION
112 WRD 04165700	Cadmium	1/9	Detroit River at Detroit
112 WRD 04193500	Cadmium	3/9	Maumee River at Waterville
112 WRD 04208000	Cadmium	2/7	Cuyahoga River at Independence
112 WRD 04208503	Cadmium	3/9	Cuyahoga River in Cleveland
	Copper	3/9	
	Zinc	1/9	
112 WRD 04212200	Cadmium	1/9	Grand River at Painesville
112 WRD 04213500	Copper	1/22	Cattaraugus Creek at Gowanda
21 MICH 580048	Cadmium	1/7	Intake, City of Monroe water supply
21 OHIO 501260	Cadmium	1/14	Vermilion River near Vermilion
21 OHIO 501510	Cadmium	5/23	Black River below Elyria
	Copper	3/23	
21 OHIO 501520	Cadmium	2/15	Black River at Elyria
	Copper	2/15	
21 OHIO 501800	Cadmium	2/18	Rocky River near Berea
	Copper	2/18	
21 OHIO 502020	Cadmium	4/12	Cuyahoga River at Independence
	Copper	1/12	
21 OHIO 502130	Cadmium	3/13	Cuyahoga River in Cleveland
	Copper	1/13	
21 OHIO 502140	Cadmium	1/3	Cuyahoga River in Cleveland
21 OHIO 502400	Cadmium	4/16	Chagrin River at Willoughby
	Copper	3/16	
21 OHIO 502520	Cadmium	1/18	Grand River at Painesville
	Copper	2/18	
21 OHIO 502530	Cadmium	7/13	Grand River near Painesville
	Copper	6/13	
21 OHIO 502870	Cadmium	15/16	Conneaut Creek at Conneaut
	Copper	10/16	
	Zinc	1/16	
21 OHIO 504030	Cadmium	12/13	Intake, Sandusky water supply
	Copper	12/13	

TABLE 58 CONTINUED

NUMBER OF TOTAL CADMIUM, TOTAL COPPER, TOTAL LEAD, TOTAL NICKEL, TOTAL SILVER AND TOTAL ZINC OBSERVATIONS CALCULATED TO EXCEED USEPA PUBLISHED CRITERIA FOR WATER QUALITY, 1978-1979 PERIOD OF RECORD.

STATION NUMBER	PARAMETER	OBSERVATIONS EXCEEDING CRITERION/ TOTAL OBS. (N)	STATION LOCATION
21 OHIO 504090	Cadmium	3/3	Crown intake, Cleveland water supply
	Copper	3/3	
21 OHIO 504130	Cadmium	1/1	Intake, Mentor-on-the-Lake water supply
	Copper	1/1	
21 OHIO 504240	Cadmium	9/12	Intake, Oregon water supply
	Copper	5/6	
21 OHIO 504250	Cadmium	5/25	Euclid Creek at Euclid
	Copper	3/25	
21 OHIO 504260	Cadmium	3/5	Turkey Creek near Conneaut
	Copper	1/5	
Grand totals			
	Cadmium	89/348 (25.6%)	
	Copper	60/348 (17.2%)	
	Zinc	2/348 (0.6%)	

TABLE 66

TOTAL METAL CONCENTRATIONS (ug/L) FOR LAKE ERIE, 1982
(Taken from Rossman 1983)

Element	East (n=3)			Central (n=4)			West (n=3)		
	$\bar{X}$	σ	Median	$\bar{X}$	σ	Median	$\bar{X}$	σ	Median
Ag	0.038	0.0021	0.039	0.025	0.0097	0.019	0.035	0.013	0.033
Al	57.	19.	52.	120.	80.	97.	4200.	1800.	5100.
As	0.30	0.020	0.30	0.57	0.14	0.54	0.61	0.28	0.52
Ba	49.	1.1	49.	51.	3.0	52.	55.	4.3	57.
Be	0.039	0.038	0.022	0.022	0.0072	0.021	0.16	0.088	0.20
Bi	1.4	0.28	1.5	0.68	0.38	0.45	0.37	0.19	0.28
Ca[1]	35.	0.57	35.	35.	1.2	34.	31.	0.87	31.
Cd	0.058	0.020	0.052	0.051	0.014	0.044	0.20	0.10	0.14
Co	0.086	0.024	0.096	0.077	0.023	0.068	0.59	0.45	0.84
Cr	0.38	0.035	0.39	0.29	0.094	0.30	3.6	0.68	3.6
Cu	2.1	0.52	2.1	1.0	0.38	0.84	3.0	1.7	2.3
Fe	42.	4.6	42.	76.	45.	37.	1400.	220.	1400.
Hg	0.075	0.062	0.048	0.082	0.057	0.063	0.066	0.0052	0.065
K[1]	1.2	0.030	1.2	1.2	0.015	1.2	1.6	0.14	1.6
Li	1.9	0.079	1.9	1.9	0.21	1.7	3.2	0.14	3.3
Mg[1]	10.	0.39	10.	11.	0.050	11.	10.	0.30	10.
Mn	2.4	0.96	2.3	10.	3.0	8.9	44.	11.	48.
Mo	2.1	0.13	2.1	1.5	0.48	1.2	1.2	0.29	1.2
Na[1]	9.3	0.11	9.3	8.6	0.18	8.6	5.8	0.63	6.2
Ni	1.0	0.32	0.85	0.99	0.13	1.0	2.9	1.5	2.3
Pb	0.21	0.039	0.20	0.26	0.096	0.21	2.4	0.66	2.4
Sb	0.062	0.041	0.071	0.31	0.11	0.34	0.056	0.025	0.047
Se	2.8	1.2	2.2	2.6	0.72	2.5	0.85	0.97	0.63
Sn	0.18	0.031	0.18	2.8	2.3	1.4	2.3	1.2	1.9
Sr	150.	10.	140.	150.	9.8	150.	130.	24.	120.
V	0.30	0.068	0.32	0.48	0.11	0.42	3.2	1.3	3.7
Zn	0.95	0.27	0.96	1.2	0.69	1.1	20.	3.7	18.

[1] mg/L

TABLE 67

CALCULATED TOXICITY UNITS FOR LAKE ERIE, 1982
(Taken from Rossman 1983)

Metal	Water Quality Objective (O_i)[1]	Observed Concentration (M_i)[1]	M_i/O_i
Ag	0.1	0.035	0.35
As	50.0	0.43	0.0086
Cd	0.2	0.096	0.48
Cr	50.0	0.39	0.0078
Cu	5.0	1.8	0.36
Fe	300.0	100.0	0.33
Hg	0.2[2]	0.024	0.12
Ni	25.0	1.1	0.044
Pb	5.0[3]	0.34	0.068
Se	1.0[4]	2.1	2.1
Zn	30.0	1.2	0.040
			3.91
Toxicity Unit	$(\sum_{n=1}^{i} M_i/O_i)$		

[1]Median (ug/L)

[2]Filtered sample

[3]3.0 ug/L for Lake Huron

[4]Recommended objective

TABLE 68

NUMBER ASSIGNMENTS, AGENCIES AND LOCATIONS FOR STATIONS SELECTED FOR TREND ANALYSIS

ASSIGNED NUMBER	STATION STORET CODE	AGENCY	STATION DESCRIPTION	LATITUDE	LONGITUDE
T1	820011	MDNR	U.S. shore of Detroit River	42°03'13.5"	83°10'40.1"
T2	000024	MDNR	Middle of Detroit River	43°03'16.2"	83°08'00.5"
T3	000029	MDNR	Canadian shore of Detroit River	42°03'17.5"	83°07'08.3"
T4	Not obtained from STORET	City of Toledo	Maumee River at C and O Dock	41°41'46.0"	83°21'39.0"
T5	04194023	City of Toledo	Maumee River at Toledo	40°41'36.0"	83°28'20.0"
T6	0419350	USGS	Maumee River at Waterville	41°30'00.0"	83°42'46.0"
T7	580046	OEPA	River Raisin at ERA Dock	41°54'02.0"	83°21'16.0"
T8	04198005	USGS	Sandusky River below Fremont	41°22'12.0"	83°06'10.0"
T9	0420050	USGS	Black River below Elyria	41°24'42.0"	82°05'45.0"
T10	04208000	USGS	Cuyahoga River at Independence	41°23'43.0"	81°37'48.0"
	50202	OEPA			
T11	502130	OEPA	Cuyahoga River at Cleveland	41°26'52.0"	81°41'06.0"
	502140	OEPA	Cuyahoga River at Cleveland	41°49'17.0"	81°41'07.0"
	380126	OEPA	Cuyahoga River at Cleveland	41°29'39.0"	81°42'12.0"
T12	01 0006	NY DEC	Buffalo River	41°51'42.3"	78°52'04.0"
T13	01 C005	NY DEC	Black Rock Canal	42°54'54.4"	78°54'10.0"
T14	01 0007	NY DEC	Niagara River	42°57'02.0"	78°54'10.0"
T15	04219640	NY DEC	Niagara River near Lake Ontario	43°15'40.0"	79°03'47.0"

TABLE 68 CONTINUED

NUMBER ASSIGNMENTS, AGENCIES AND LOCATIONS FOR STATIONS SELECTED FOR TREND ANALYSIS

ASSIGNED NUMBER	STATION STORET CODE	AGENCY	STATION DESCRIPTION	LATITUDE	LONGITUDE
I1	580048	MDNR	Monroe water intake	41°56'12.3"	83°13'24.3"
I2	504030	OEPA	Sandusky water intake	41°27'51.0"	82°38'50.0"
I3	504090	OEPA	Crown water intake	41°31'08.0"	81°52'46.0"
I4	J4108	Erie Co. Dept. of Health	Erie water intake	42°09'24.0"	80°09'12.0"
M1	Not obtained from STORET	Toledo Edison	Locust Point - Davis-Besse	41°35'57.0" (cooling tower)	83°05'28.0"

MDNR Michigan Department of Natural Resources
USGS United States Geological Survey
OEPA Ohio Environmental Protection Agency
NY DEC New York Department of Environmental Conservation

T = tributary stations
I = municipal water intakes
M = industrial monitor

TABLE 69

SUMMARY OF LINEAR REGRESSION TRENDS OF WATER QUALITY PARAMETERS AT SELECTED STATIONS ON LAKE ERIE

STATION LOCATION	TEMP	pH	ALK.	DO	COND.	CHLOR.	TURB.	SOLIDS	RES.	SIL.	BOD	NIT.
Tributaries												
820011 (US Shore)	0		-	-	-	-	-	-	-	0	-	0
000024 (Livingstone Chan.)	0	+		+	-	-	0		0	0	0	0
000029 (Canadian Shore)	0	+		0	+	0	0	0	0	0	0	0
River Raisin						0						
C and O Dock	0	-	-	-	0	+	0	0			+	
Toledo		0	0		0	0		0	0			
Waterville	0	+	0	0	0	+	0	0		0		0
Sandusky River		0	0		-	0						
Black River			+									
Cuyahoga at Independence		+	0		0	0						+
Cuyahoga R. at Cleveland (1963-1974)		+	+		-	0						
Cuyahoga R. at Cleveland (1974-1981)			+			0						
Buffalo River	0	+	0	+	-	-	0		-		-	-
Black Rock Canal	0	+		0	0	-	0		0		0	0
Niagara River (0007)	0	-	0		0	-	0		0		0	-
Niagara River at Lake Ont.	+	0	0	0	-	-	0					0
Intakes												
Monroe water intake	0	0	0		0	0			0			
Sandusky water intake	+	-	-	0	+	0	0		+			0
Crown water intake	+	-	+	0	0	0	-					
Erie water intake	0	-	-	+		-	+	-				
Davis-Besse	0	0	0	0		-	0	0		0	0	

TABLE 69 CONTINUED

SUMMARY OF LINEAR REGRESSION TRENDS OF WATER QUALITY PARAMETERS AT SELECTED STATIONS ON LAKE ERIE

STATION LOCATION	NO_3	NH_3+ NH_4	TOTAL KJEDHAL NIT.	NO_3- NO_2	TOTAL ORGAN. CARBON	TOTAL PHOS.	ORTHO PHOS.	TOTAL COLI.	FECAL COLI.	PHENOLS	IRON
<u>Tributaries</u>											
820011 (US Shore)		-	-	0	-	-	-	0	0	-	-
000024 (Livingstone Chan.)		-	-	-	-	-	-	-		-	0
000029 (Canadian Shore)		0	0	0	-	-	-	-	+	-	0
River Raisin				0							
C and O Dock	-	0 (NH_3)					-		-		
Toledo	+										
Waterville		-	0	0	0	-					
Sandusky River	0										
Black River											
Cuyahoga at Independence	0	0	+		+	0		+		0	0
Cuyahoga R. at Cleveland (1963-1974)				-		0		0			+
Cuyahoga R. at Cleveland (1974-1981)		0	0		+	0			0	0	
Buffalo River	+	-	-	0			0	0	0	-	0
Black Rock Canal	0	0		0			0	0			0
Niagara River (0007)	0	0									
Niagara River at Lake Ont.	0	0		0				0			0
<u>Intakes</u>											
Monroe water intake		0				0		0	0	+	
Sandusky water intake	+	0	0		+	0	-		0		+
Crown water intake	0	0	0		+	0			+		
Erie water intake						0		-	-		-
Davis-Besse				+		0					

+ = a significant increasing trend (P .05)

- = a significant decreasing trend

0 = no significant trend observed

A blank indicates the parameter was not sampled

TABLE 70

COMPARISON OF HISTORICAL DATA FROM BEETON (1961) WITH 1978 CENTRAL BASIN NEARSHORE DATA (HEIDELBERG COLLEGE)
(Taken from Richards 1981b)

	Regression analysis of Beeton's data						Extrapolation to 1979		HCWQL data			Comparison	
Parameter	$\underline{Y}$	$\underline{X}$-1900	$\underline{N}$	$\underline{b}$	t_b*	P_b*	$\underline{Y}$	$\underline{S}_y$	$\underline{N}$	$\underline{Y}$	S_y	$\underline{t}$**	$\underline{p}$**
Conductivity													
@TDS .62	267.04	40.20	24	1.25	7.97	.001	315.67	6.81	1041	293.09	14.53	3.31	.001
@TDS .65	254.72	40.20	24	1.20	7.97	.001	300.91	6.45	1041	293.09	14.53	1.21	n.s.
Calcium	36.9	46.6	20	.098	3.09	.01	40.09	1.13	146	35.79	3.06	3.73	.001
Sodium plus Potassium	8.91	45	17	.115	3.87	.01	12.84	1.11	145	11.48	2.19	1.21	n.s.
Chloride	17.6	42.4	30	.305	16.12	.001	28.91	.767	1031	19.16	2.47	12.65	.001
Sulfate	22	48.75	20	.177	5.58	.001	27.25	1.08	1029	24.13	5.56	2.86	.01

*calculated t value, and associated probability level, for t-test of the null hypothesis, H_o: b = 0.
All regression slopes are significant, i.e., significantly different (greater than) from 0.

**calculated t value, and associated probability level, for t-test of the null hypothesis, H_o: $Y_{1978} = \hat{Y}_{1978}$. All parameters show highly significant decreases except sodium plus potassium, which is lower than, but not significantly different from the trend of Beeton's data.

TABLE 71

R-SQUARE AND T VALUES FOR REGRESSION ANALYSES OF DATA FROM THE DIVISION OF WATER INTAKE, CLEVELAND, OHIO, BEFORE AND AFTER FILTERING THE DATA TO REMOVE SEASONAL FLUCTUATIONS.

n.s. indicates slope not significantly different from 0 at the .05 level of significance. A negative t value indicates a decrease in that parameter's concentration through time, a positive t value indicates an increase.

(Taken from Richards 1981b)

	Before			After		
Parameter	r^2	t	significance	r^2	t	significance
Total Phosphorus	.021	-1.8	n.s.	.028	-2.07	.05
Soluble Reactive P	.354	-7.66	.001	.454	-9.43	.001
Nitrate + Nitrite	.122	4.53	.001	.319	8.32	.001
Ammonia Nitrogen	.010	-1.21	n.s.	.010	-1.25	n.s.
Sol. Reactive Silica	.029	1.61	n.s.	.015	1.17	n.s.
Alkalinity	.005	1.52	n.s.	.004	1.30	n.s.
pH	.012	2.29	.05	.030	3.72	.001
Specific Conductance	.001	-0.65	n.s.	.001	-0.66	n.s.
Sulfate	.053	3.43	.001	.050	3.35	.001
Chloride	.264	-8.83	.001	.298	-9.63	.001

TABLE 72

COMPARISON OF MAXIMUM STANDING CROP VALUES[1] FROM THE 1979 and 1980 LAKE ERIE CLADOPHORA SURVEILLANCE PROGRAM

SITE	YEAR	DEPTH (m) 0.5	1	2	3	TRANSECT[2] AVERAGE
Stony Point	1979	107 g/m^2	64	30	0	50
	1980	186 g/m^2	70	T	0	64
South Bass	1979	10 g/m^2	75	110	2	49
	1980	218 g/m^2	174	49	T	110
Walnut Creek	1979[4]	24 g/m^2	20	24	16	21
	1980[3]	18 g/m^2	37	18	59	33
Rathfon Point	1979[4]	983 g/m^2	444	410	214	513
	1980	ND	ND	ND	ND	ND
Hamburg	1979[4]	36 g/m^2	48	52	100	59
	1980[3]	0.1 g/m^2	63	61	86	53

[1]Based on dry weight 64°, except Rathfon Point, dry weight 105°

[2]Transect Average = dry weight of $\frac{0.5, 1, 2, 3m}{4}$

[3]Data from Catherine Carnes, Great Lakes Laboratory, State University College at Buffalo, New York. Personal Communication, 1981.

[4]Data from Sweeney 1980

Table 73. ANNOTATED LIST OF LAKE ERIE FISH SPECIES[1]

FAMILY/COMMON NAME/SCIENTIFIC NAME[2]	ABUNDANCE[3] PRE-1900	PRESENT	NOTES[4]
Petromyzontidae			
silver lamprey (Ichthyomyzon unicuspis)	A	U	WW, SS
sea lamprey (Petromyzon marinus)	-	U	CW, SS
Acipenseridae			
lake sturgeon (Acipenser fulvescens)	A	R	WW, SS, CS*, SF*
Lepisosteidae			
spotted gar (Lepisosteus oculatus)	U	E	WW, WD
longnose gar (Lepisosteus osseus)	C	CD	WW, WD
Amiidae			
bowfin (Amia calva)	C	CD	WW, WD
Clupeidae			
alewife (Alosa pseudoharengus)	-	A	CW, RS, MI, PS
gizzard shad (Dorosoma cepedianum)	C	A	WW, SS, RS, CS, PS
Salmonidae			
longjaw cisco (Coregonus alpenae)	U	E	CW
cisco, lake herring (Coregonus artedii)	A	R	CW, RS, CS*, PS*
lake whitefish (Coregonus clupeaformis)	A	R	CW, RS, CS*, PS*
coho salmon (Oncorhynchus kisutch)	U	C	CW, SS, EI, CS, SF
chinook salmon (Oncorhynchus tshawytscha)	U	C	CW, SS, EI, CS, SF
rainbow trout (Salmo gairdneri)	U	U	CW, SS, EI, RS, SF
lake trout (Salvelinus namaycush)	C	E	CW, RS, CS*, SF*
Osmeridae			
rainbow smelt (Osmerus mordax)	-	A	CW, SS, RS, MI/EI, CS, SF, PS
Hiodontidae			
mooneye (Hiodon tergisus)	C	R	WW, SS, RS, CS*, PS
Umbridae			
central mudminnow (Umbra limi)	C	CD	WW, WD
Esocidae			
grass pickerel (Esox americanus)	C	CD	WW, WD
northern pike (Esox lucius)	A	U	WW, WD, SS, CS*, SF
muskellunge (Esox masquinongy)	A	R	WW, WD, SS, CS*, SF*
Cyprinidae			
goldfish (Carassius auratus)	U	C	WW, WD, SS, EI, CS
common carp (Cyprinus carpio)	U	A	WW, WD, SS, EI, CS, SF, PS
silver chub (Hybopsis storeriana)	A	U	WW, SS, RS, PS*
golden shiner (Notemigonus crysoleucas)	C	CD	WW, WD, PS
pugnose shiner (Notropis anogenus)	C	E	CW, WD
emerald shiner (Notropis atherinoides)	A	A	WW, CS, PS
striped shiner (Notropis chrysocephalus)	C	C	WW
pugnose minnow (Notropis emiliae)	C	R	WW, WD, PS*
blackchin shiner (Notropis heterodon)	C	E	CW, WD, PS*
blacknose shiner (Notropis heterolepis)	C	R	WW, WD, PS*
spottail shiner (Notropis hudsonius)	A	A	WW, PS
spotfin shiner (Notropis spilopterus)	C	C	WW, PS
sand shiner (Notropis stramineus)	C	C	WW, PS
mimic shiner (Notropis volucellus)	C	C	WW, PS
bluntnose minnow (Pimephales notatus)	C	C	WW, PS
fathead minnow (Pimephales promelus)	US	C	WW, PS
longnose dace (Rhinichthys cataractae)	C	U	CW, SS
Catostomidae			
quillback (Carpiodes cyprinus)	C	C	WW, SS, CS, SF
longnose sucker (Catostomus catostomus)	C	CD	CW, SS, CS*
white sucker (Catostomus commersoni)	A	A	WW, SS, RS, CS, SF, PS
lake chubsucker (Erimyzon sucetta)	C	R	WW, WD
northern hogsucker (Hypentelium nigricans)	C	C	WW, SS
bigmouth buffalo (Ictiobus cyprinellus)	A	C	WW, SS, CS
spotted sucker (Minytrema melanops)	C	U	WW, WD, SS
silver redhorse (Moxostoma anisurum)	C	C	WW, SS
golden redhorse (Moxostoma erythrurum)	C	C	WW, SS
shorthead redhorse (Moxostoma macrolepidutum)	A	C	WW, SS, CS, PS
Ictaluridae			
black bullhead (Ictalurus melas)	C	C	WW, WD, SS, CS, SF
yellow bullhead (Ictalurus natalis)	C	U	WW, WD, SS, SF
brown bullhead (Ictalurus nebulosus)	C	C	WW, WD, SS, CS, SF
channel catfish (Ictalurus punctatus)	C	C	WW, SS, CS, SF
flathead catfish (Pylodictis olivaris)	U	U	WW, SF
stonecat (Noturus flavus)	C	C	WW
tadpole madtom (Noturus gyrinus)	C	U	WW, WD
brindled madtom (Noturus miurus)	C	CD	WW

TABLE 73 CONTINUED

FAMILY/COMMON NAME/SCIENTIFIC NAME[2]	ABUNDANCE[3] PRE-1900	PRESENT	NOTES[4]
Anguillidae			
American eel (Anguilla rostrata)	U	U	WW, MS, MI
Cyprinodontidae			
banded killifish (Fundulus diaphanus)	C	R	CW, WD
Gadidae			
burbot (Lota lota)	C	R	CW, RS, CS*
Percopsidae			
trout-perch (Percopsis omiscomaycus)	C	CD	WW, PS
Percichthyidae			
white perch (Morone americana)	-	C	WW, SS, RS, MI, CS, SF, PS
white bass (Morone chrysops)	A	A	WW, SS, RS, CS, SF, PS
Centrarchidae			
rock bass (Ambloplites rupestris)	A	C	WW, CS*, SF
green sunfish (Lepomis cyanellus)	C	C	WW, CS*, SF
pumpkinseed (Lepomis gibbosus)	C	CD	WW, WD, CS*, SF
bluegill (Lepomis macrochirus)	A	C	WW, CS*, SF
smallmouth bass (Micropterus dolomieui)	A	C	WW, CS*, SF
largemouth bass (Micropterus salmoides)	A	C	WW, CS*, SF
white crappie (Pomoxis annularis)	A	A	WW, CS*, SF
black crappie (Pomoxis nigromaculatus)	A	CD	WW, WD, CS*, SF
Percidae			
eastern sand darter (Ammocrypta pellucida)	C	R	WW
greenside darter (Etheostoma blennioides)	C	U	WW
Iowa darter (Etheostoma exile)	C	E	CW, WD
fantail darter (Etheostoma flabellare)	C	U	WW
Johnny darter (Etheostoma nigrum)	C	C	WW
yellow perch (Perca flavescens)	A	A	WW, RS, CS, SF, PS
logperch (Percina caprodes)	C	CD	WW
channel darter (Percina copelandi)	C	R	WW
river darter (Percina shumardi)	U	E	WW
sauger (Stizostedion canadense)	A	U	WW, SS, CS*, SF*, PS
blue pike (Stizostedion vitreum glaucum)	A	E	CW, RS, CS*, RS*
walleye (Stizostedion vitreum vitreum)	A	A	WW, SS, RS, CS, SF, PS
Sciaenidae			
freshwater drum (Aplodinotus grunniens)	A	A	WW, SS, RS, CS, SF, PS
Cottidae			
mottled sculpin (Cottus bairdi)	C	C	WW
spoonhead sculpin (Cottus ricei)	R	E	CW
fourhorn sculpin (Myoxocephalus quadricornis)	R	E	CW
Atherinidae			
brook silverside (Labidesthes sicculus)	A	U	WW, PS

[1]From Trautman (1957, 1981), Hubbs and Lagler (1964), and Van Meter and Trautman (1970); excluding species present in the Lake Erie basin but restricted entirely to tributaries with only occasional strays in the lake.

[2]From Robins et al. (1980).

[3]A = abundant; C = common; CD = common but decreasing; U = uncommon; R = rare; E = probably extirpated; - = absent

[4]WW = warmwater or coolwater species; CW = coldwater species; WD = largely or entirely wetland dependent; SS = migratory stream spawner; RS = migratory reef spawner; MS = migratory marine spawner; EI = intentional exotic introduction; MI = marine invader; CS = commercially significant; SF = significant sport fish; PS = significant prey fish; *currently not significant due to depleted populations or legal protection.

TABLE 74
CURRENT POPULATION STATUS OF MAJOR LAKE ERIE FISH SPECIES

Species	Figure Reference	Date of Decline or Extinction	Current Status	Reasons for Status Change
Lake Whitefish	128	1961	Commercially Insignificant	- Environmental degradation of three major spawning sites by 1920 - Overharvest of cyclically low populations
Lake Herring	128	1960's	Extinct	- Overharvest of cyclically low populations (collapse 1925) - Siltation of clean gravel spawning areas - Deterioration of dissolved oxygen regimes in central basin
Lake Sturgeon	---	Mid 1950's	Rare 4,500 kg/yr	- Deliberate and destructive overharvest - Loss of clean gravelly spawning areas required in tributaries and nearshore waters due to dams, channelization and siltation
Lake Trout	---	1930	Extinct	- Overharvested as early as 1850 - Siltation of the rock and gravel spawning areas - Deterioration of dissolved oxygen regimes in its deepwater central basin habitat
Muskellunge	---	1950	Virtually Extinct	- Siltation and damming of tributaries - Draining, filling and diking of marshes around the western basin - Overharvest
Northern Pike	---	1915	Uncommon	- Siltation and damming of tributaries - Draining, filling and diking of marshes around the western basin - Overharvest
Blue Pike	128	1960	Extinct	- Commercial overharvest - Siltation and pollution of nearshore spawning areas - Habitat loss due to deteriorating summer dissolved oxygen regimes - Hybridization with the more abundant walleye populations
Sauger	128	1960	Extinct	- Commercial overharvest - Siltation and pollution of nearshore spawning areas - Habitat loss due to deteriorating summer dissolved oxygen central basin regimes - Hybridization with the more abundant walleye populations

TABLE 74
CONTINUED
CURRENT POPULATION STATUS OF MAJOR LAKE ERIE FISH SPECIES

Species	Figure Reference	Date of Decline or Extinction	Current Status	Reasons for Status Change
Walleye	128	1962	Abundant	- Overharvest - Competition with the increasing smelt population - Environmental degradation
Yellow Perch	129	---	Abundant	- Increased landings due to use of nylon gill nets, increased Canadian fishing pressure and increased market demand
Rainbow Smelt	129	---	Increasing	- Increased commercial landings reflect seasonal and longterm changes in marketability rather than absolute stock size
Carp	130	---	Abundant	- Increased commercial landings reflect seasonal and longterm changes in marketability rather than absolute stock size
Suckers	130	---	Common	- Increased commercial landings reflect seasonal and longterm changes in marketability rather than absolute stock size
Channel Catfish	130	---	Common	- Increased commercial landings reflect seasonal and longterm changes in marketability rather than absolute stock size
Bullheads	130	---	Common	- Increased commercial landings reflect seasonal and longterm changes in marketability rather than absolute stock size
White Bass	130	---	Common	- Increased commercial landings reflect seasonal and longterm changes in marketability rather than absolute stock size
Freshwater Drum	130	---	Common	- Underexploited
Bowfin	---	---	---	- Not available
Gizzard Shad	130	---	Abundant	- Underexploited
Pacific Salmon	---	---	---	- Artificially stocked since 1870
Goldfish	---	---	Common	- Underexploited

TABLE 74
CONTINUED
CURRENT POPULATION STATUS OF MAJOR LAKE ERIE FISH SPECIES

Species	Figure Reference	Date of Decline or Extinction	Current Status	Reasons for Status Change
Burbot	---	1950	Extinct	- Environmental degradation (siltation and pollution) - Overharvest - Loss of deep water central basin habitat due to oxygen depletion
American Eel	---	---	Uncommon	- Not available
White Perch	---	---	Increasing	- Not available
Centrarchids	---	---	Common	- Not available

TABLE 75

RELATIVE ABUNDANCE OF LARVAL FISHES CAPTURED IN THE WESTERN BASIN OF LAKE ERIE IN 1977

SPECIES	AVERAGE DENSITY[1] (# larvae/100m^3)	PERCENT OF TOTAL CATCH[2]
Gizzard Shad	266.16	82.58
Yellow Perch	21.31	6.61
Emerald Shiner	18.72	5.81
White Bass	7.85	2.44
Carp	2.82	0.88
Freshwater Drum	1.76	0.55
Log Perch	1.43	0.44
Walleye	0.99	0.31
Rainbow Smelt	0.88	0.28
Spottail Shiner	0.18	0.06
Unidentified Sunfish (Lepomis spp.)	0.05	0.02
Whitefish	0.04	0.01
Unidentified Cyprinidae spp.	0.03	0.01
White Sucker	0.02	0.01
Quillback Carpsucker	0.02	0.01
Channel Catfish	0.01	0.01
Trout Perch	0.01	0.01
Sauger	0.01	0.01
Unidentified Percidae spp.	0.01	0.01
Unidentified Crappie (Pomoxis spp.)	0.01	0.01
TOTAL	322.30	

[1] Average densities found by dividing the sum of the calculated densities by the number of tows taken during period of larval occurrence.

[2] Species ranked according to descending percent of catch.

TABLE 76
RELATIVE ABUNDANCE OF LARVAL FISHES CAPTURED ALONG THE OHIO SHORELINE OF THE CENTRAL BASIN IN 1978

SPECIES	AVERAGE DENSITY (# of larvae/100m^3)	PERCENT OF TOTAL CATCH[2]
Emerald Shiner	32.30	34.28
Gizzard Shad	28.42	30.53
Spottail Shiner	16.37	17.58
Freshwater Drum	3.92	4.21
Rainbow Smelt	3.40	3.66
Carp	2.85	3.06
Yellow Perch	1.25	1.34
Trout Perch	1.00	1.01
Johnny Darter	0.80	0.84
Log Perch	0.74	0.79
Mottled Sculpin	0.47	0.50
Cyprinidae	0.46	0.48
Notropis sp.	0.25	0.26
Percidae	0.20	0.21
Unidentified Larvae	0.07	0.08
Unidentified Sunfish (*Lepomis* spp.)	0.07	0.06
Striped Shiner	0.06	0.06
White Sucker	0.05	0.04

TABLE 76 CONTINUED

RELATIVE ABUNDANCE OF LARVAL FISHES CAPTURED ALONG THE OHIO SHORELINE OF THE CENTRAL BASIN IN 1978

SPECIES	AVERAGE DENSITY (# of larvae/100m^3)[1]	PERCENT OF TOTAL CATCH[2]
Walleye	0.04	0.04
White Bass	0.03	0.03
Rock Bass	0.02	0.03
Burbot	0.02	0.03
Golden Shiner	0.02	0.02
Unidentified Crappie		
(*Pomoxis* spp.)	0.01	0.02
Sauger	0.01	0.02
Quillback Carpsucker	0.01	0.01
Black Crappie	0.01	0.01
Smallmouth Bass	0.01	0.01
TOTAL	92.76	

[1] Average density found by dividing the sum of the calculated densities by the number of samples collected during the period of larval occurrence.

[2] Species ranked in descending order of average density.

TABLE 77

LARVAL FISH ENTRAINMENT ESTIMATES FOR WESTERN BASIN POWER PLANTS PER YEAR (1977)

Species	Monroe	Whitting	Bayshore	Davis-Besse	Total
Gizzard Shad	2.70×10^9 6.53×10^8	4.90×10^8 8.10×10^6	1.20×10^9 2.00×10^8	1.30×10^7 3.21×10^6	4.40×10^9 5.86×10^8
Rainbow Smelt	3.79×10^5 1.10×10^5	2.98×10^6 4.27×10^5	7.24×10^6 1.04×10^6	1.99×10^5 3.32×10^4	1.08×10^7 1.64×10^6
Carp	2.13×10^8 1.05×10^7	1.50×10^6 1.64×10^5	3.65×10^6 3.99×10^5	2.54×10^4 4.23×10^3	2.18×10^7 5.28×10^6
White Bass	3.31×10^6 4.68×10^5	2.05×10^7 2.51×10^5	4.99×10^7 6.09×10^6	2.63×10^4 4.24×10^3	7.37×10^7 1.14×10^7
Sauger		4.34×10^5 4.89×10^4	1.05×10^6 1.19×10^5		1.49×10^6 2.49×10^5
Walleye		5.35×10^5 4.79×10^4	1.30×10^6 1.16×10^5	1.22×10^5 1.23×10^4	1.96×10^6 2.93×10^5
Yellow Perch	3.10×10^7 4.35×10^6	2.09×10^7 2.06×10^6	5.07×10^7 5.01×10^6	2.24×10^6 6.48×10^5	1.05×10^8 1.01×10^7
Total*	2.97×10^9 1.50×10^8	5.49×10^8 3.09×10^7	1.33×10^9 6.62×10^7	1.58×10^7 7.47×10^5	4.87×10^9 2.43×10^8

*Total represents the sum of all species collected

Lower number in each cell is equal to one standard error of the mean.

TABLE 78

LARVAL FISH ENTRAINMENT ESTIMATES FOR CENTRAL BASIN POWER PLANTS PER YEAR (1978)

Species	Edgewater	Avon Lake	Eastlake	Lake Shore	Ashtabula A & B	Ashtabula C	Total
Gizzard Shad	7.91×10^6 2.03×10^6	2.38×10^7 3.44×10^6	9.21×10^6 2.60×10^6	4.77×10^6 8.60×10^5	1.01×10^7 2.90×10^6	5.60×10^6 1.75×10^6	6.14×10^7 2.59×10^6
Rainbow Smelt	2.91×10^5 1.54×10^3	1.27×10^6 1.53×10^5	2.19×10^7 3.44×10^6	9.33×10^5 1.03×10^5	4.46×10^6 3.40×10^5	3.06×10^6 3.88×10^5	3.19×10^7 3.08×10^6
Emerald Shiner	9.73×10^5 2.10×10^5	7.44×10^5 1.65×10^5	1.33×10^7 2.91×10^6	2.39×10^6 7.02×10^5	3.18×10^7 8.69×10^6	3.09×10^7 6.76×10^6	8.01×10^7 5.48×10^6
Spottail Shiner	2.48×10^5 5.52×10^4	1.12×10^5 2.91×10^4	5.82×10^6 5.84×10^5	5.45×10^5 7.45×10^4	4.11×10^6 8.68×10^5	3.32×10^5 1.50×10^5	1.12×10^7 9.20×10^5
Walleye			7.65×10^4 1.28×10^4	4.05×10^4 4.75×10^3			1.17×10^5 1.20×10^4
Yellow Perch	4.83×10^4 8.05×10^3	9.84×10^4 3.61×10^3	8.57×10^5 1.59×10^5	1.10×10^6 1.89×10^5	1.70×10^6 1.57×10^5	7.94×10^5 1.98×10^5	4.60×10^6 2.33×10^5
Total*	1.18×10^7 4.21×10^5	3.67×10^7 1.36×10^6	5.40×10^7 1.38×10^6	1.62×10^7 3.00×10^5	7.61×10^7 1.71×10^6	5.12×10^7 1.68×10^6	2.52×10^8 8.59×10^6

*Total represents the sum of all species collected

Lower number in each cell is equal to one standard error of the mean.

TABLE 79

COMPARISON OF NEARSHORE VOLUME WEIGHTED FISH LARVAL ABUNDANCE WITH ESTIMATED ENTRAINMENT

SPECIES	VOLUME WEIGHTED ABUNDANCE	TOTAL NUMBER ENTRAINED	% OF ABUNDANCE
Western Basin			
White Bass	2.65×10^8	7.73×10^7	29.0
Yellow Perch	1.35×10^9	1.05×10^8	7.8
Walleye	6.08×10^7	1.96×10^6	3.2
Central Basin			
Yellow Perch	1.09×10^8	4.60×10^6	3.7
Rainbow Smelt	4.28×10^8	3.19×10^7	7.4

TABLE 80

SUMMARY OF TOXIC SUBSTANCES FROM LAKE ERIE FISH STUDIES, 1977-1980

Author(s)	Report Year	Collection Year	Sampling Area	Fish	Tissue(s)	Parameters
Gessner & Griswald	1978	1977	Maumee Bay Locust Pt. Sandusky Bay	Shad Perch Carp Drum Catfish	WB & F	% lipid DDE DDD Total DDT Dieldrin Aldrin trans-chlordane cis-Chlordane BHC Heptachlor epoxide Lindane PCB (1254 + 1260)
	<u>Study Variables</u> 1. PCB analysis included Arochlors 1254 + 1260 only 2. Results presented without correction for recoveries 3. Recoveries ranged from 50-100% 4. Includes a good review of toxics in water, sediment and fish for Lake Erie south shore					
Gessner	1980	1978	Locust Pt. Port Clinton Cedar Point Bass Islands Erie, PA	C. Catfish Drum Walleye Walleye (age 1) Y. Perch C. Salmon	WB & F	% lipid pp' DDE pp' DDD pp' DDT Dieldrin Aldrin Chlordane BHC

TABLE 80 CONTINUED

SUMMARY OF TOXIC SUBSTANCES FROM LAKE ERIE FISH STUDIES, 1977-1980

Author(s)	Report Year	Collection Year	Sampling Area	Fish	Tissue(s)	Parameters
Gessner (cont.)	1980	1978				BHC (Lindane)
						Heptachlor
						PCB (1254 only)

Study Variables

1. 15 composites of 5 fish for each species
2. Dieldrin and pp' DDE were the only pesticides found in the samples
3. All PCB 1254 and pp' DDE data reported was corrected for % recovery
4. With the exception of yearling walleye, all fish collected were sexually mature

Author(s)	Report Year	Collection Year	Sampling Area	Fish	Tissue(s)	Parameters
Burby et al.	1981	1979	Tributary Survey			
			Raisin River	W. Bass	WB	% Fat
			Maumee River	Y. Perch		Aldrin
			Toussaint	Drum		BHC
			Sandusky	Shad		BHC
			Black	S. Shiner		BHC
			Cuyahoga	E. Shiner		
			Chagrin	C. Shiner		Chlordane
			Grand, Ohio	R. Smelt		
			Ashtabula	N. Pike		op' DDD
			Walnut Creek	C. Catfish		pp' DDD
			Cattaraugus Cr	B. Bullhead		op' DDE
				Carp		pp' DDE
						op' DDT
						pp' DDT
						Dieldrin

TABLE 80 CONTINUED

SUMMARY OF TOXIC SUBSTANCES FROM LAKE ERIE FISH STUDIES, 1977-1980

Author(s)	Report Year	Collection Year	Sampling Area	Fish	Tissue(s)	Parameters
Burby et al. (cont.)	1981	1979	Uptake Survey			α Endosulfan
			Maumee	YOY Bluegill	WB	β Endosulfan
			Cuyahoga	YOY C. Catf.		Endrin
						Heptachlor
						Heptachlor epoxide
						Heptachlorobenzene
		1980	Uptake Survey			2,4-D (Isopropyl ester)
			Maumee	YOY Bluegill	WB	Methoxychlor
			Cuyahoga	YOY C. Catf.		Mirex
			Ashtabula			Toxaphene
						Trifluralin
						PCB's
						arochlor 1016
						arochlor 1254
						arochlor 1260

Study Variables

1. Fish species broken down by age group before analysis
2. Study was broken down into 2 parts:
   1. Survey of 11 tributaries
   2. Uptake Studies
      a. 1979, Autumn
      b. 1980, Spring
3. 1979 Uptake Study consisted of 4 weeks exposure
4. 1980 uptake study lasted 6 weeks with some fish removed weekly to check exposure with time
5. Percent recoveries varied for the survey (15-85%) and uptake (40-104%) studies
6. Data is not corrected for recoveries

TABLE 80 CONTINUED

SUMMARY OF TOXIC SUBSTANCES FROM LAKE ERIE FISH STUDIES, 1977-1980

Author(s)	Report Year	Collection Year	Sampling Area	Fish	Tissue(s)	Parameters
Clark et al.	1982	1980	Detroit Rv Huron Riv., OH Chagrin Rv. Trout Run, PA	C. Salmon (3 yr.)	F	PCB's 1260 1254 1248 1242 total PCB's
		1980	Detroit Rv Huron Rv, OH Chagrin Rv, OH Trout Run, PA	C. Salmon (3 yrs.)	WB	pp DDE pp DDD pp DDT total DDT "Apparent Toxaphene" Mirex Dieldrin Endrin cis-Chlordane trans-Chlordane cis-Nonachlor trans-Nonachlor Mercury Hexachlorobenzene Octachlor epoxide

TABLE 80 CONTINUED

SUMMARY OF TOXIC SUBSTANCES FROM LAKE ERIE FISH STUDIES, 1977-1980

Author(s)	Report Year	Collection Year	Sampling Area	Fish	Tissue(s)	Parameters
Clark et al. (cont.)	1982	1980				Heptachlor
						Heptachlor epoxide
						BHC
						BHC (Lindane)
						Dacthal
						pentachloro-pheny methyl ether
						Hexachlorobutadiene
						1,2,3,4-Tetrachlorobenzene
						Chloryrifos
						Diazinon
						Trifluralin
						8, monohydromirex

1. Three composites of 5 fillet samples each were analyzed for 4 tributaries in Lake Erie as well as for tributaries in all the Great Lakes
2. Lipid content was not analyzed
3. Selection of sites not based on agricultural or industrial use but where 15 coho's could be obtained.

WB = Whole Body
F = Fillets

TABLE 81

FISH SAMPLES[1] COLLECTED FROM LAKE ERIE TRIBUTARY MOUTHS FOUND IN EXCESS OF IJC[2] AND FDA[3] LIMITS ON FISH TISSUE CONCENTRATIONS - 1979
(Taken from Burby et al. 1981)

Contaminant	Limit (ug/g) IJC	FDA	Tributary	Species	Age Group	Concentration (ug/g)
DDT and Metabolites (sum total)	1.0 (whole fish)		Sandusky	Channel Catfish	VI	2.34
			Black	Carp	IX	1.55
Mirex	Detection Limit		Raisin	Spottail Shiner	I	0.05
			Maumee	Gizzard Shad	0	0.03
			Maumee	Spottail Shiner	I	0.02
			Maumee	Yellow Perch	II	0.01
			Maumee	White Bass	0	0.03
			Maumee	Carp	IV	0.03
			Sandusky	Freshwater Drum	0	0.04
			Sandusky	Freshwater Drum	I	0.02
			Sandusky	Gizzard Shad	0	0.06
			Sandusky	White Bass	I	0.02
			Sandusky	White Bass	II	0.04
			Sandusky	Carp	IV	0.02

TABLE 81 CONTINUED

FISH SAMPLES[1] COLLECTED FROM LAKE ERIE TRIBUTARY MOUTHS FOUND IN EXCESS OF IJC[2] AND FDA[3] LIMITS ON FISH TISSUE CONCENTRATIONS - 1979
(Taken from Burby et al. 1981)

Contaminant	Limit (ug/g) IJC	FDA	Tributary	Species	Age Group	Concentration (ug/g)
Mirex (cont'd.)	Detection Limit		Sandusky	Channel Catfish	VI	0.02
			Black	Spottail Shiner	I	0.04
			Black	Freshwater Drum	0	0.04
			Cuyahoga	Gizzard Shad	0	0.01
			Chagrin	Gizzard Shad	0	0.02
			Chagrin	Emerald Shiner	I	0.04
			Grand	Emerald Shiner	I	0.01
			Grand	Gizzard Shad	0	0.03
			Ashtabula	Gizzard Shad	0	0.02
			Ashtabula	Emerald Shiner	I	0.01
Total PCBs		5.0 (edible portion)	Raisin	Carp	IV	17.60
			Raisin	Spottail Shiner	I	5.76
			Raisin	Brown Bullhead	II	9.6
			Sandusky	Channel Catfish	VI	5.1

[1] All samples were homogenates of whole fish.

[2] International Joint Commission (1978)

[3] Food and Drug Administration (1978)

PLAN IMPLEMENTATION
AND LAKE ASSESSMENT

INTERNATIONAL JOINT COMMISSION

Water Quality Board

Water Quality Program Committee

Surveillance Work Group

Lake Erie Task Force

Lake Erie Technical Assessment Team

Lake Erie Surveillance Plan Implementation

a. Intensive Surveys (1978-1979)
b. Annual Survey (1980)
c. Lake Assessment

Figure 1. Organizational Structure Responsible for the Implementation of the Lake Erie Study Plan (Taken from Herdendorf, 1981).

Topic	Organization Responsible
A. MAIN LAKE	
1. Main Lake Monitoring Report	USEPA/CLEAR
2. Oxygen Studies	NWRI/CCIW
3. Sedimentation/Carbon Flux	NWRI/CCIW
4. Sediment Oxygen Demand	CLEAR/NWRI
5. Lake Response to Nutrient Loading	USEPA/LLRS
6. Lake Circulation	NOAA/GLERL
7. Lake Physics Studies	NWRI/CCIW
a. Interbasin transfer	
b. Nearshore-offshore movement	
c. Vertical drift	
B. NEARSHORE	
1. Canadian Nearshore	MOE
2. Western Basin, U.S.	OSU/CLEAR
3. Central Basin, U.S.	Heidelberg Coll.
4. Eastern Basin, U.S.	SUNY/GLL
5. Cladophora	SUNY/GLL
6. Cleveland Intakes	NOACA
7. Toledo/Maumee Bay	TPCA
C. INPUT AND PROBLEM AREAS	
1. NY Beaches, Tributaries, Intakes and Pt. Sources	NYSDEC
2. PA Beaches, Tributaries, Intakes and Pt. Sources	ECDH
3. OH Beaches, Tributaries, Intakes and Pt. Sources	OEPA

Topic	Organization Responsible
4. MI Beaches, Tributaries, Intakes, Point Sources and and Detroit River	MDNR
5. ONT Beaches, Tributaries, Intakes, Point Sources, and Niagara River	MOE
6. Tributary, Point Source, and Atmospheric Loading	IJC
7. Meteorological/Hydrological Summary	NOAA/GLERL
D. CONTAMINANTS	
1. Radioactivity	IJC
2. Fish Contaminants	USEPA/USF&WS
3. Wildlife Contaminants	Canada Wildlife
E. DATA QUALITY	
1. Data Quality Report	IJC
2. Data Management Report	IJC
3. Field and Lab. Procedures	IJC
F. SPECIAL CONTRIBUTIONS	
1. Fish Stock Assessment	GLFC
2. Remote Sensing Experiments	NASA
3. Wastewater Management Study	USACOE
4. Tributary and Storm Event Reports	USGS
5. Phosphorus Management Study	IJC
6. Primary Productivity Study	NWRI/CCIW OSU/CLEAR

Figure 2. The Major Organizations and Participants Involved in the Two-Year Lake Erie Plan (taken from Herdendorf, 1981).

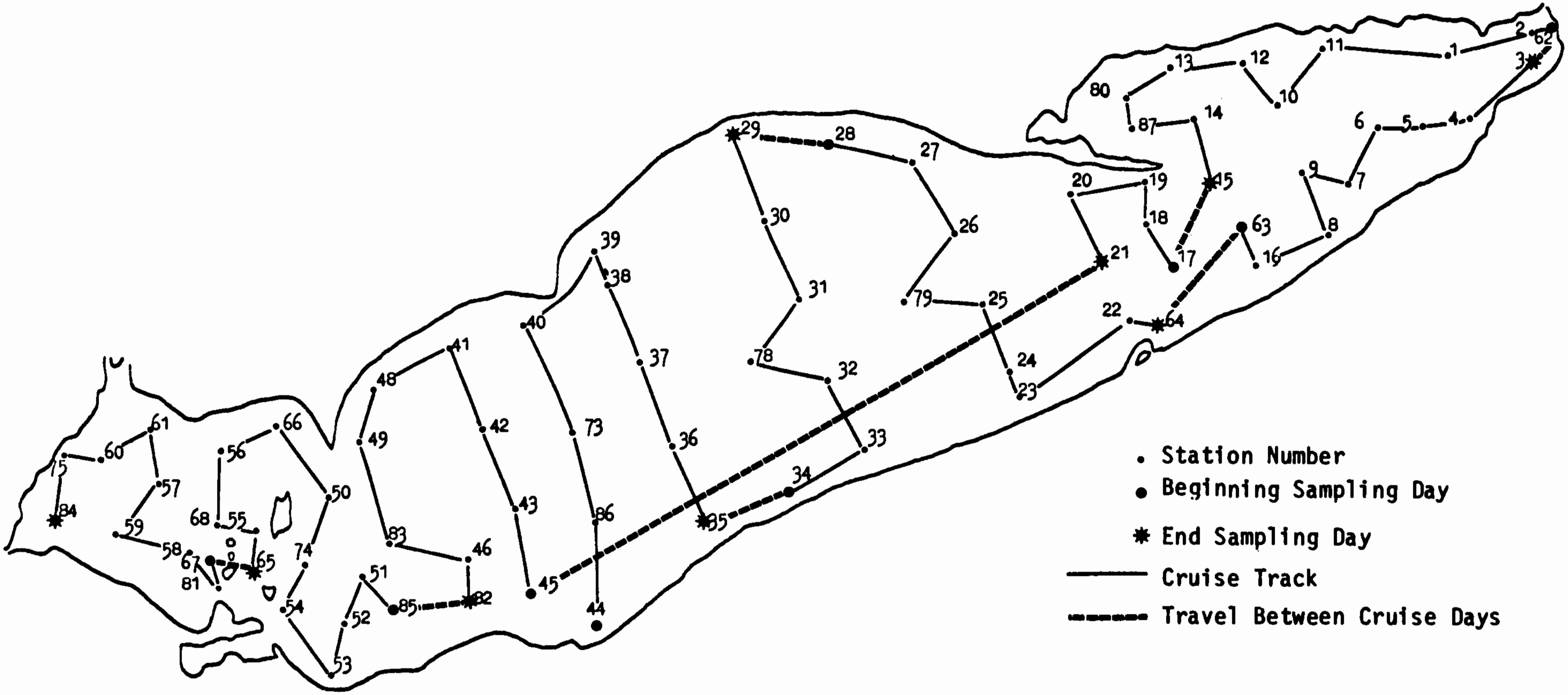


FIGURE 3. REPRESENTATIVE CRUISE TRACK USED BY USEPA-GLNPO DURING 1978 (TAKEN FROM CRUISE 7, AUGUST 29 - SEPTEMBER 6).

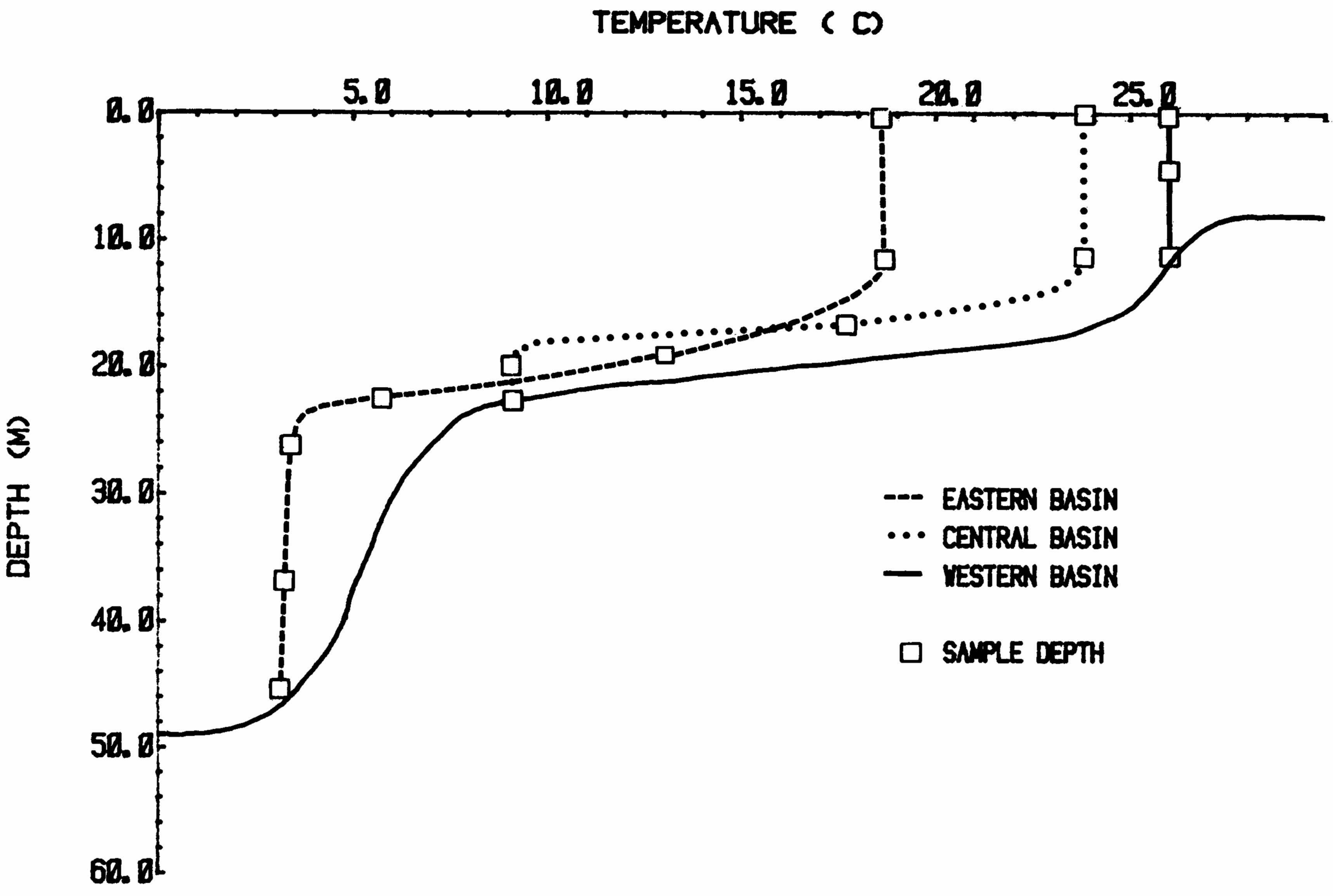


FIGURE 4. SCHEMATIC REPRESENTATION OF THE HORIZONS SAMPLED IN THE THREE BASINS DURING THE STRATIFIED SEASON.

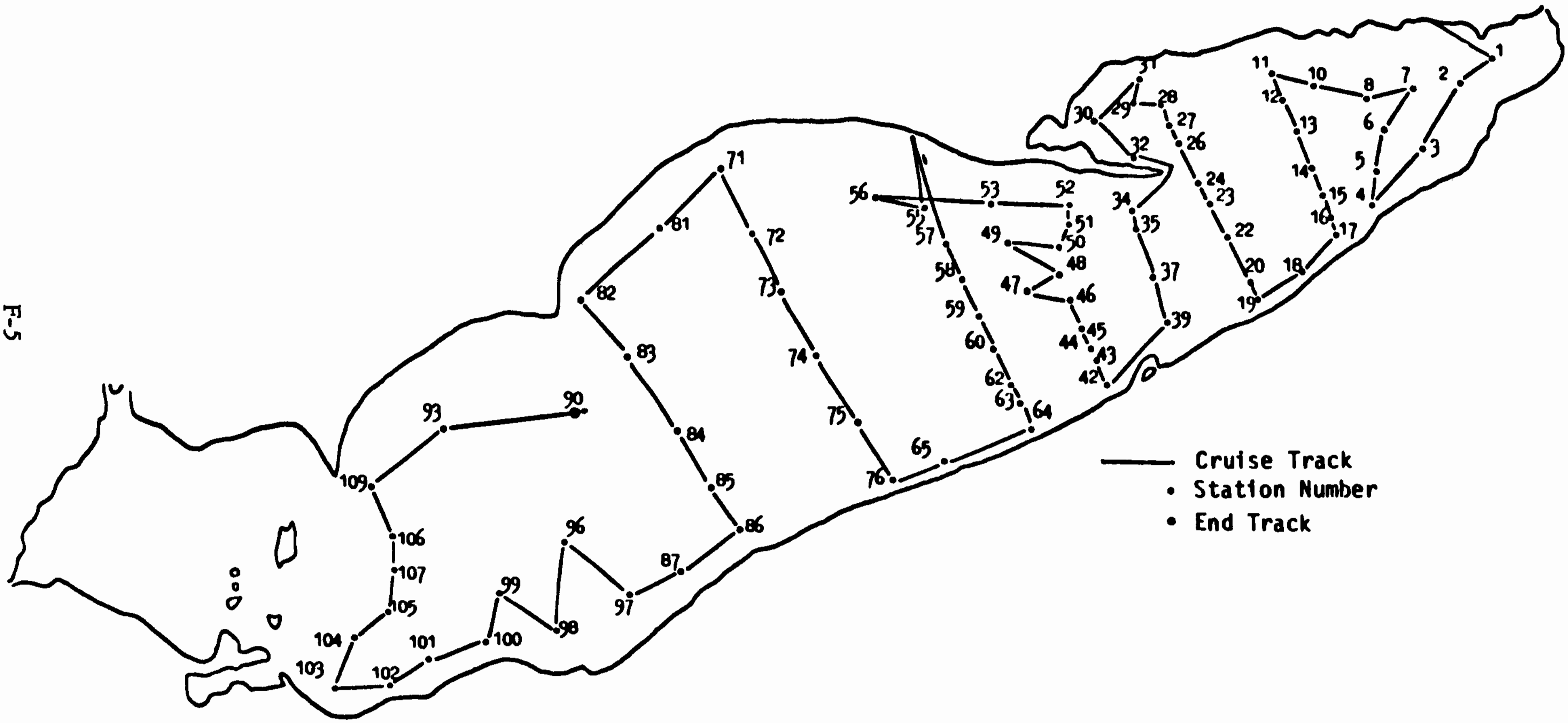


FIGURE 5. REPRESENTATIVE CRUISE TRACK USED BY CCIW-NWRI DURING 1978 (TAKEN FROM CRUISE 103, May 15 - June 2).

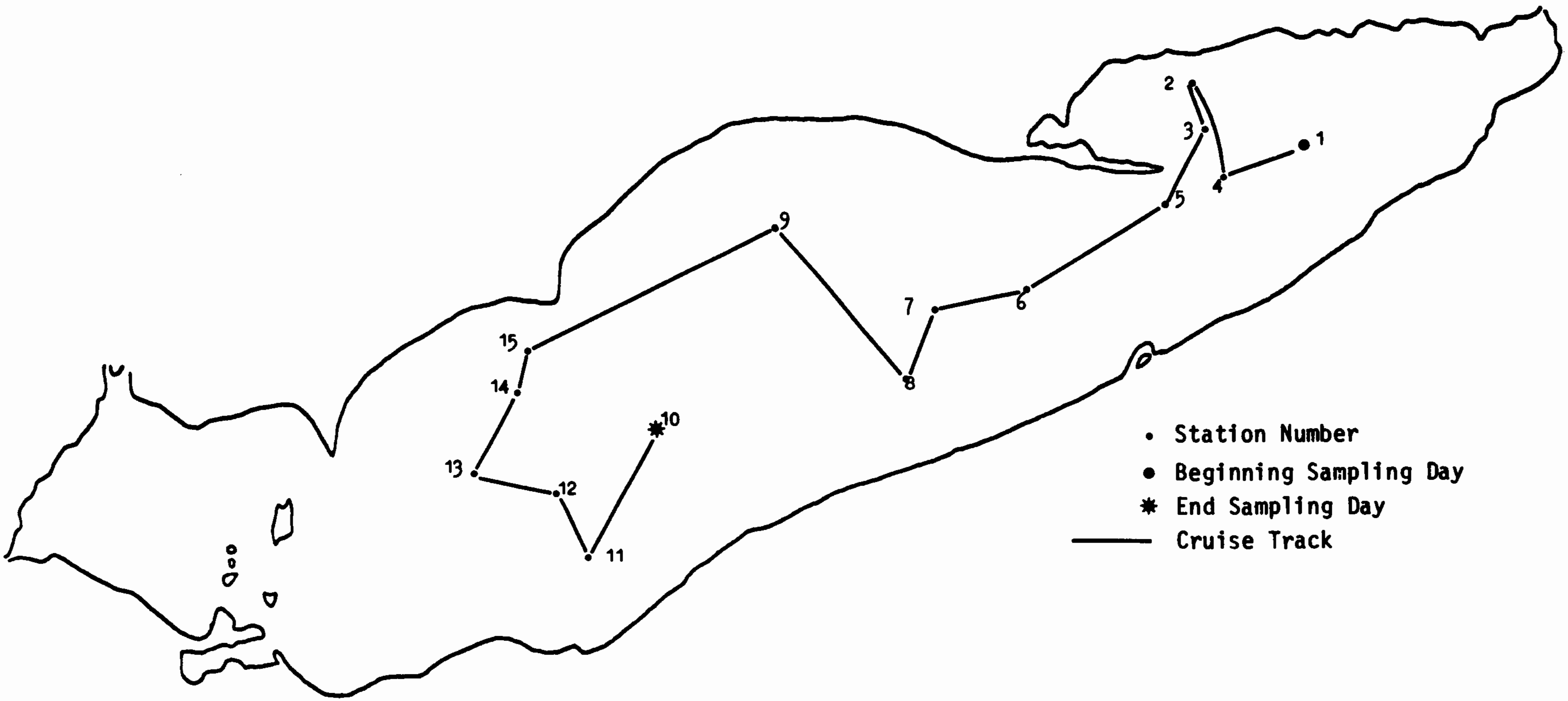


FIGURE 6. REPRESENTATIVE CRUISE TRACK USED BY CCIW-NWRI DURING 1979 (TAKEN FROM CRUISE 103, MAY 15 - MAY 18).

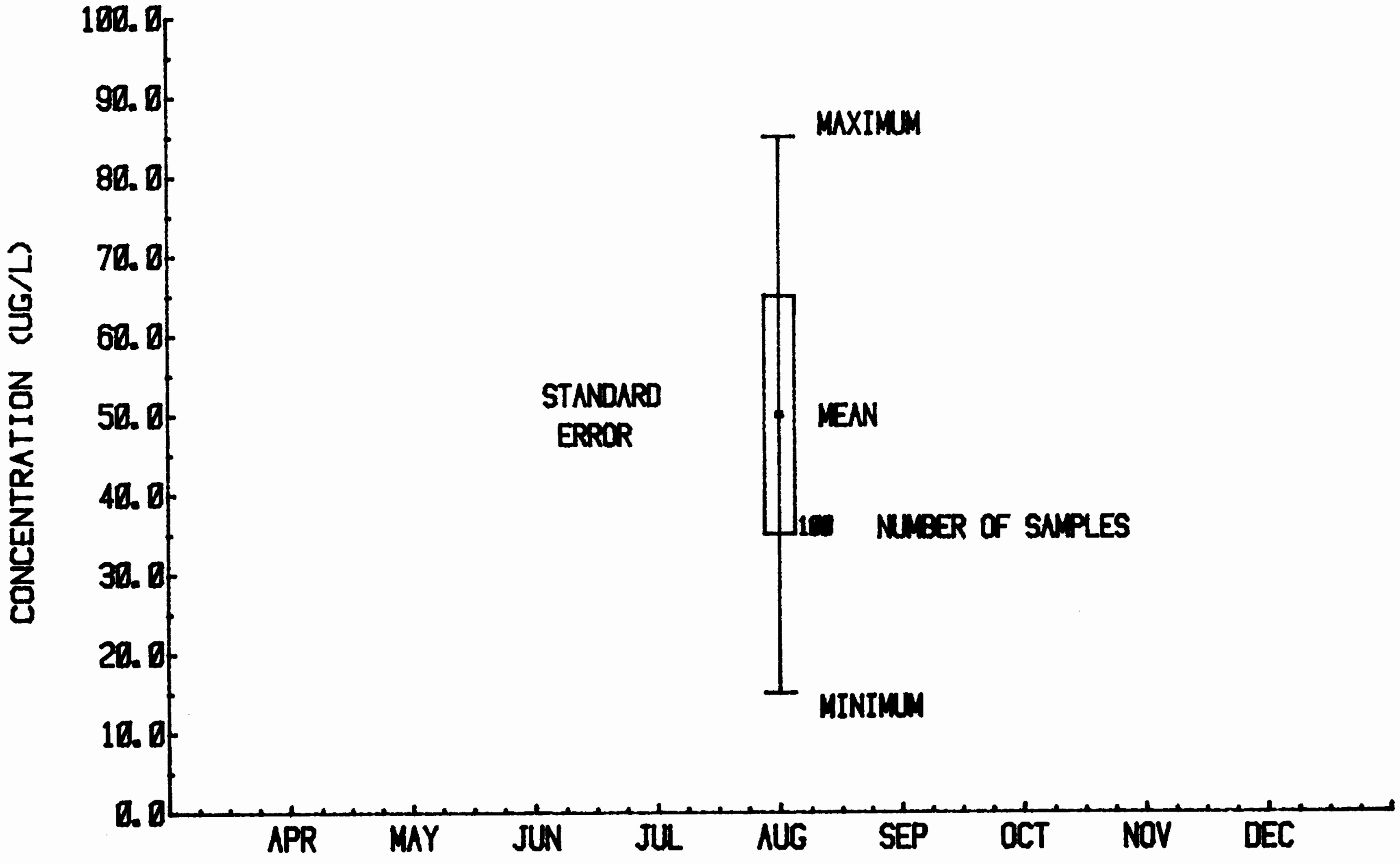


FIGURE 7. EXPLANATION OF PLOTS USED TO DISPLAY DATA.

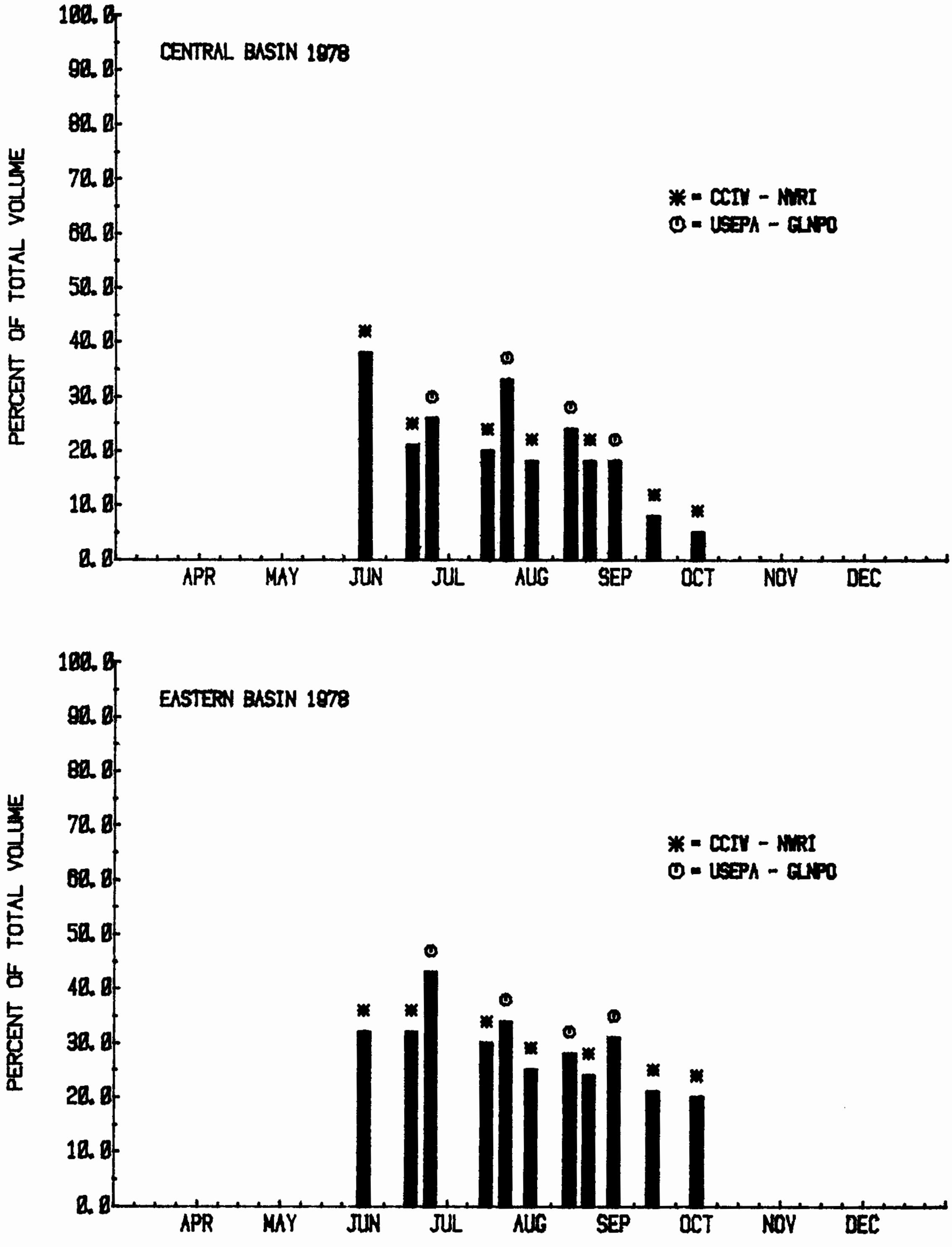


FIGURE 8. COMPARISON OF PERCENT 1978 CENTRAL AND EASTERN HYPOLIMNION VOLUMES FOR EACH CRUISE AS ESTIMATED BY CCIW-NWRI AND USEPA-GLNPO.

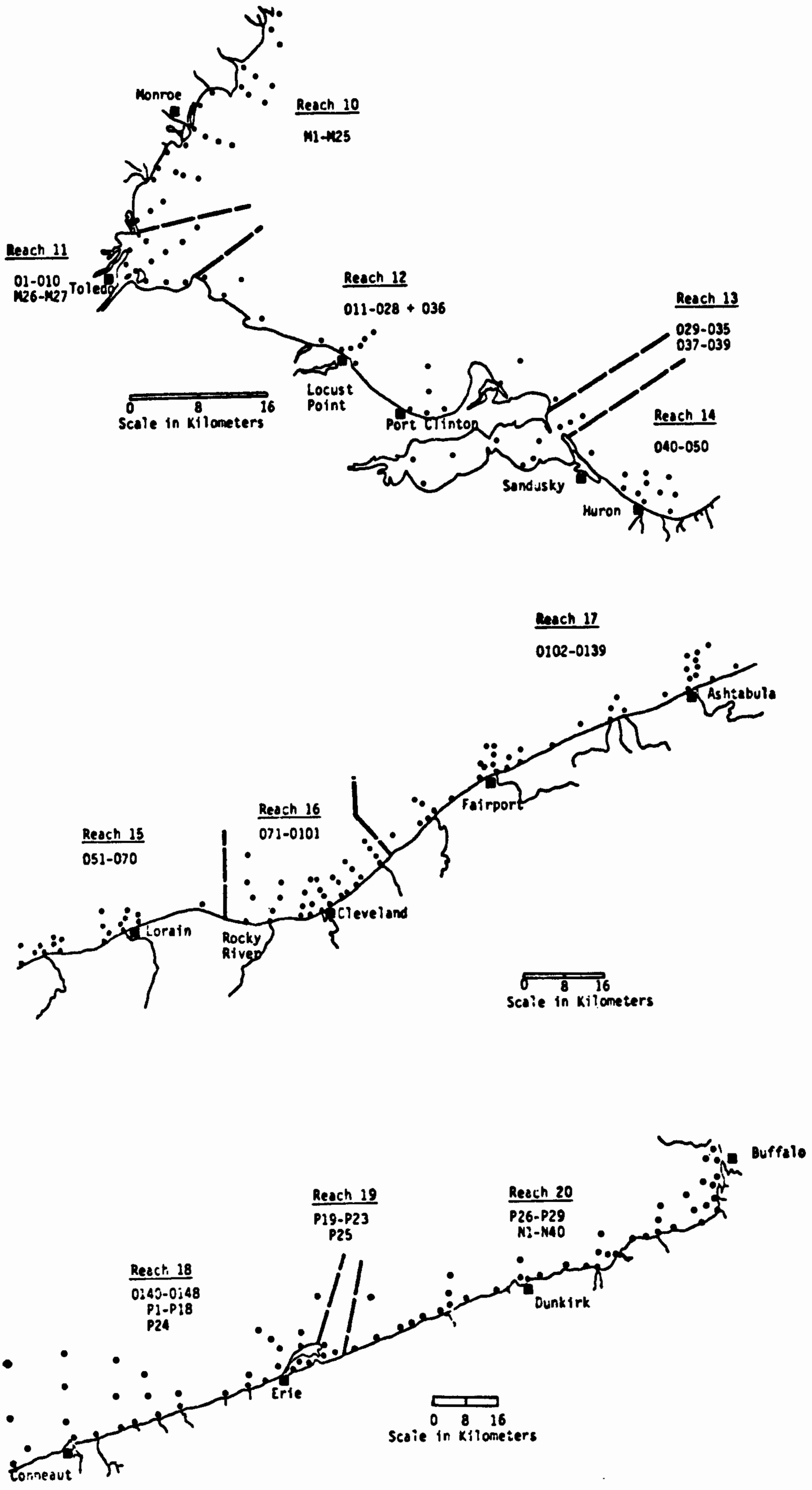


FIGURE 9. U.S. NEARSHORE STATION PATTERN AND REACH DESIGNATION FOR 1978 and 1979.

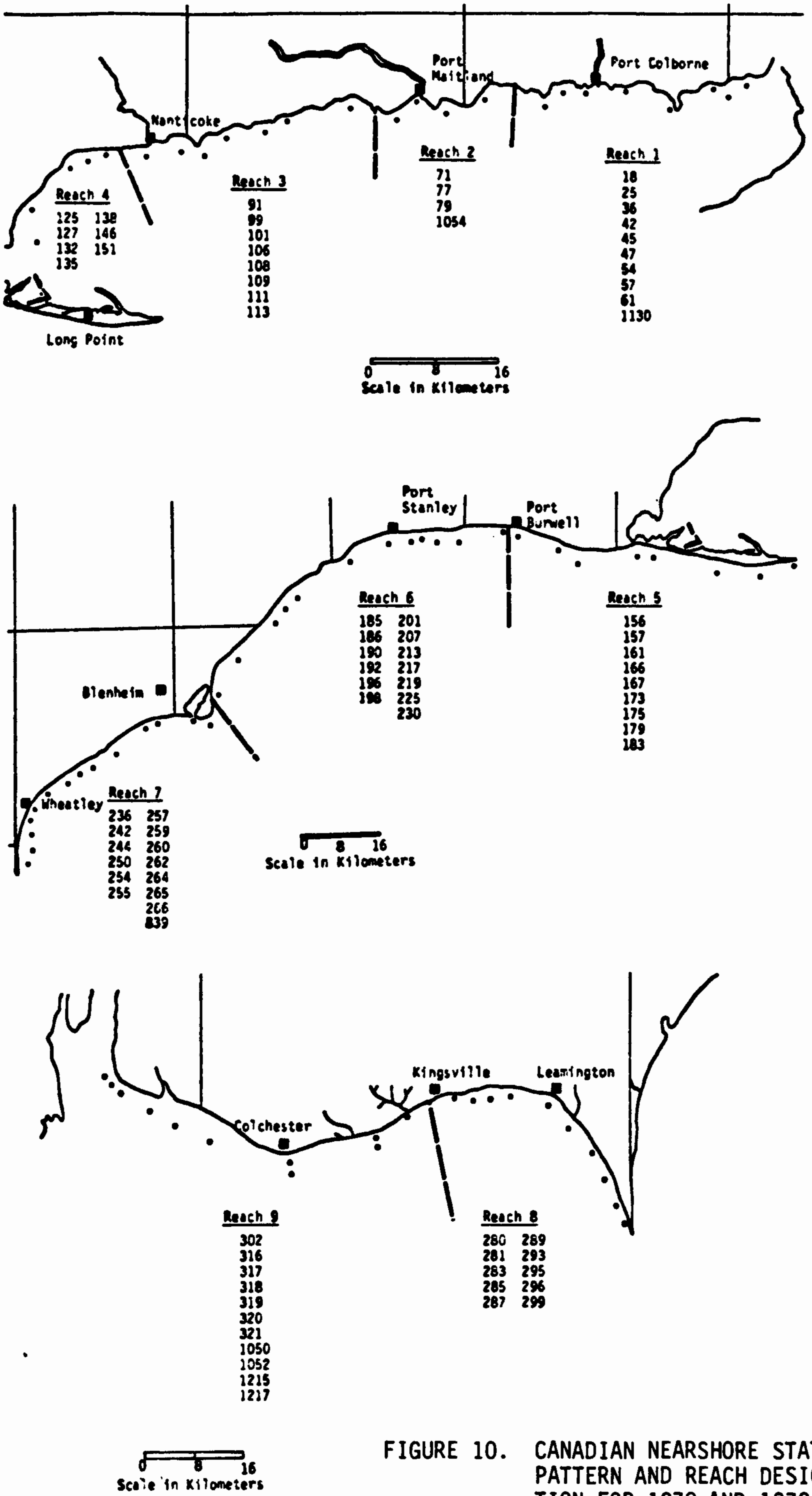


FIGURE 10. CANADIAN NEARSHORE STATION PATTERN AND REACH DESIGNATION FOR 1978 AND 1979.

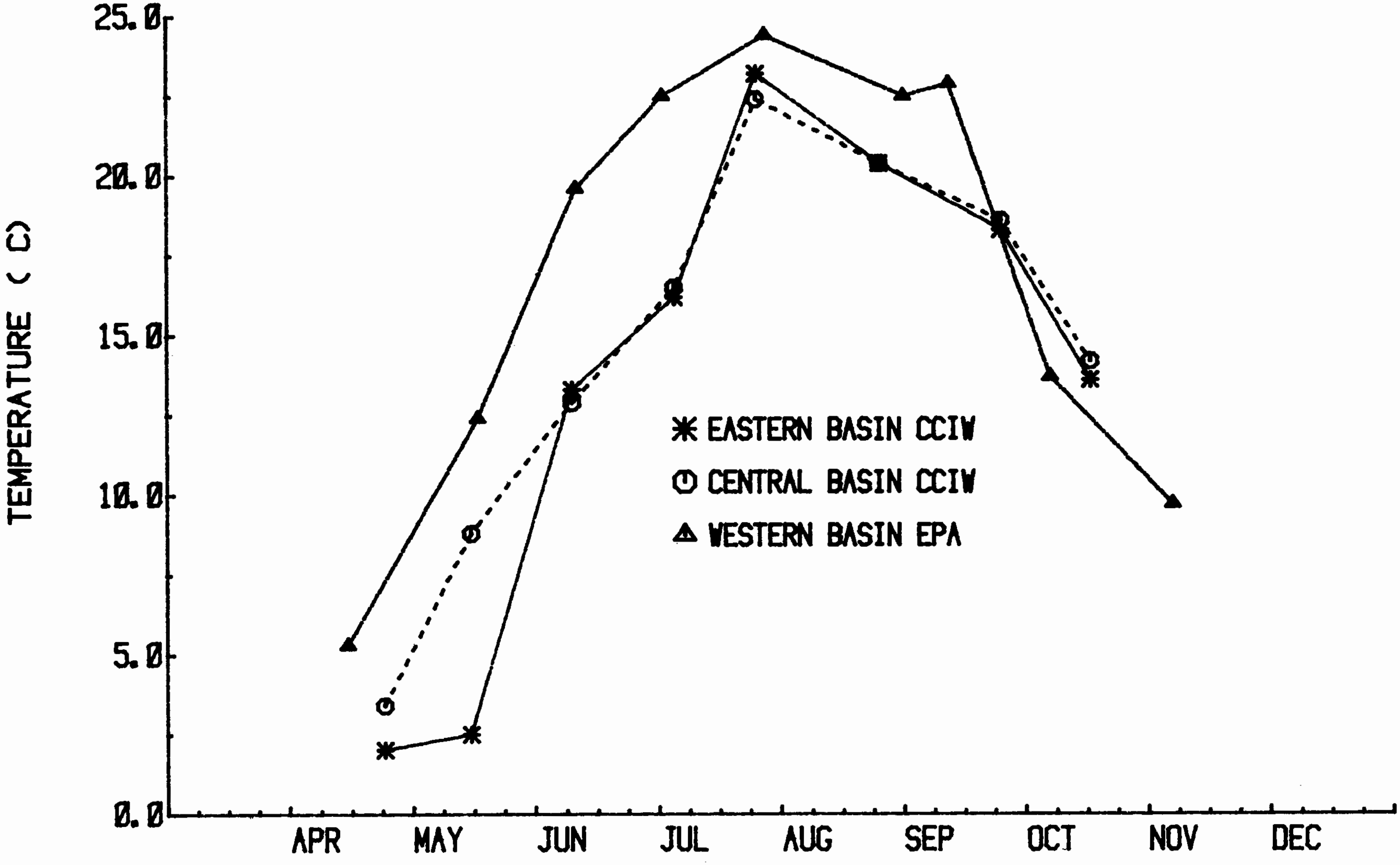


FIGURE 11. OPEN LAKE SEASONAL SURFACE TEMPERATURE PATTERN RECORDED FOR ALL THREE BASINS IN 1979.

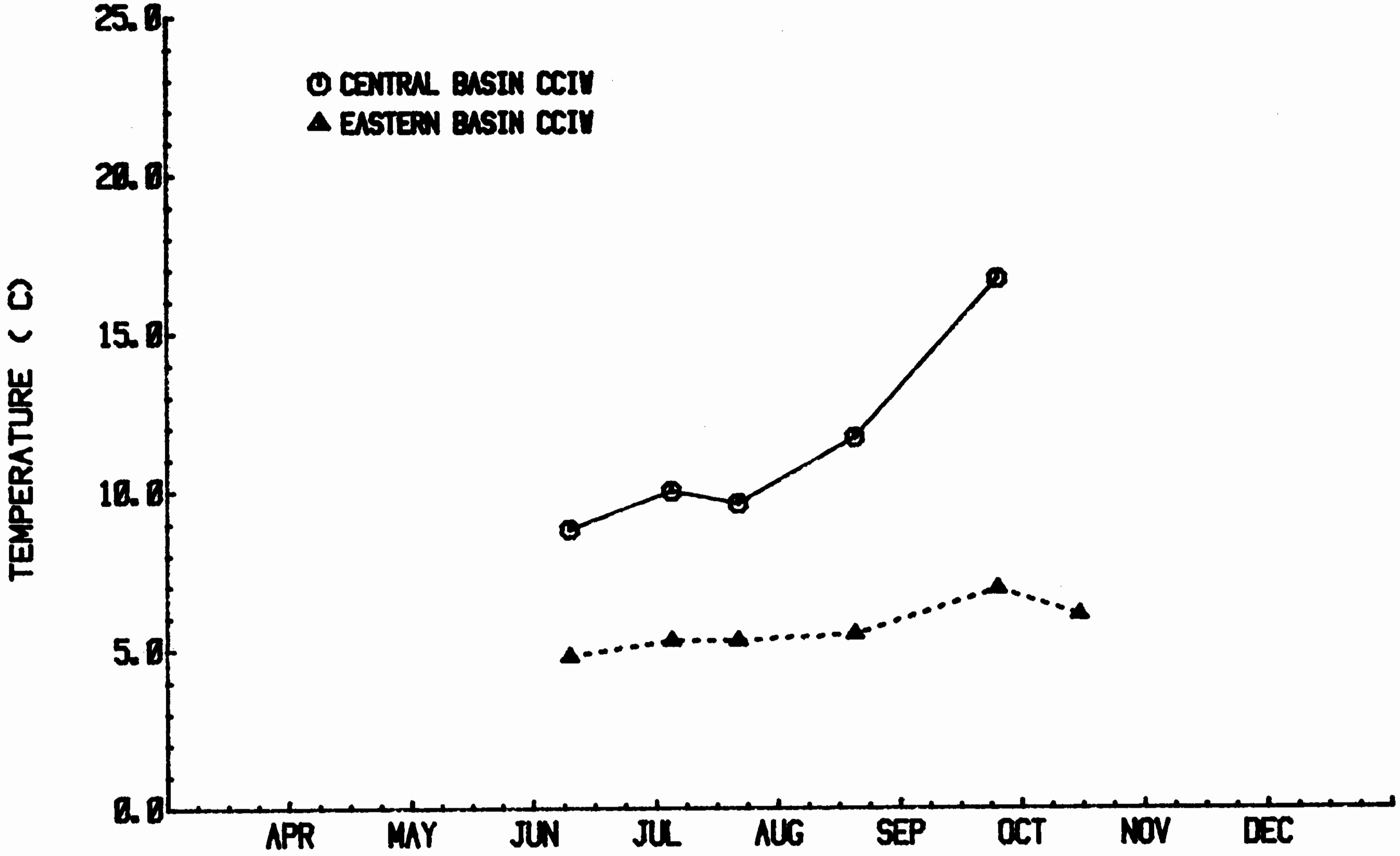


FIGURE 12. OPEN LAKE SEASONAL BOTTOM TEMPERATURE PATTERN RECORDED FOR THE CENTRAL AND EASTERN BASINS DURING 1979.

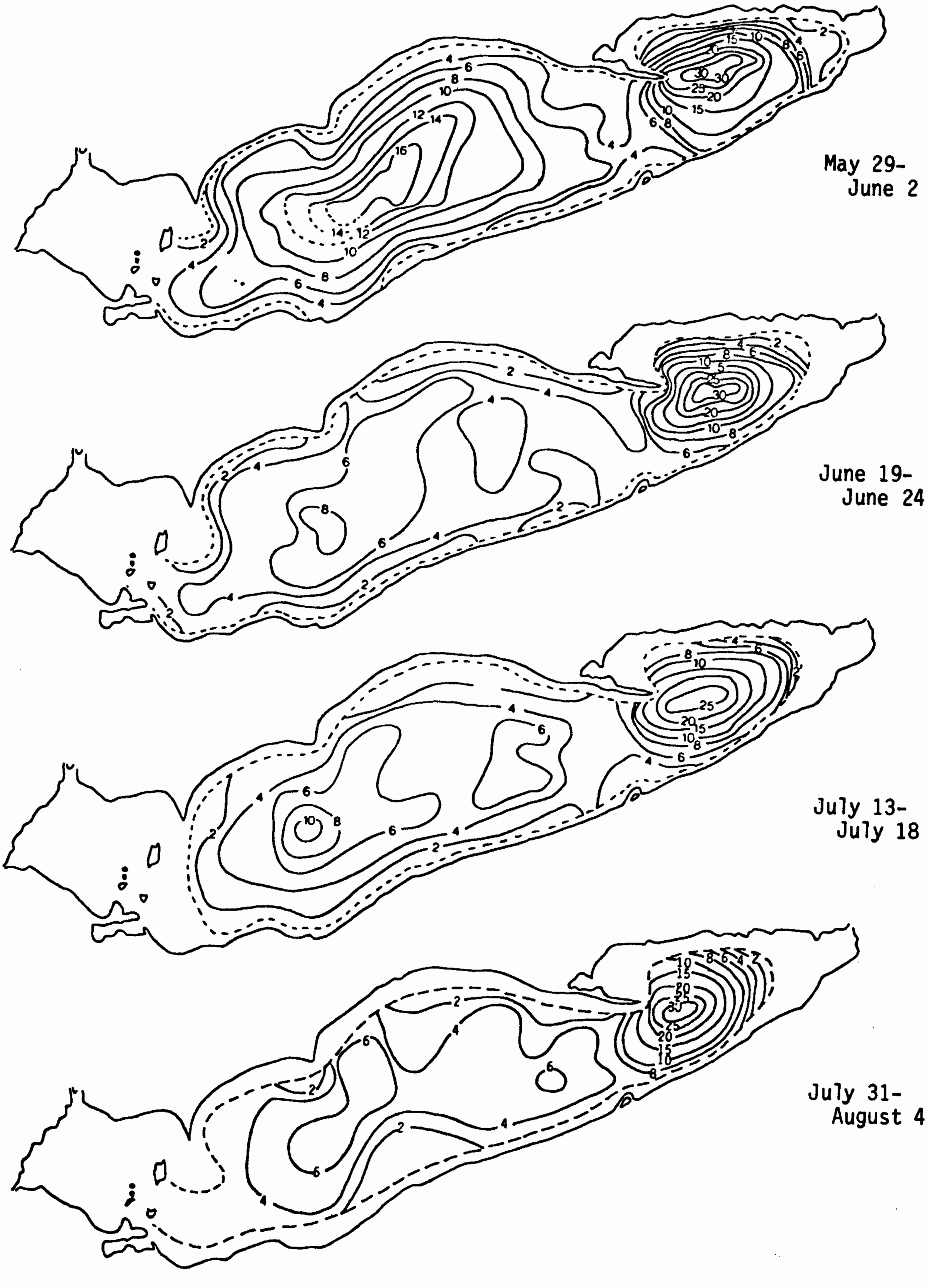


FIGURE 13. SEASONAL PATTERN OF HYPOLIMNION THICKNESS (m) AS RECORDED IN THE CENTRAL AND EASTERN BASINS OF LAKE ERIE DURING THE 1978 CCIW-NWRI FIELD SEASON.

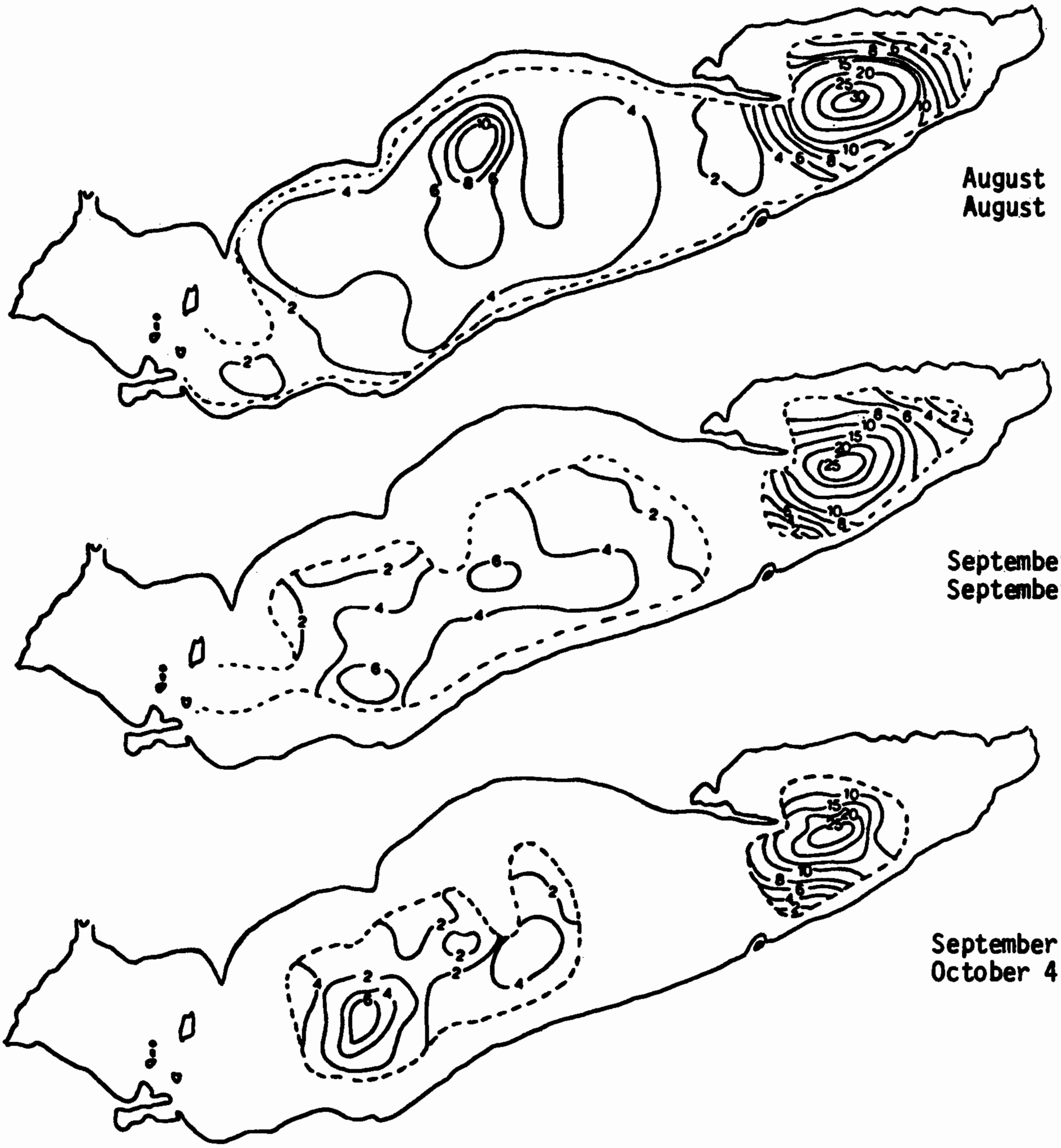


FIGURE 13. Continued

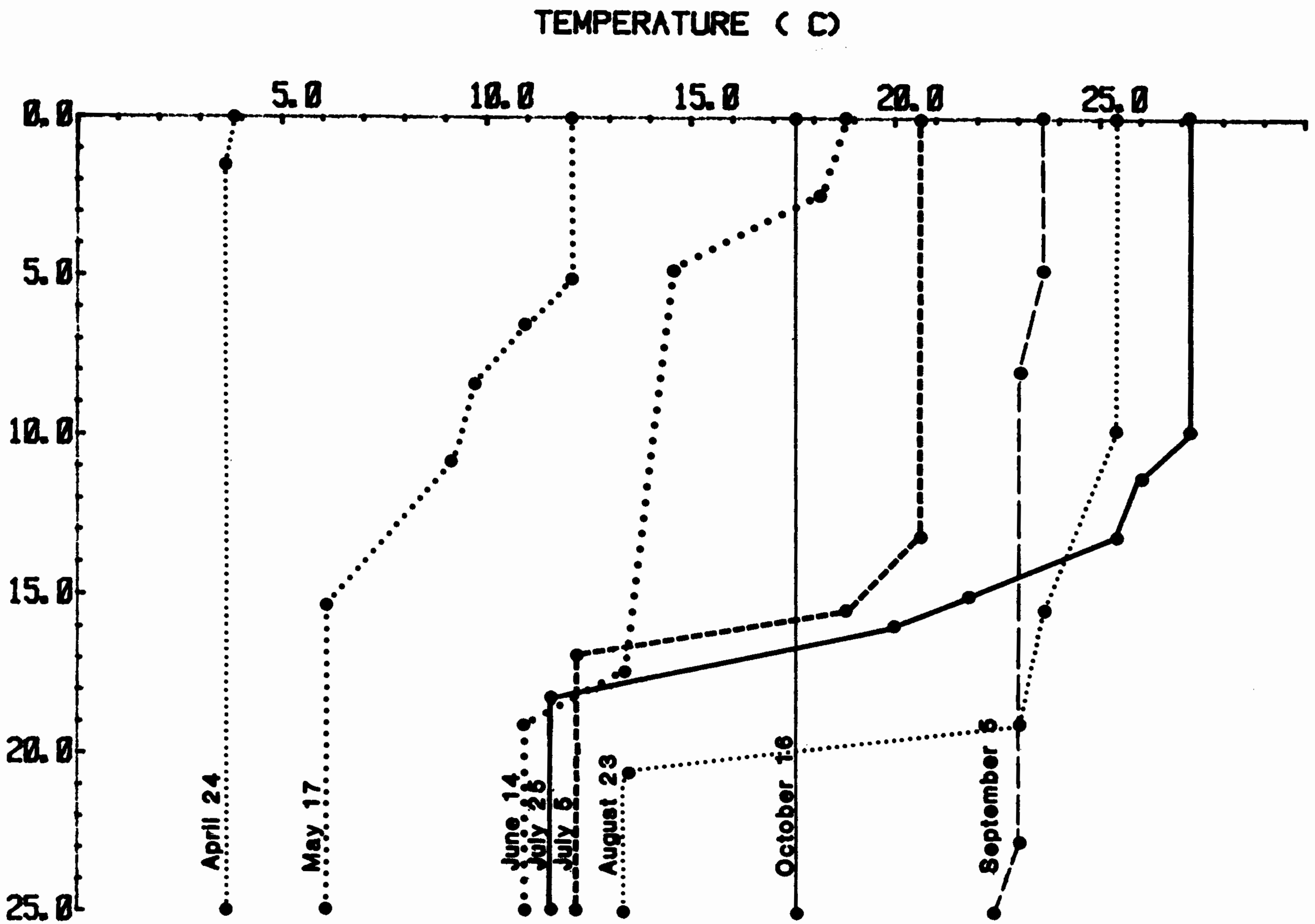


FIGURE 14. REPRESENTATIVE SEASONAL THERMAL STRUCTURE FOR THE CENTRAL BASIN AS RECORDED BY CCIW-NWRI AT STATION 12 (1979).

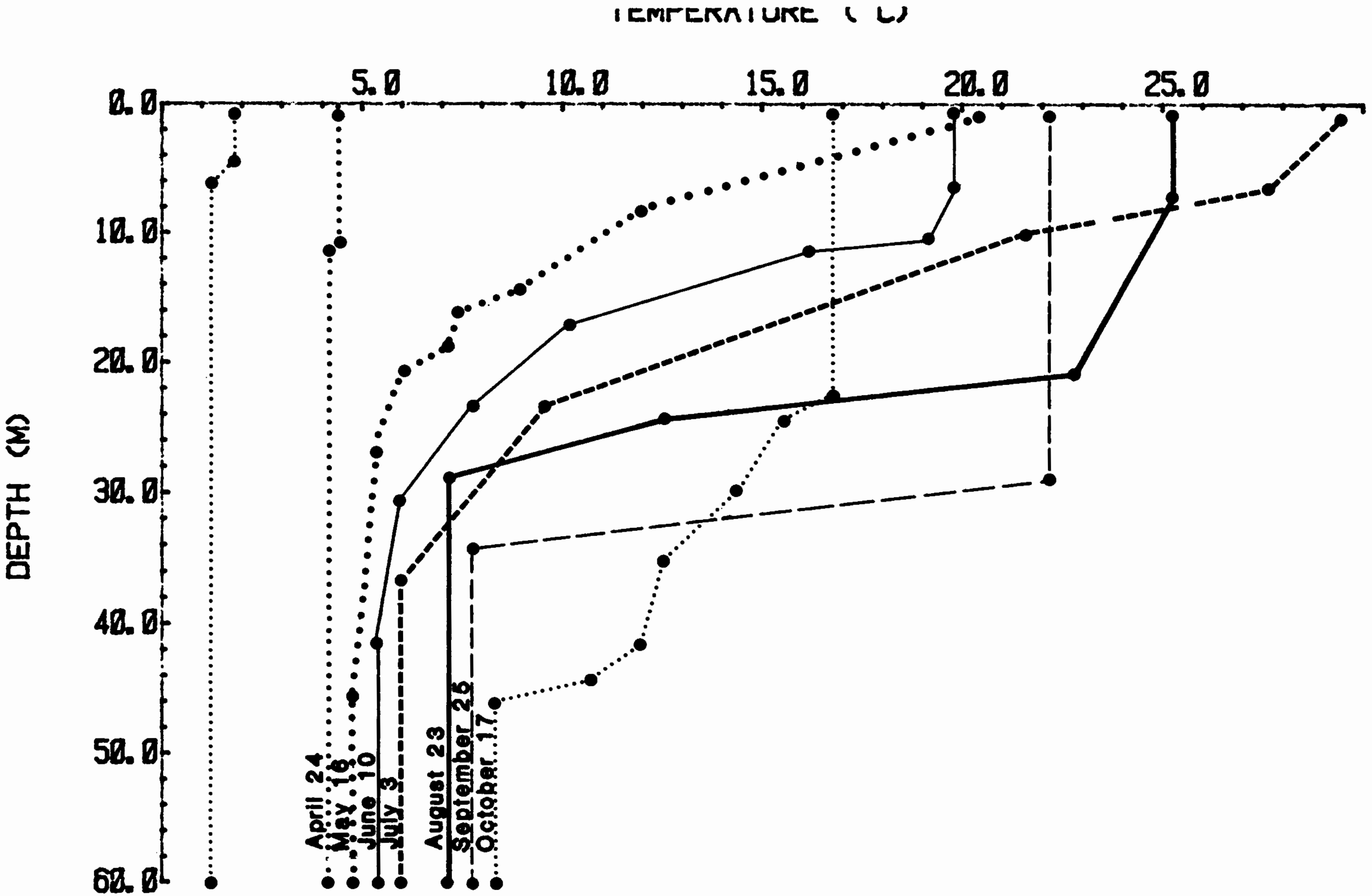


FIGURE 15. REPRESENTATIVE SEASONAL THERMAL STRUCTURE FOR THE EASTERN BASIN AS RECORDED BY CCIW-NWRI AT STATION 4 (1979).

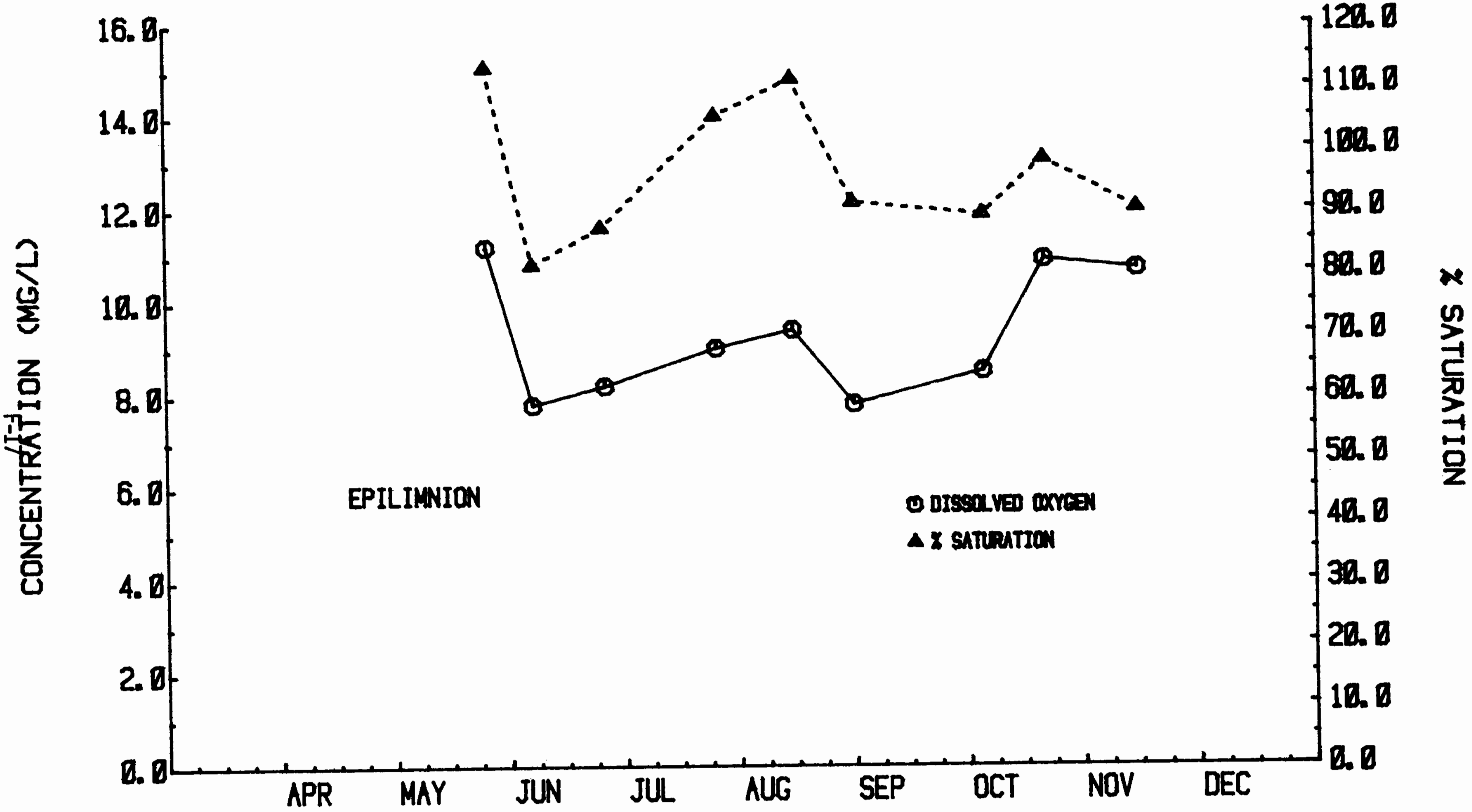


FIGURE 16. THE MEAN WESTERN BASIN DISSOLVED OXYGEN CONCENTRATIONS AND PERCENT SATURATIONS FOR 1978 USEPA - GLNPO.

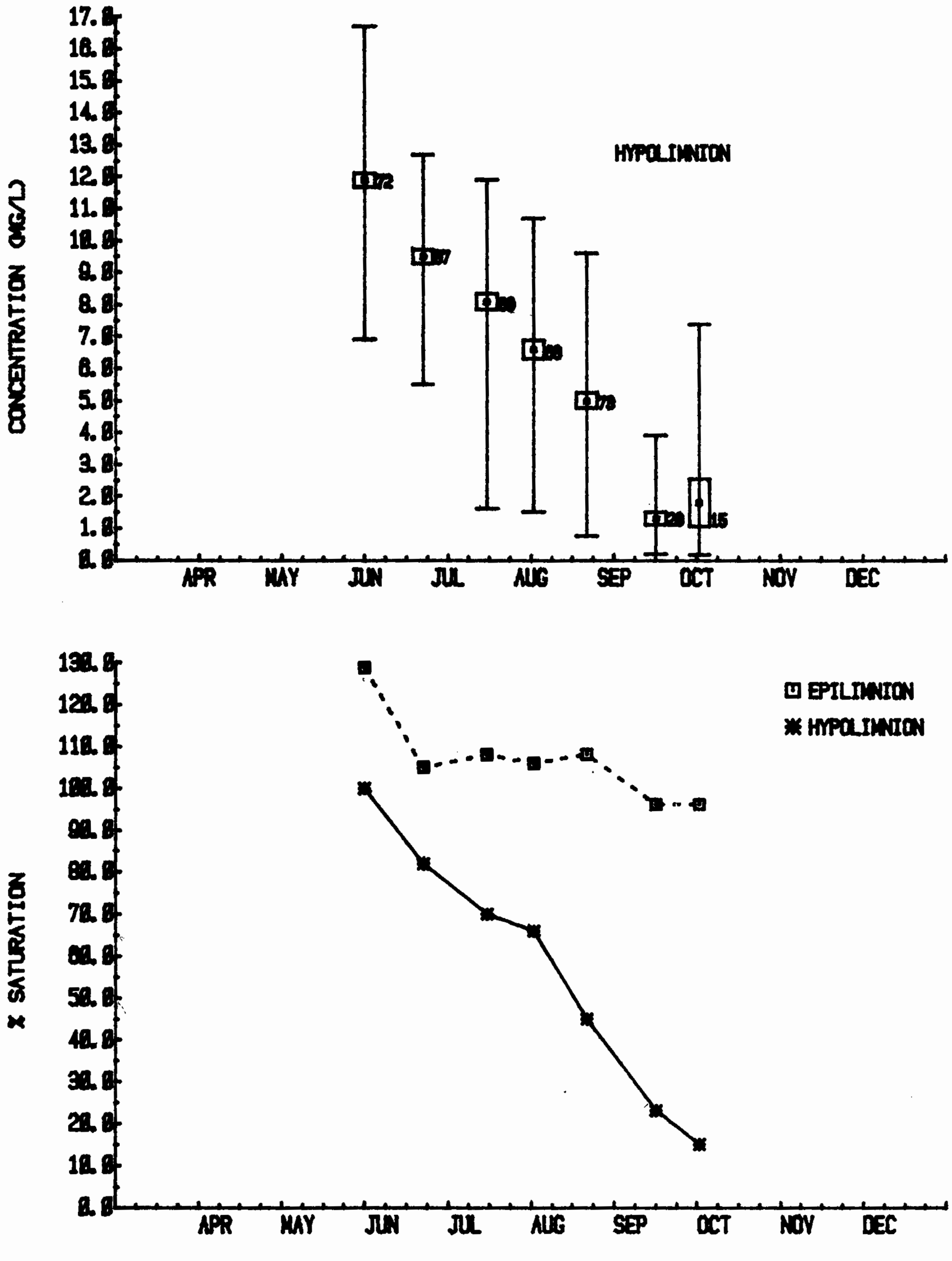


FIGURE 17. THE MEAN CENTRAL BASIN DISSOLVED OXYGEN CONCENTRATIONS AND PERCENT SATURATIONS FOR 1978 CCIW - NWRI.

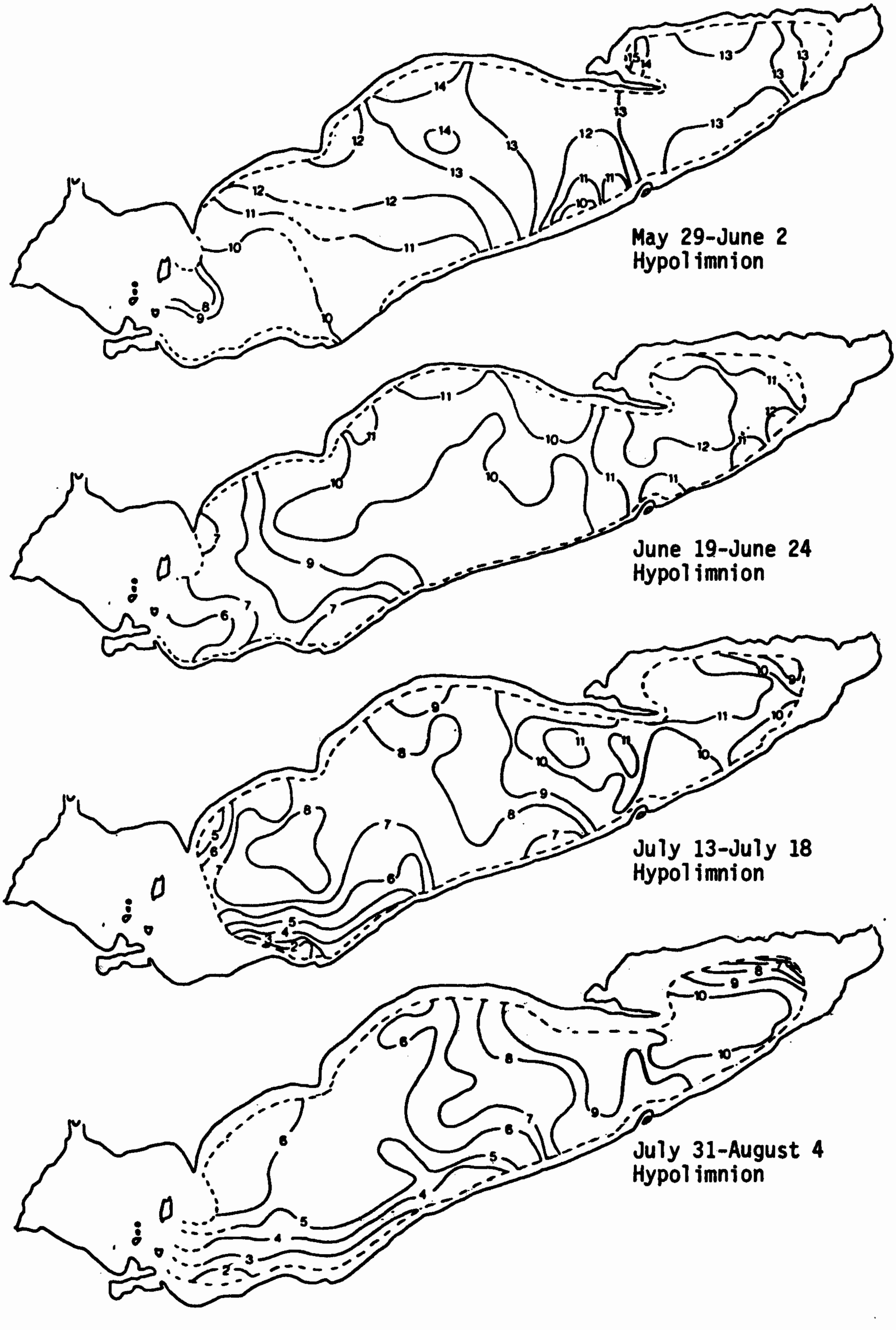


FIGURE 18. THE SEASONAL HYPOLIMNION DISSOLVED OXYGEN (mg/l) DISTRIBUTION PATTERNS FOR THE CENTRAL AND EASTERN BASINS OF LAKE ERIE DURING 1978.

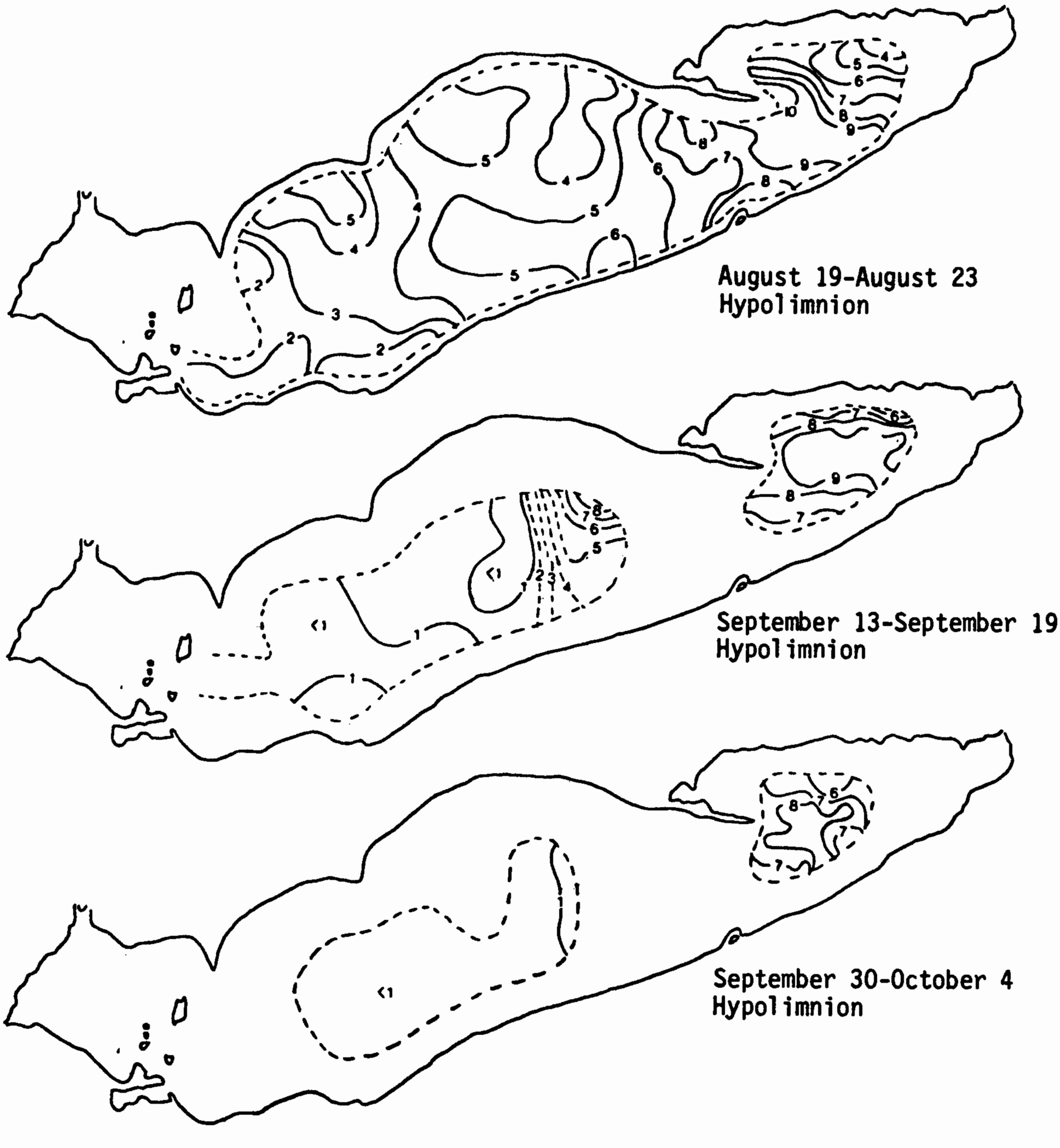


FIGURE 18. Continued.

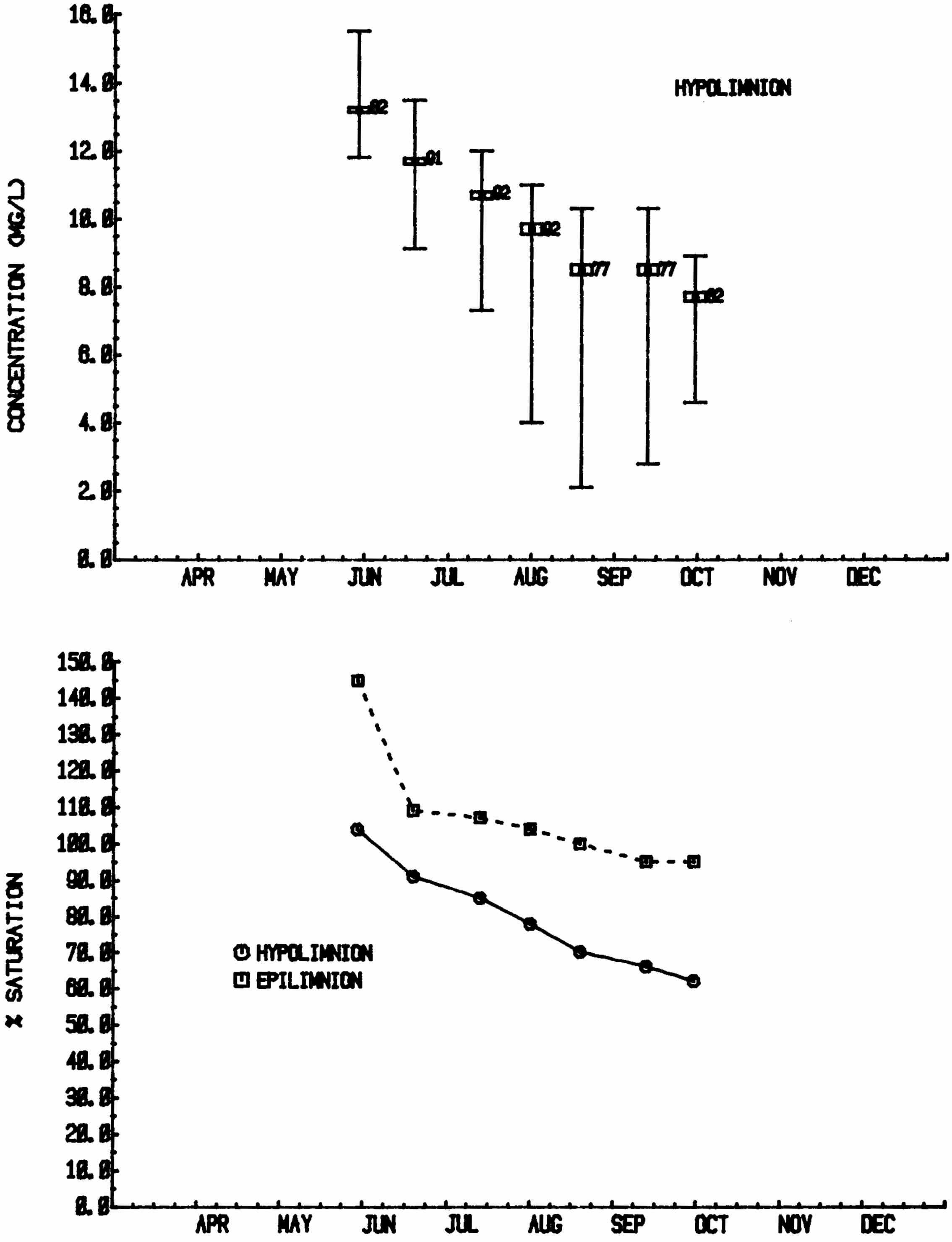


FIGURE 19. THE MEAN EASTERN BASIN DISSOLVED OXYGEN CONCENTRATIONS AND PERCENT SATURATIONS FOR 1978 CCIW - NWRI.

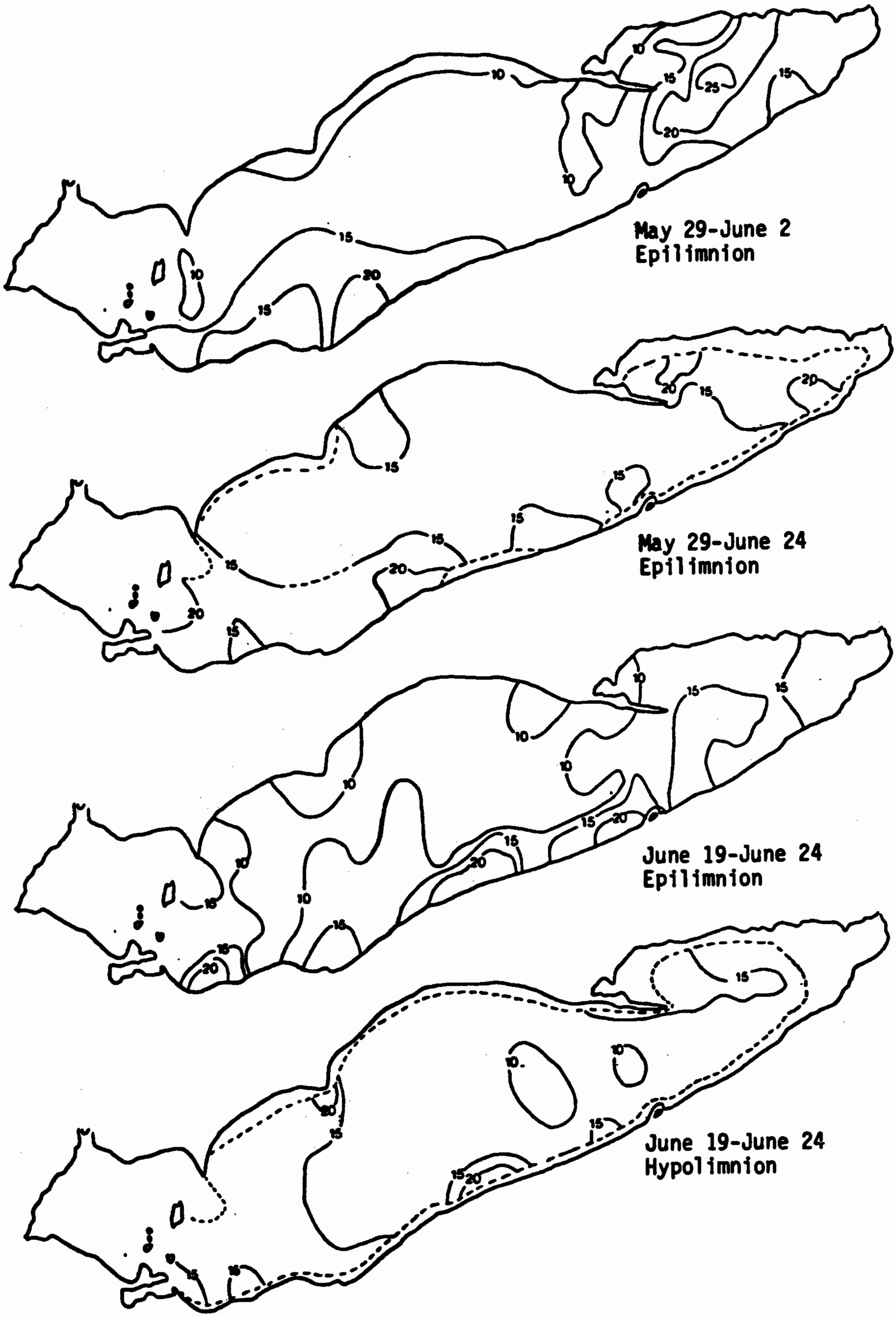


FIGURE 20. THE SEASONAL EPILIMNION AND HYPOLIMNION TOTAL PHOSPHORUS (µg/l) DISTRIBUTION PATTERNS FOR THE CENTRAL AND EASTERN BASINS OF LAKE ERIE FOR 1978 (CCIW-NWRI).

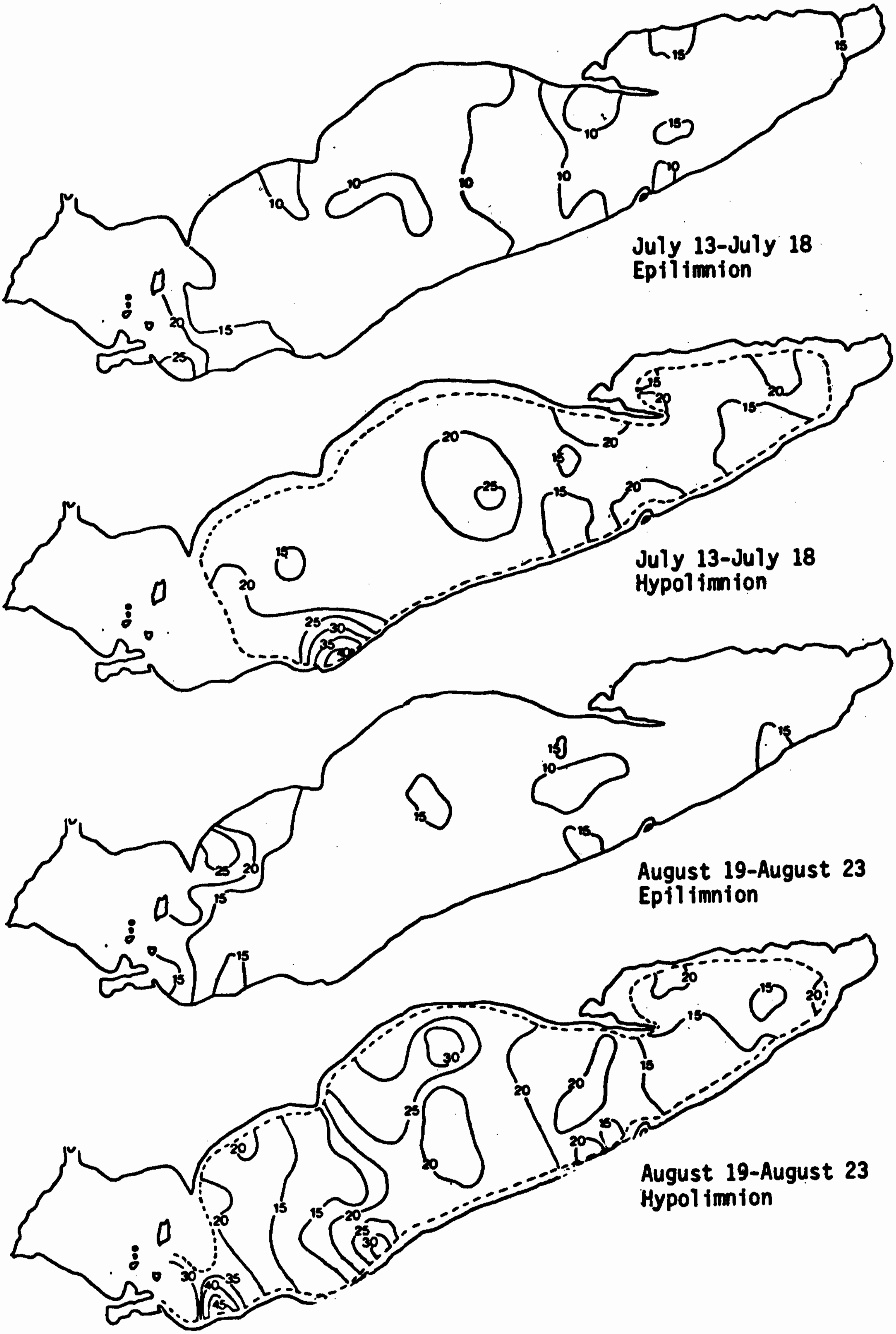


FIGURE 20. Continued

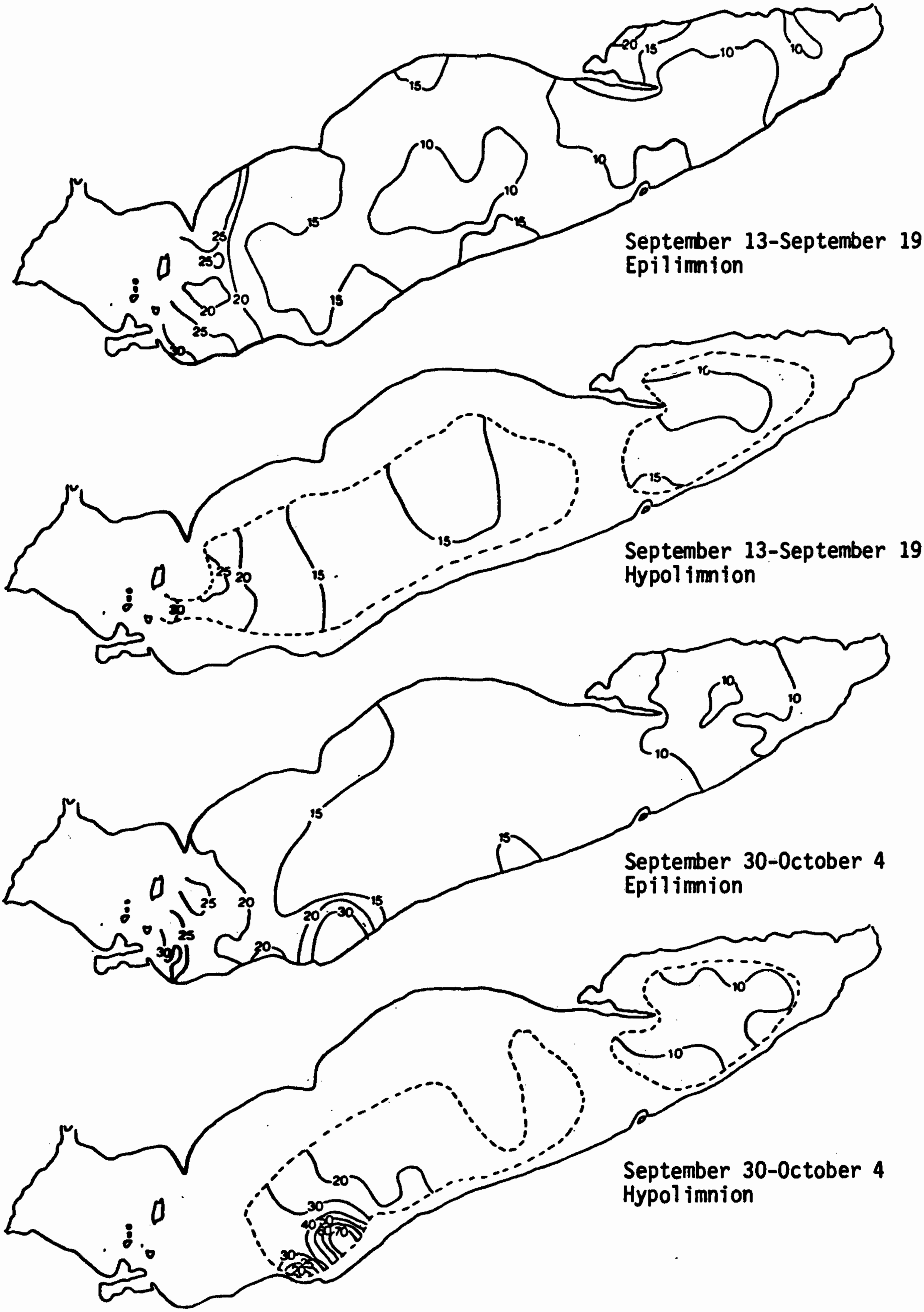


FIGURE 20. Continued

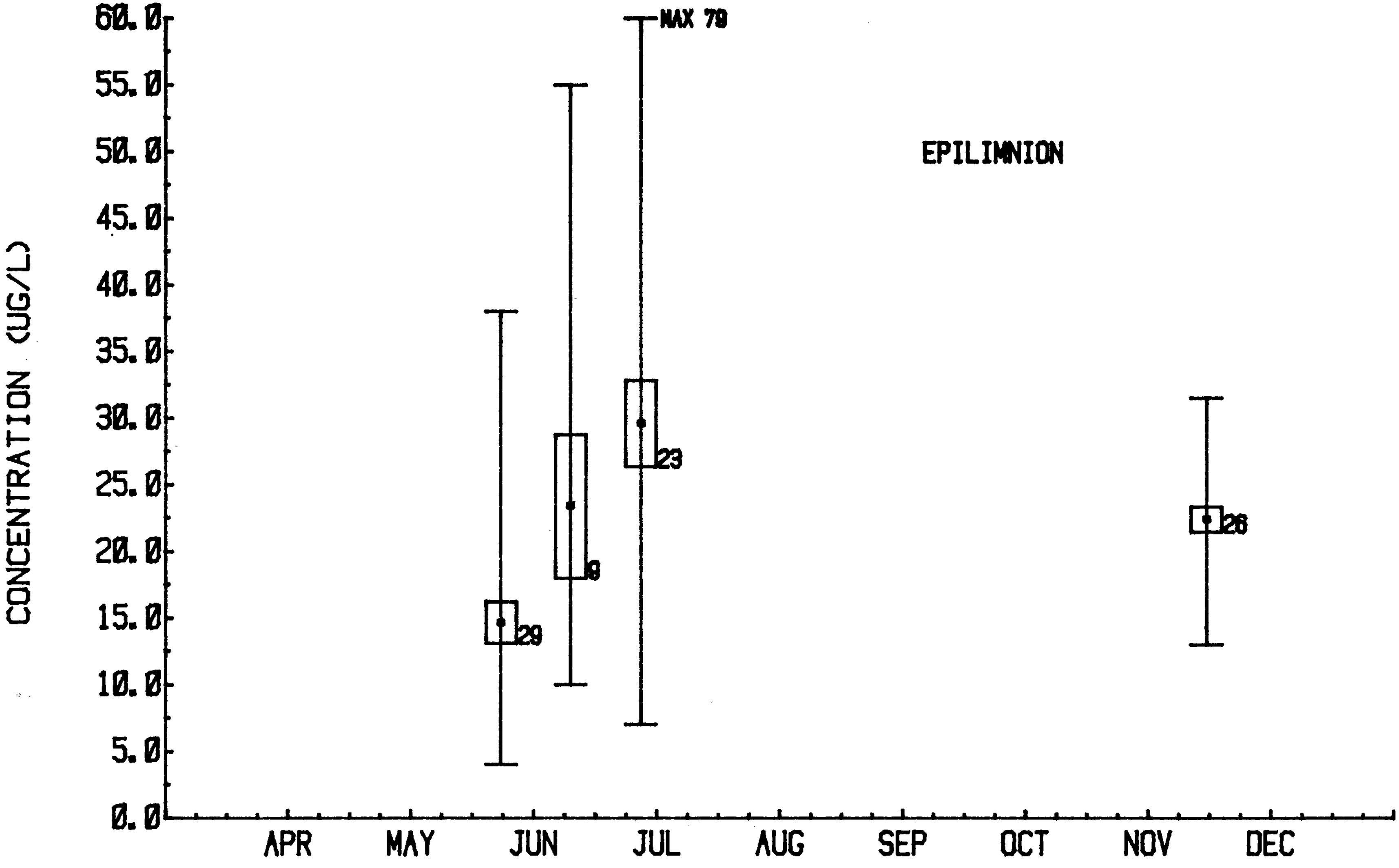
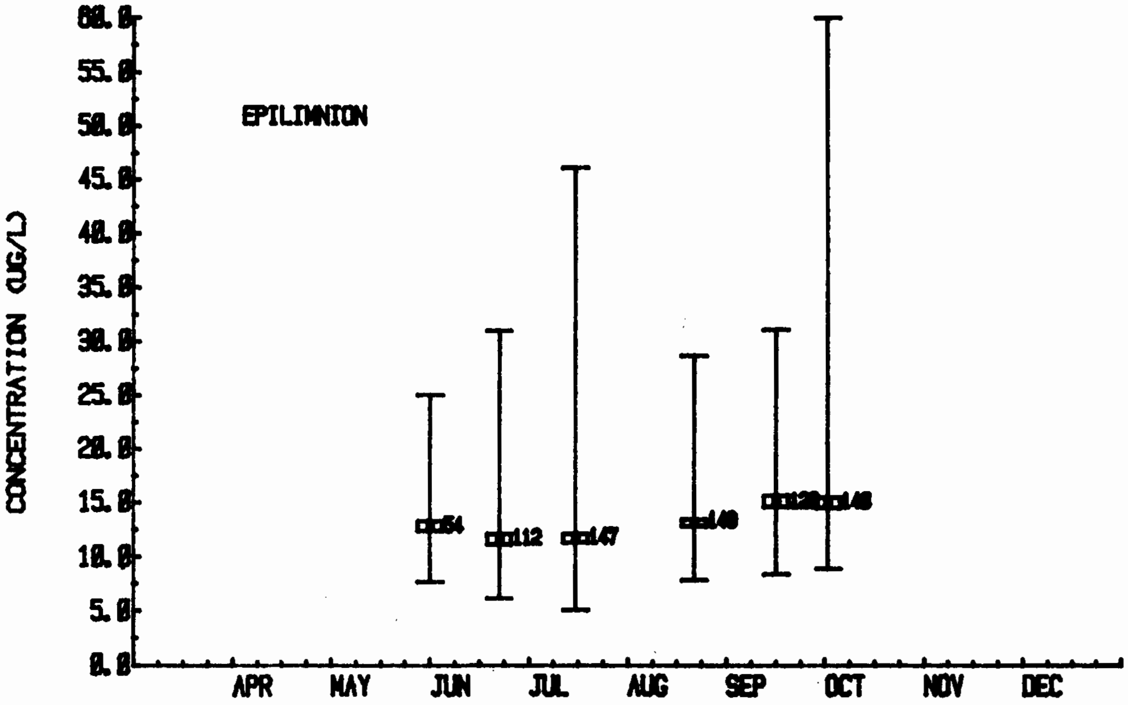


FIGURE 21. THE MEAN WESTERN BASIN TOTAL PHOSPHORUS CONCENTRATIONS FOR 1978 (USEPA-GLNPO).



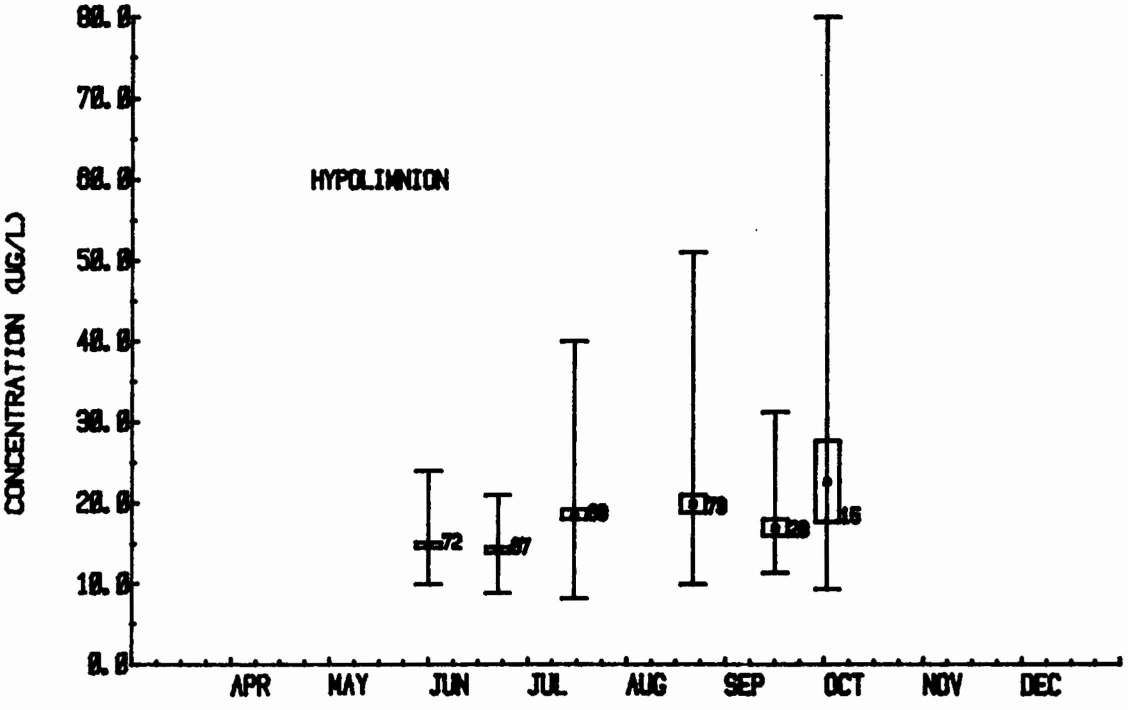


FIGURE 22. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION TOTAL PHOSPHORUS CONCENTRATIONS FOR 1978 (CCIW - NWRI).

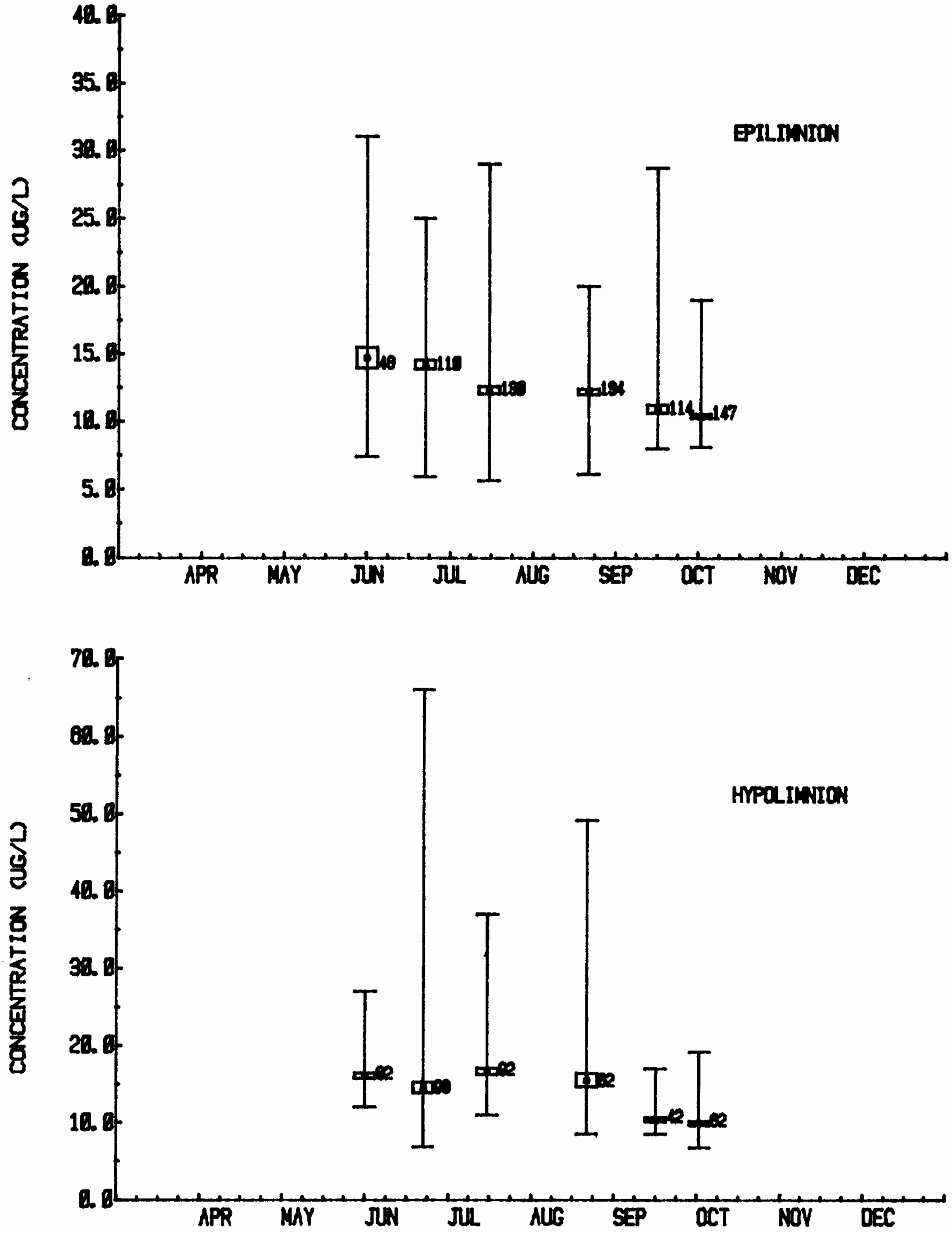


FIGURE 23. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION TOTAL PHOSPHORUS CONCENTRATIONS FOR 1978 (CCIW - NWRI).

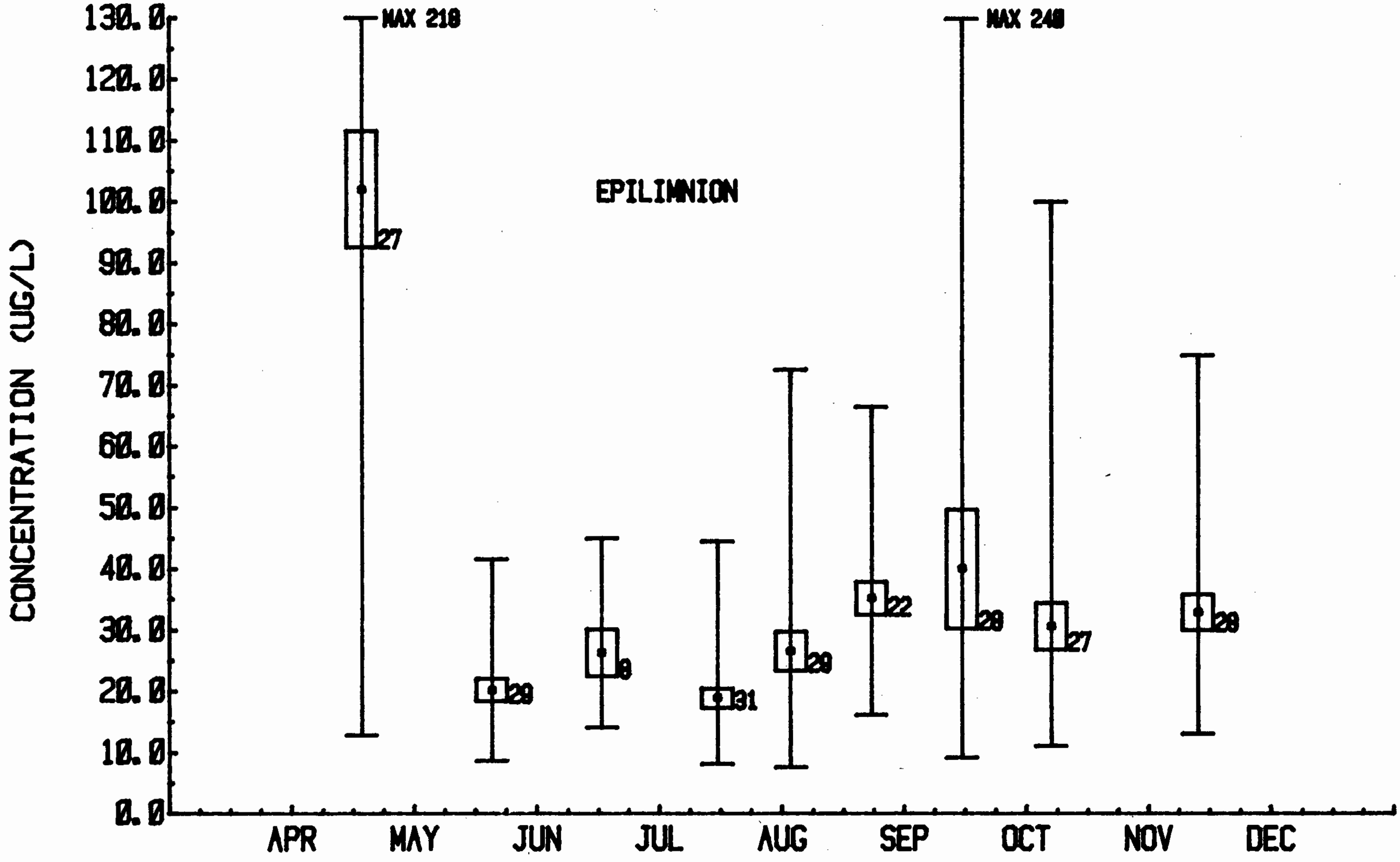


FIGURE 24. THE MEAN WESTERN BASIN TOTAL PHOSPHORUS CONCENTRATIONS FOR 1979 (USEPA-GLNPO).

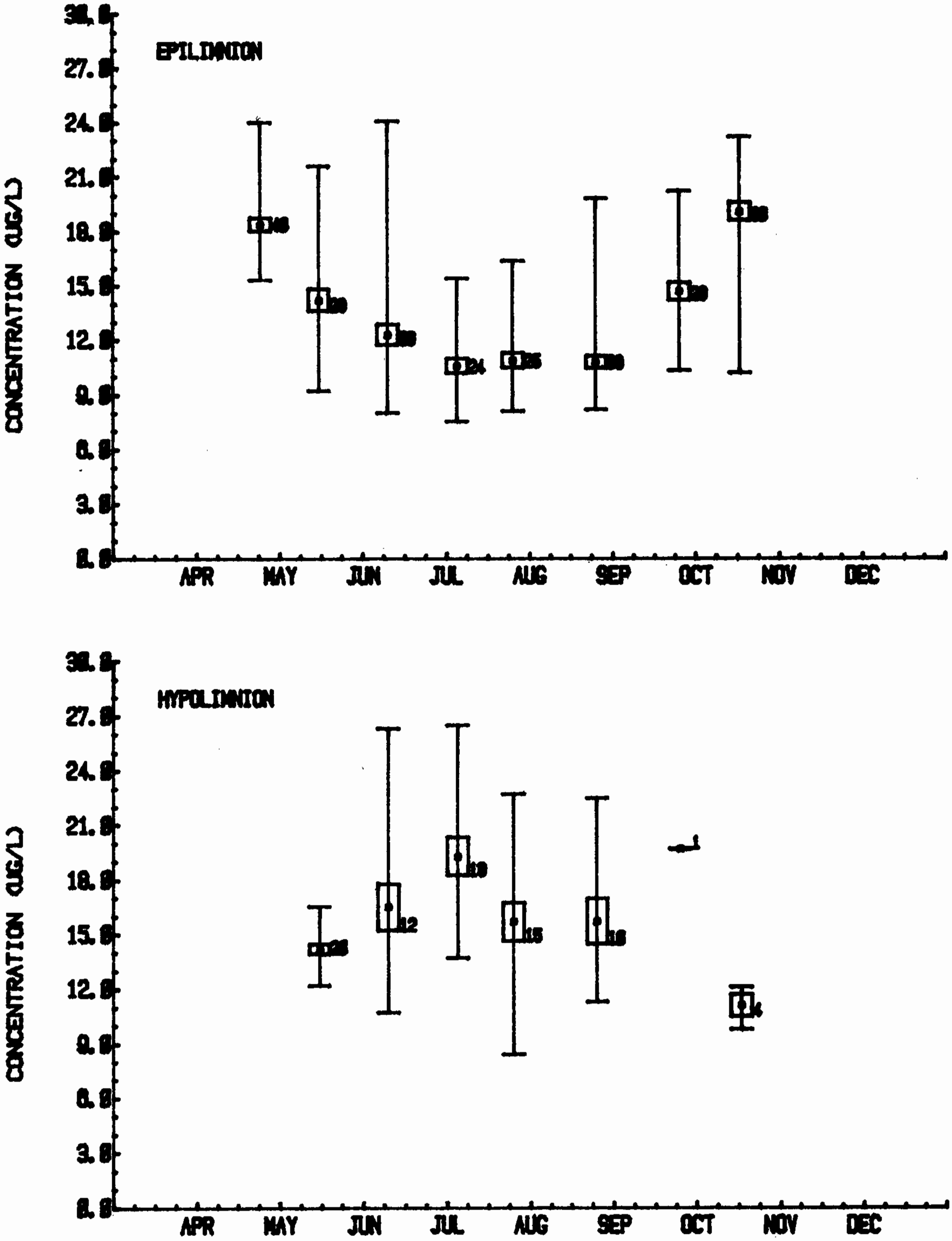


FIGURE 25. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION TOTAL PHOSPHORUS CONCENTRATIONS FOR 1979 (CCIW-NWRI).

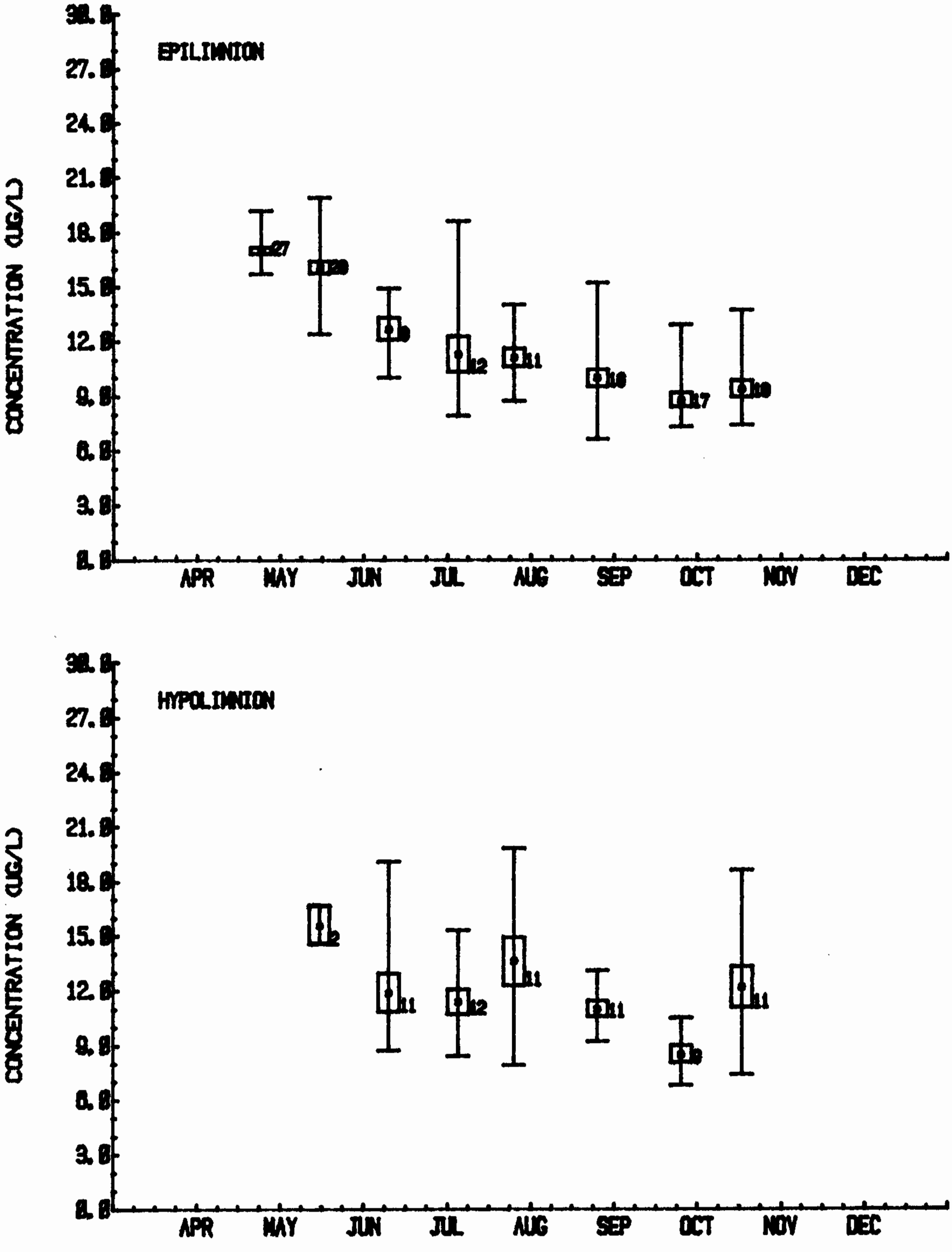


FIGURE 26. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION TOTAL PHOSPHORUS CONCENTRATIONS FOR 1979 (CCIW-NWRI).

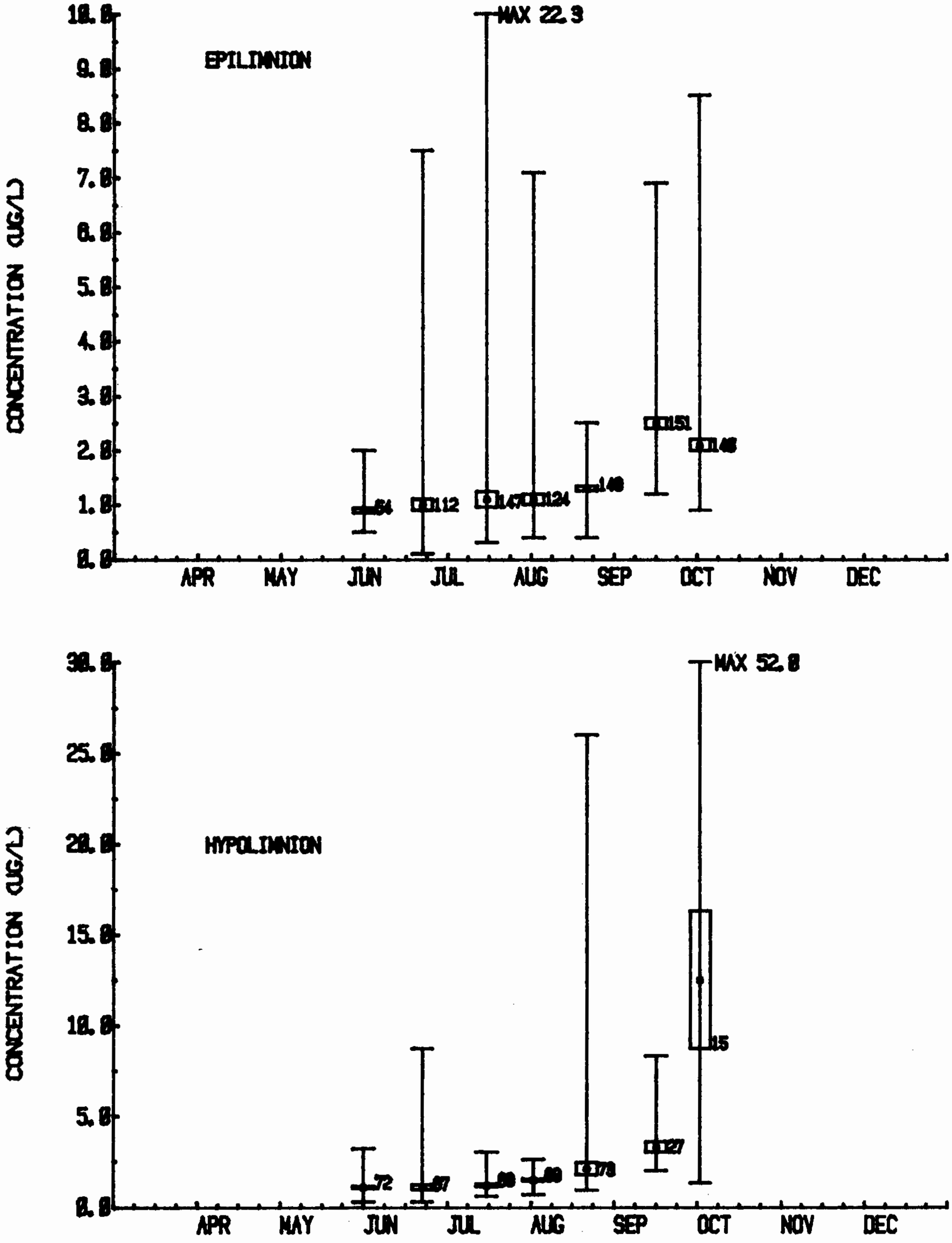


FIGURE 27. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION SOLUBLE REACTIVE PHOSPHORUS CONCENTRATIONS FOR 1978 (CCIW - NWRI).

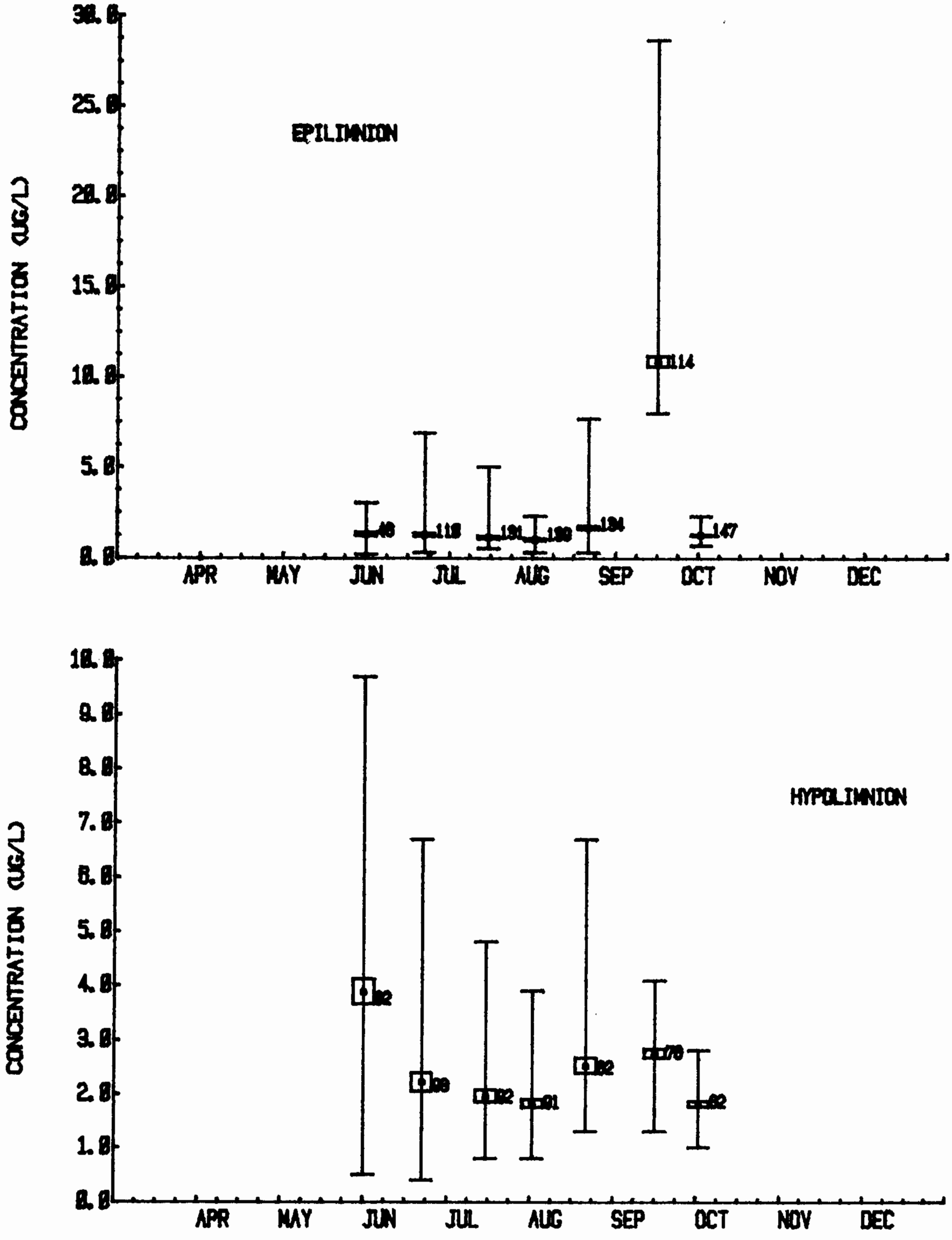


FIGURE 28. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION SOLUBLE REACTIVE PHOSPHORUS CONCENTRATIONS FOR 1978 (CCIW-NWRI).

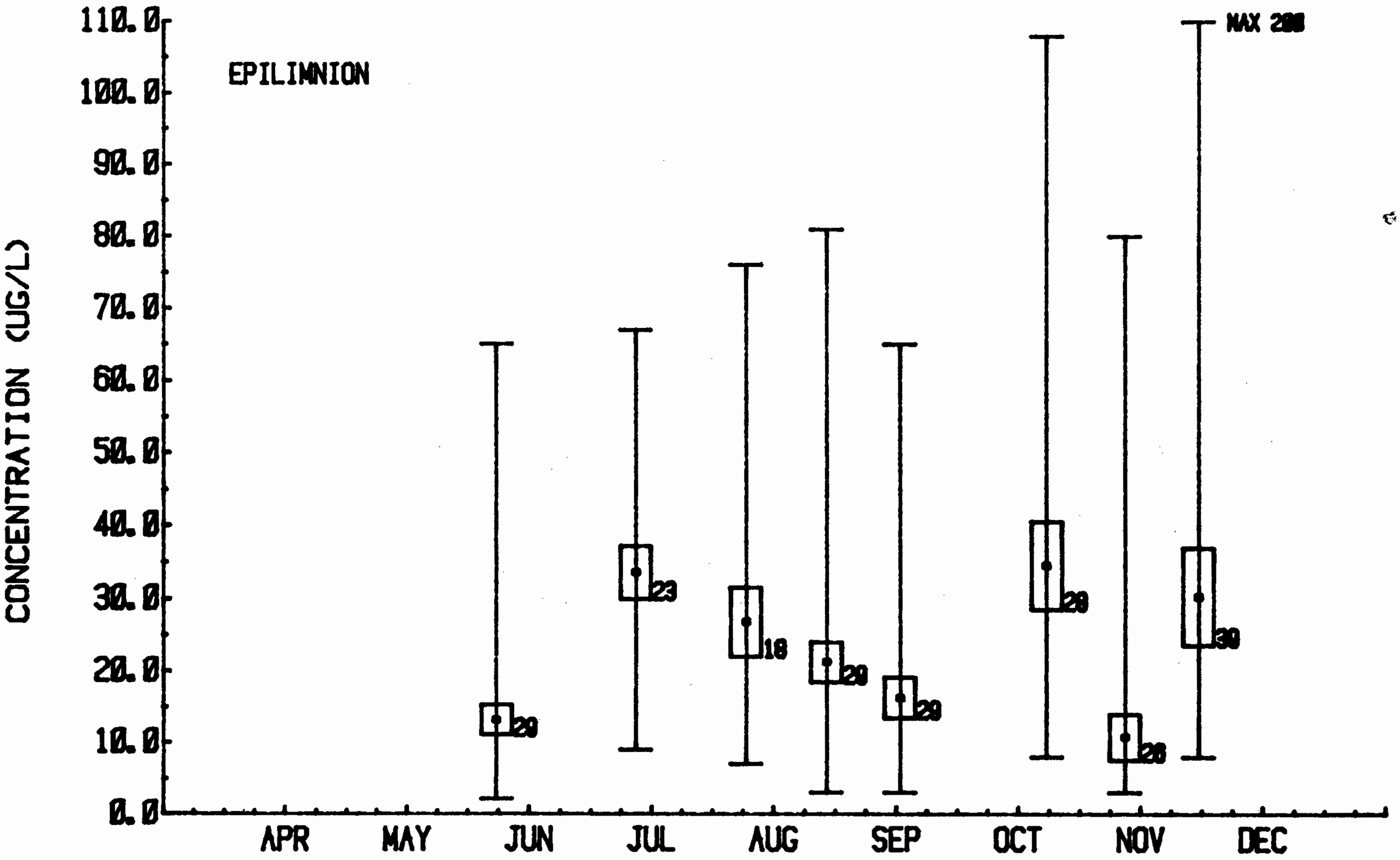


FIGURE 29. THE MEAN WESTERN BASIN AMMONIA CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

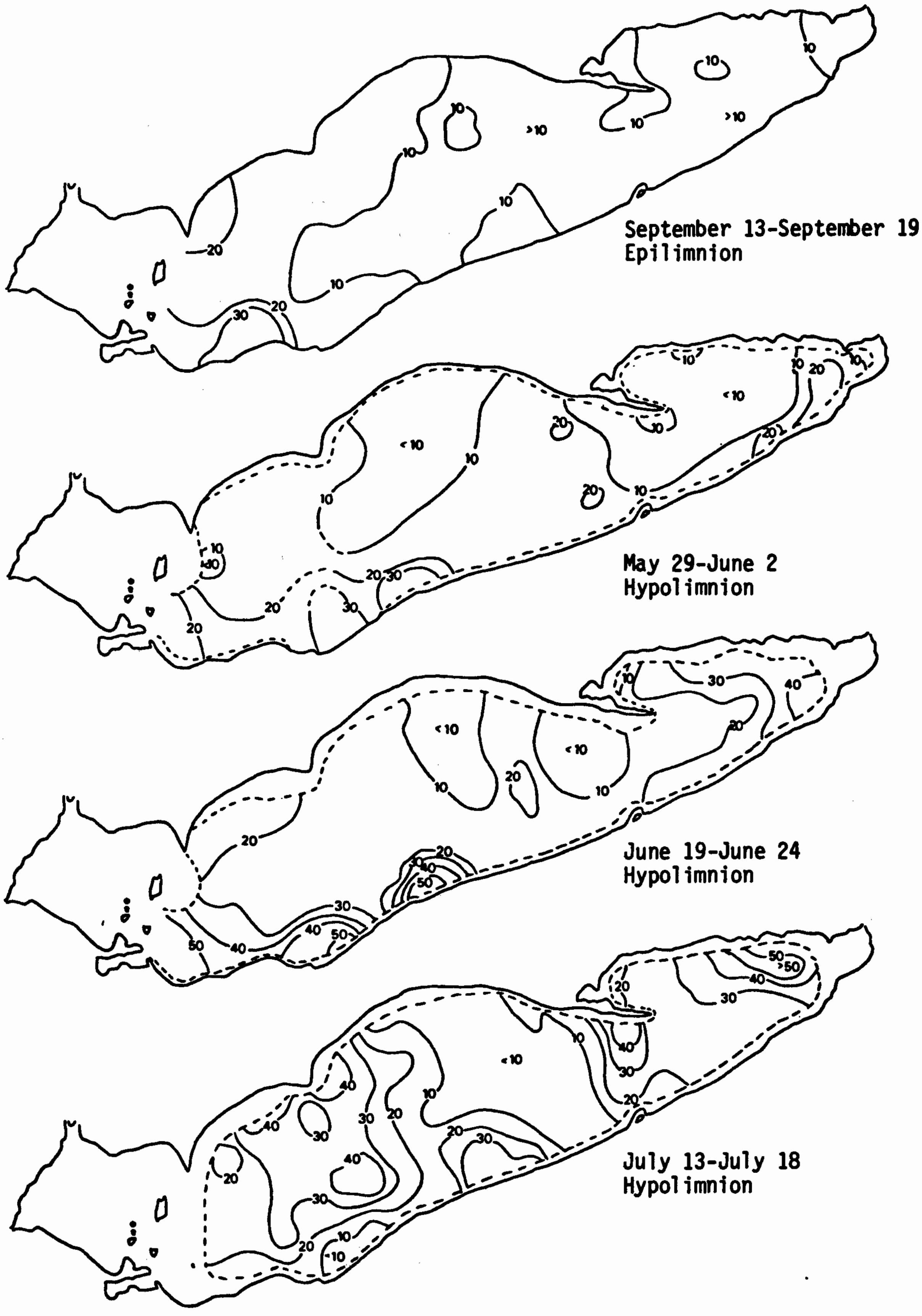


FIGURE 30. THE SEASONAL EPILIMNION AND HYPOLIMNION AMMONIA (ug/l) DISTRIBUTION PATTERNS FOR THE CENTRAL AND EASTERN BASIN OF LAKE ERIE FOR 1978 (CCIW-NWRI).

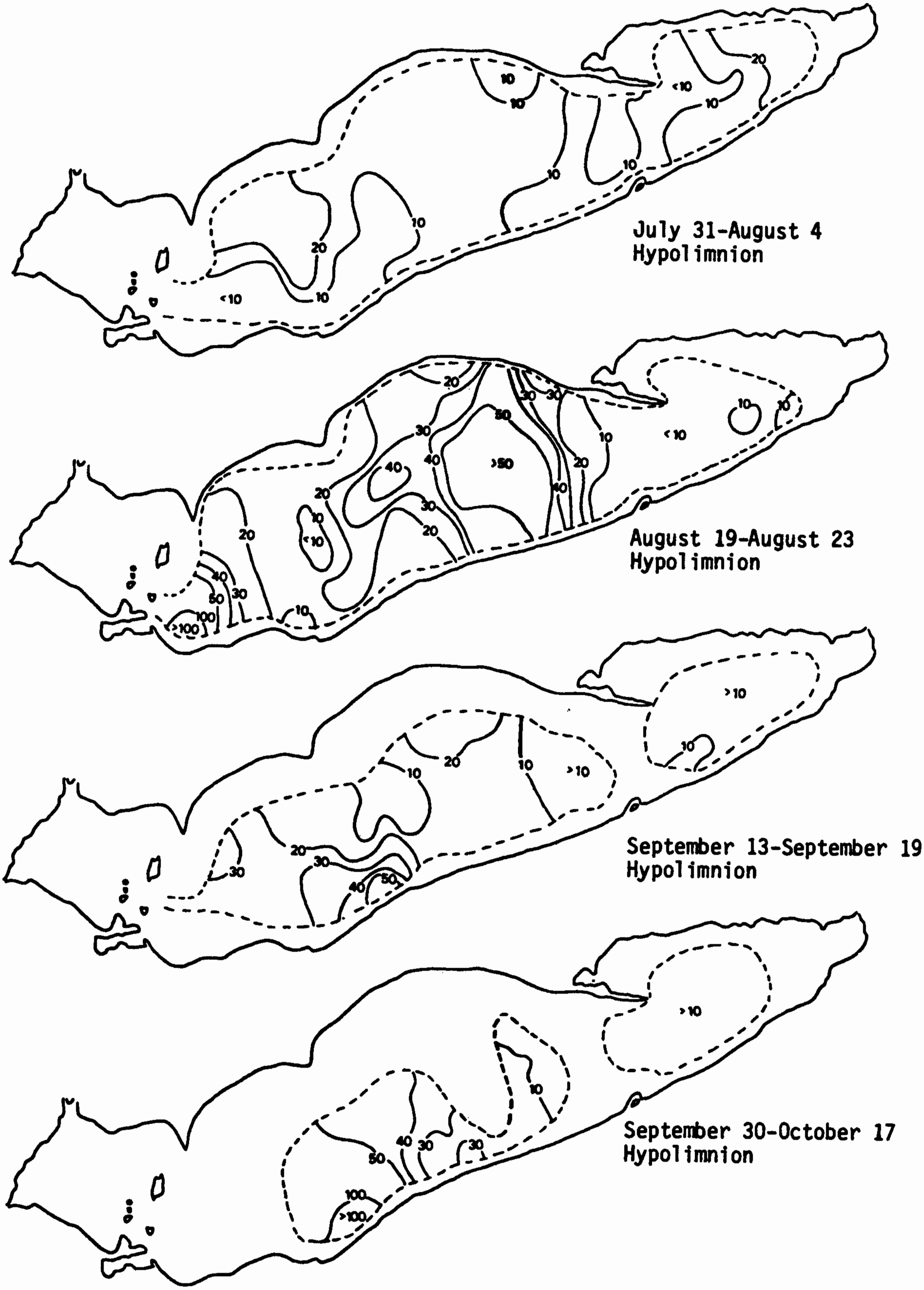


FIGURE 30. CONTINUED

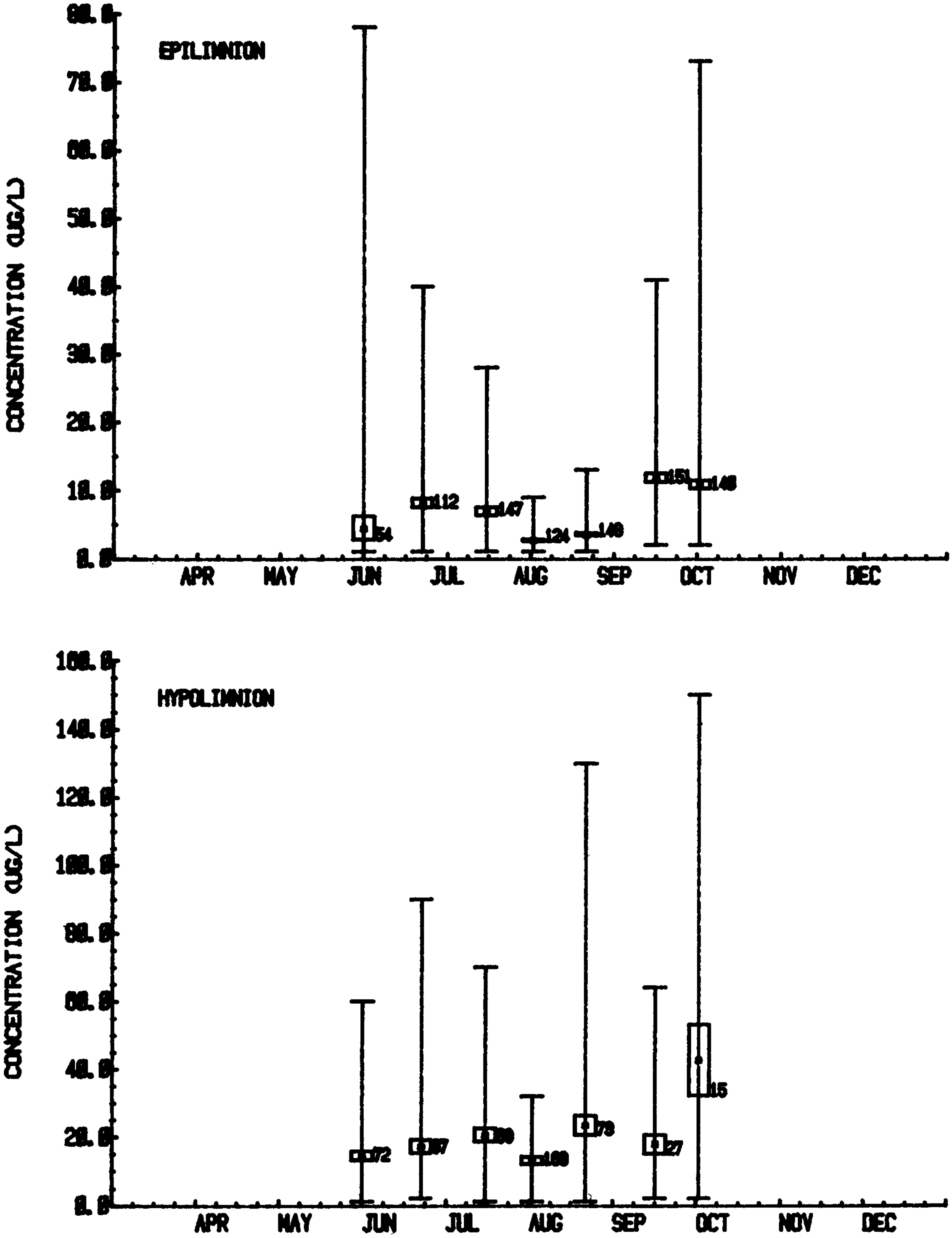


FIGURE 31. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION AMMONIA CONCENTRATIONS FOR 1978 (CCIW-NWRI).

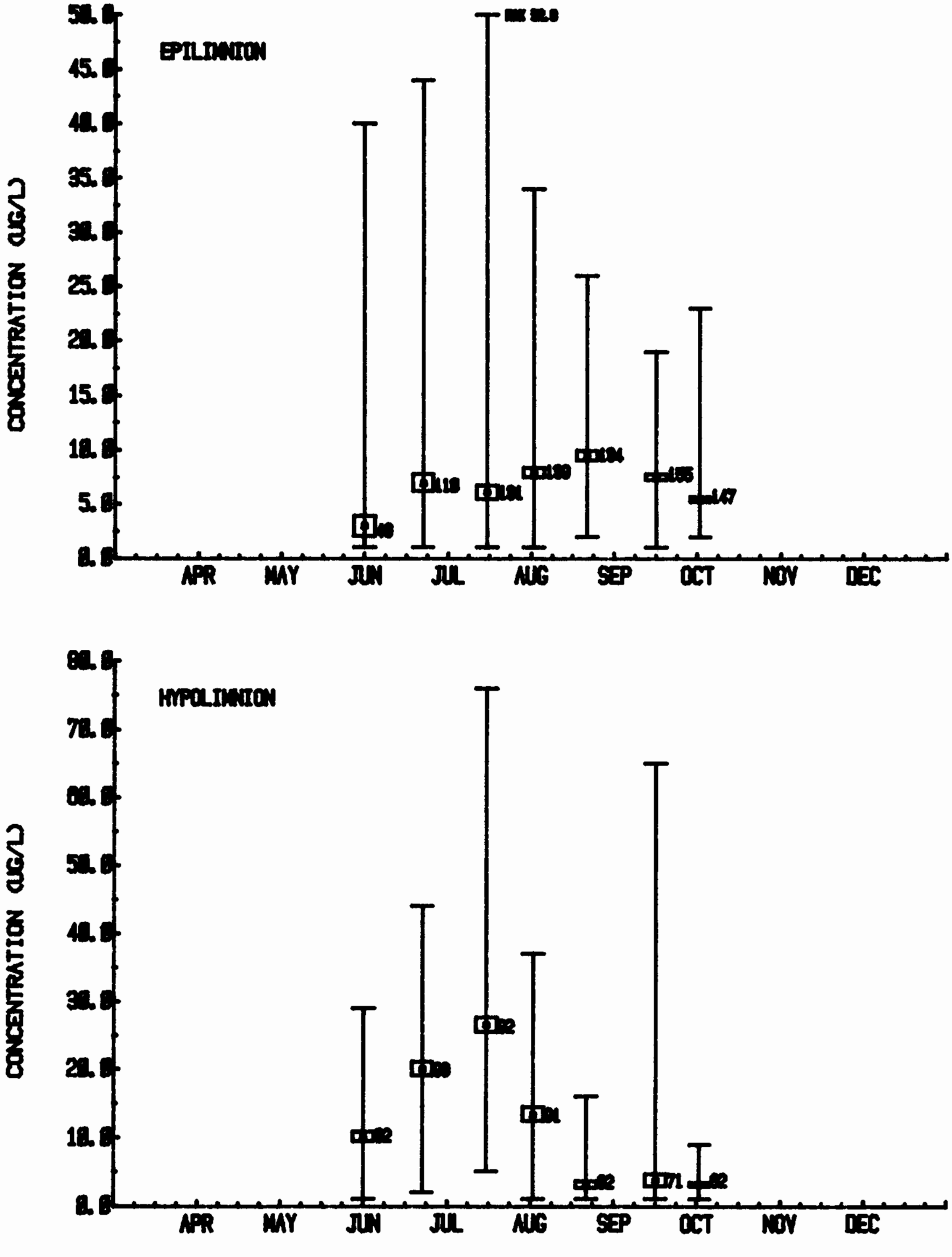


FIGURE 32. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION AMMONIA CONCENTRATIONS FOR 1978 (CCIW-NWRI).

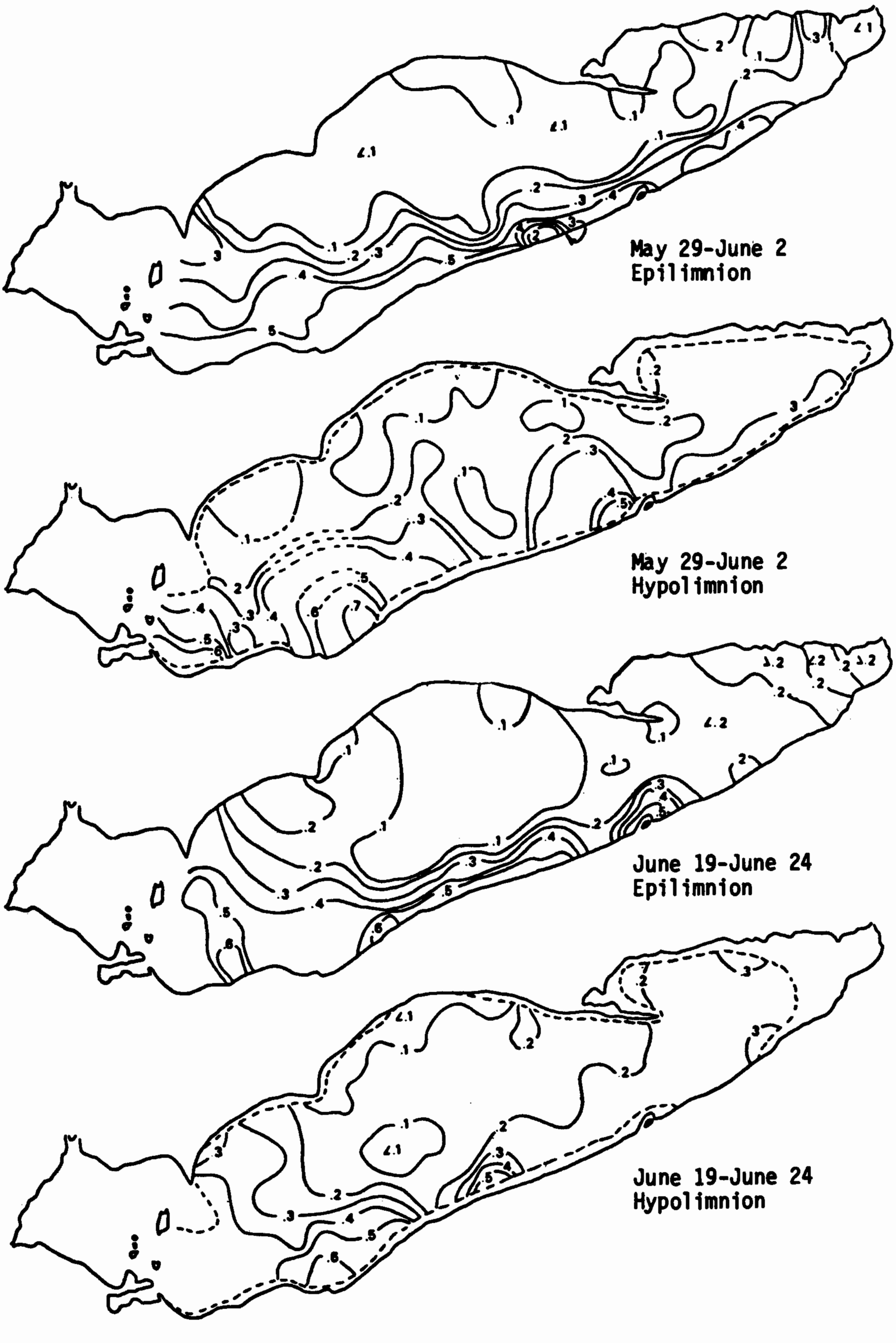


FIGURE 33. THE SEASONAL EPILIMNION AND HYPOLIMNION NITRATE PLUS NITRITE (mg/l) DISTRIBUTION PATTERNS FOR THE CENTRAL AND EASTERN BASINS OF LAKE ERIE FOR 1978 (CCIW-NWRI).

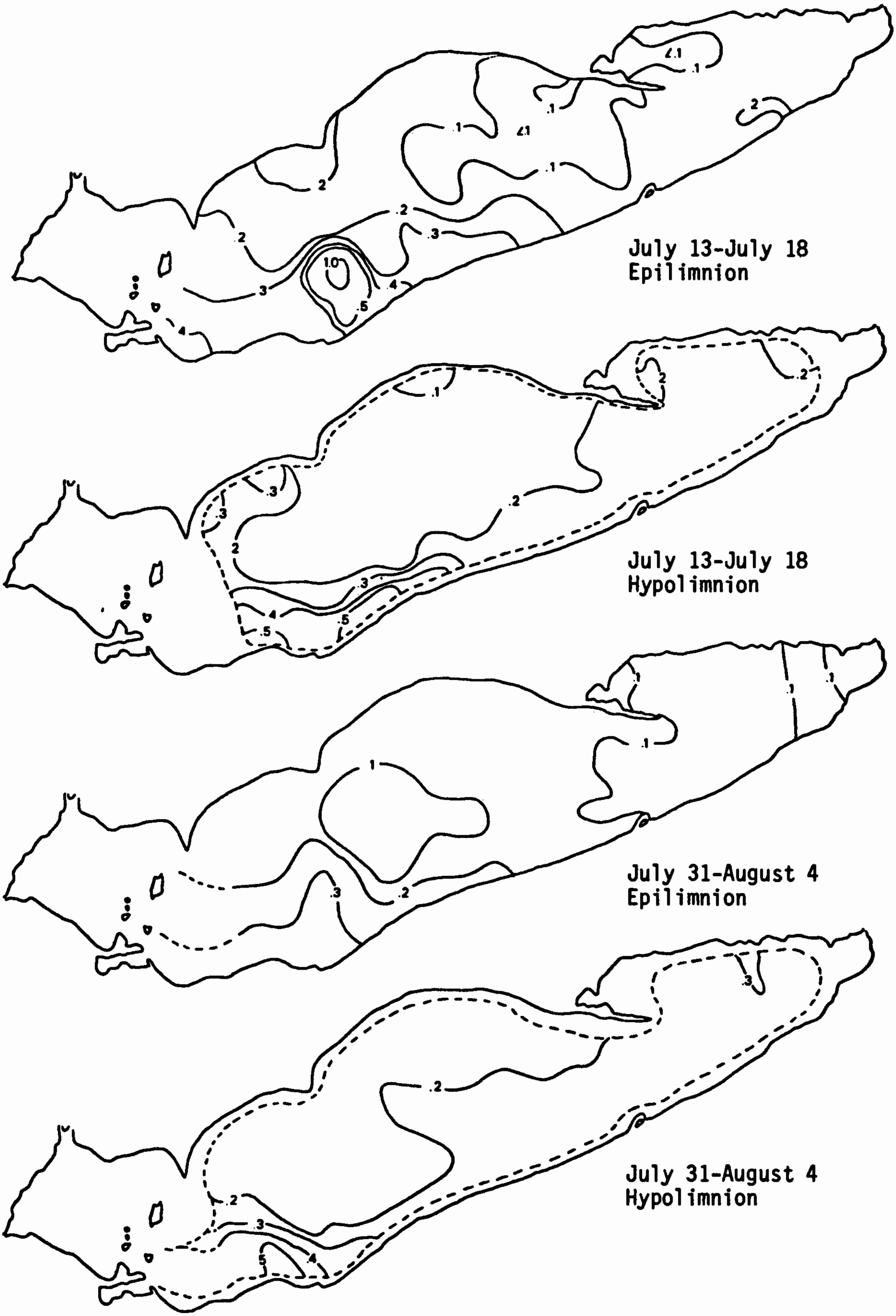
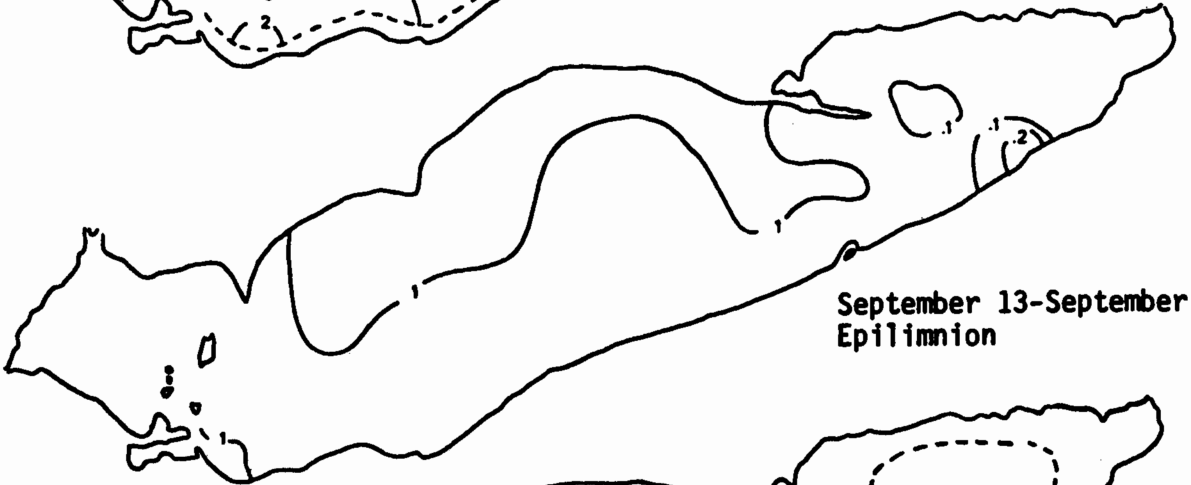


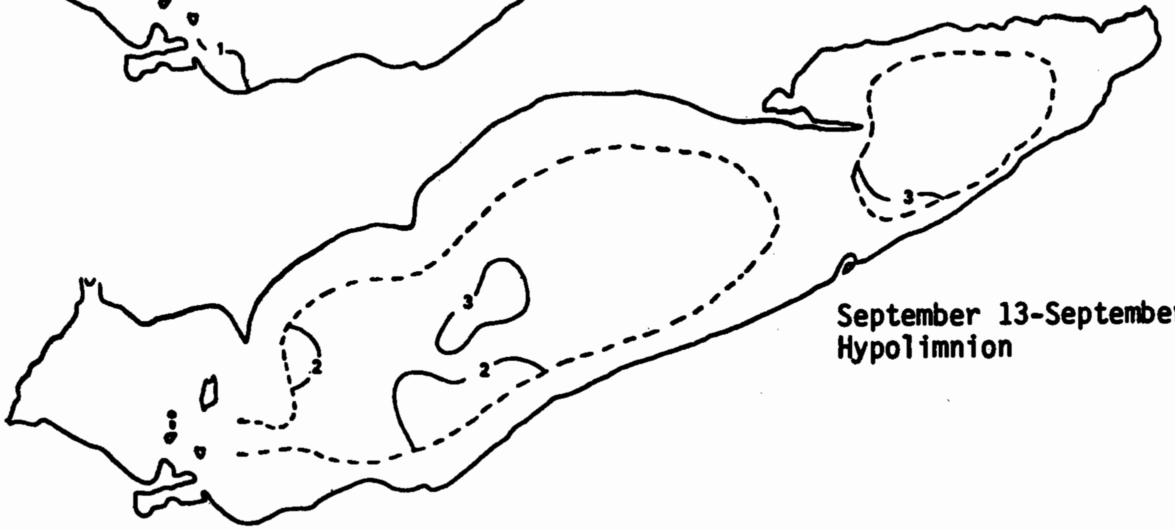
FIGURE 33. Continued

August 19-August 23
Epilimnion

August 19-August 23
Hypolimnion

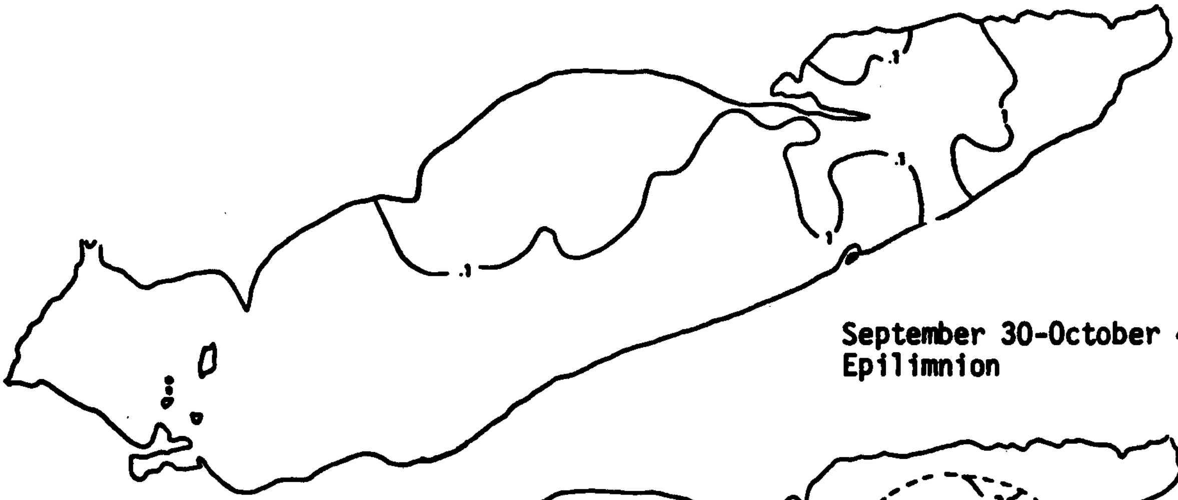


September 13-September 19
Epilimnion

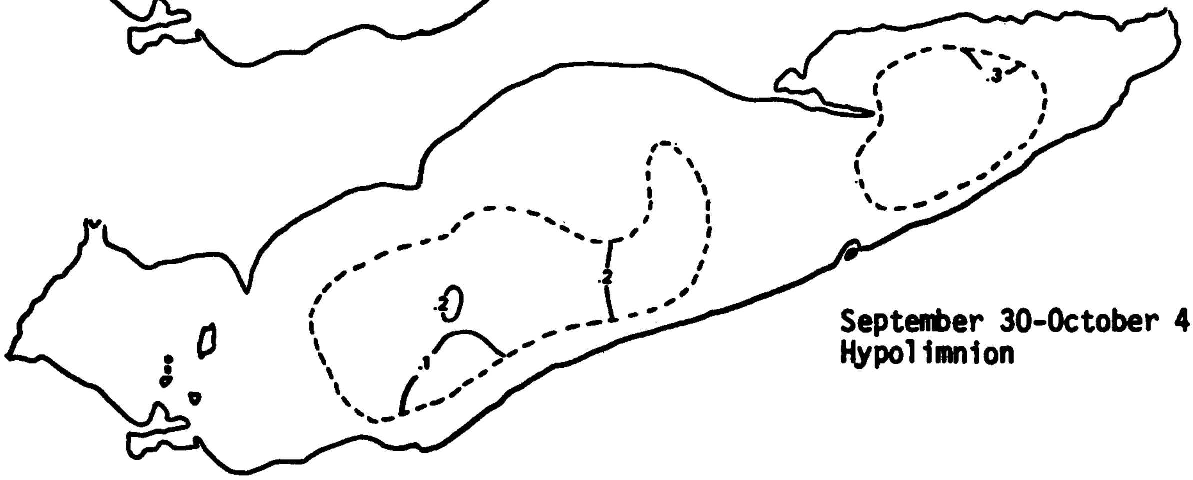


September 13-September 19
Hypolimnion

FIGURE 33. Continued



September 30-October 4
Epilimnion



September 30-October 4
Hypolimnion

FIGURE 33. Continued

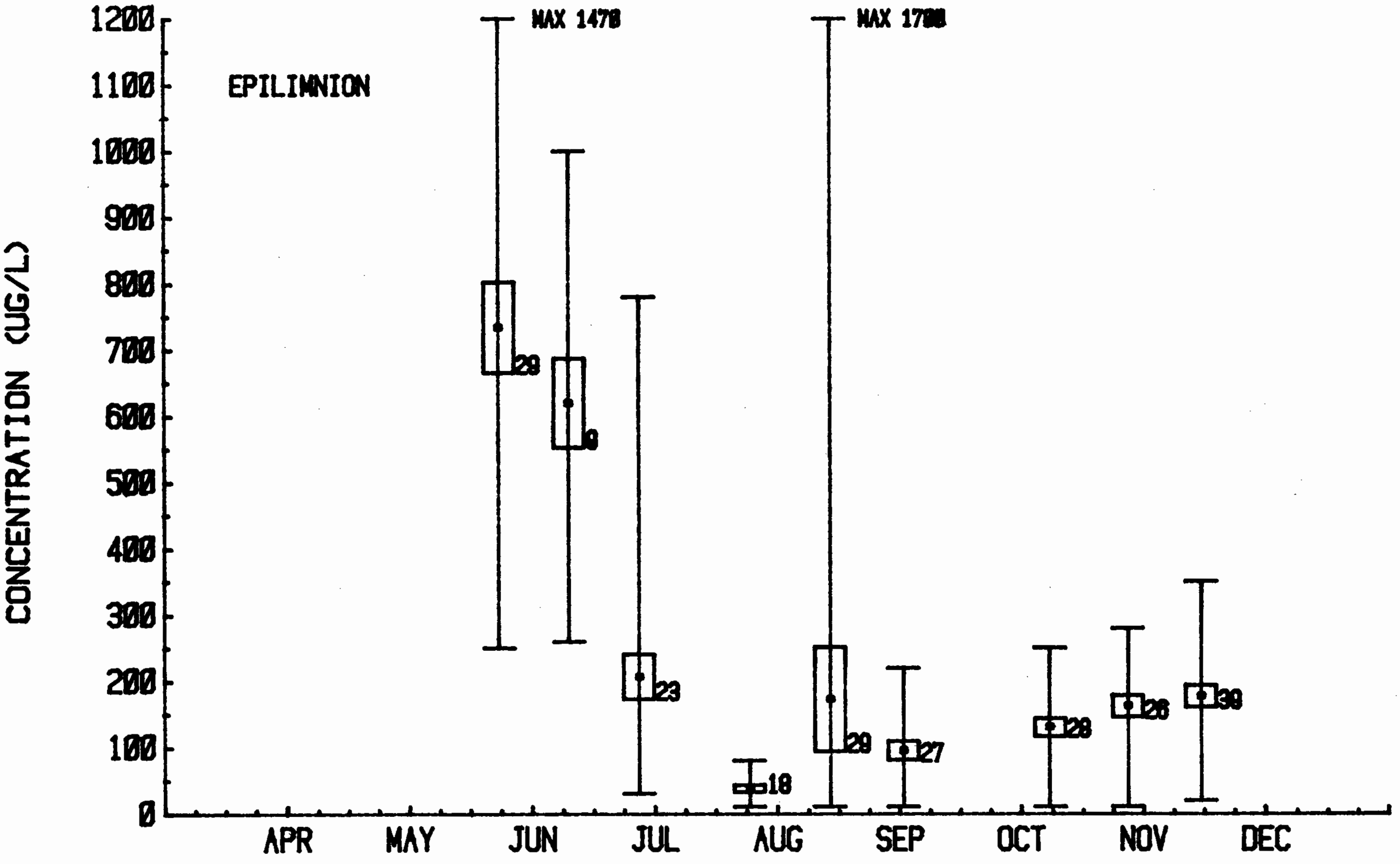


FIGURE 34. THE MEAN WESTERN BASIN NITRATE PLUS NITRITE CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

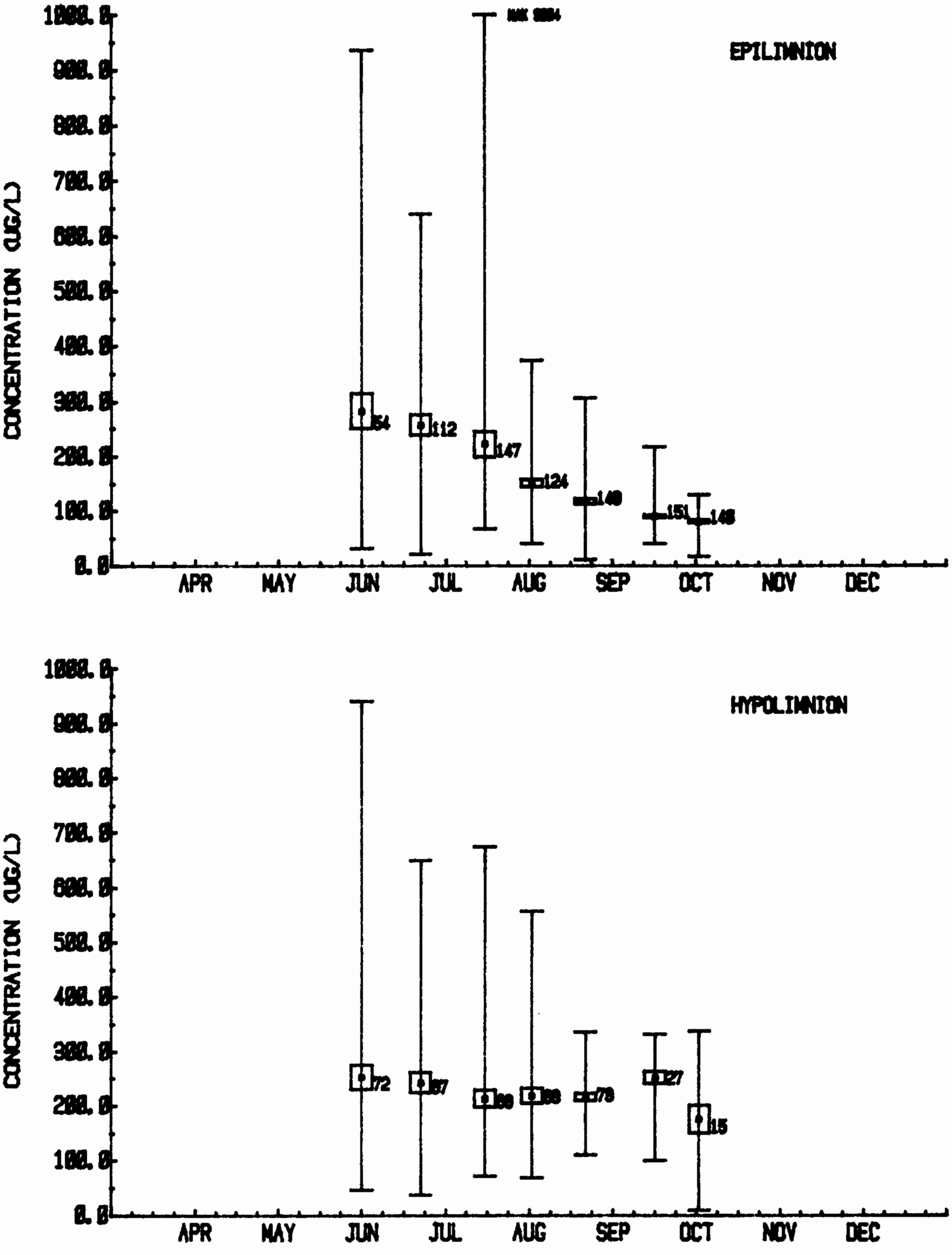


FIGURE 35. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION NITRATE PLUS NITRITE CONCENTRATIONS FOR 1978 (CCIW-NWRI).

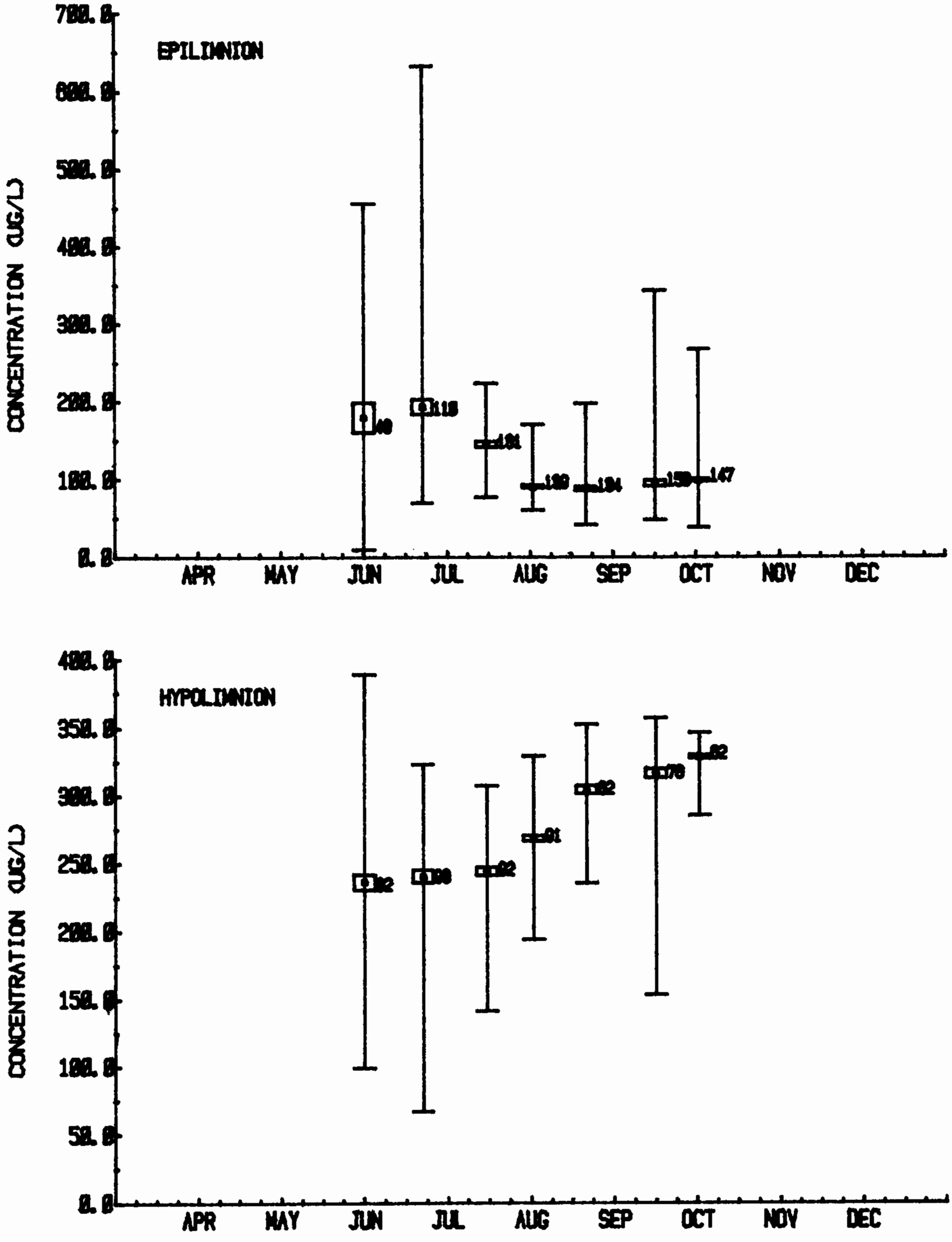


FIGURE 36. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION NITRATE PLUS NITRITE CONCENTRATIONS FOR 1978 (CCIW-NWRI).

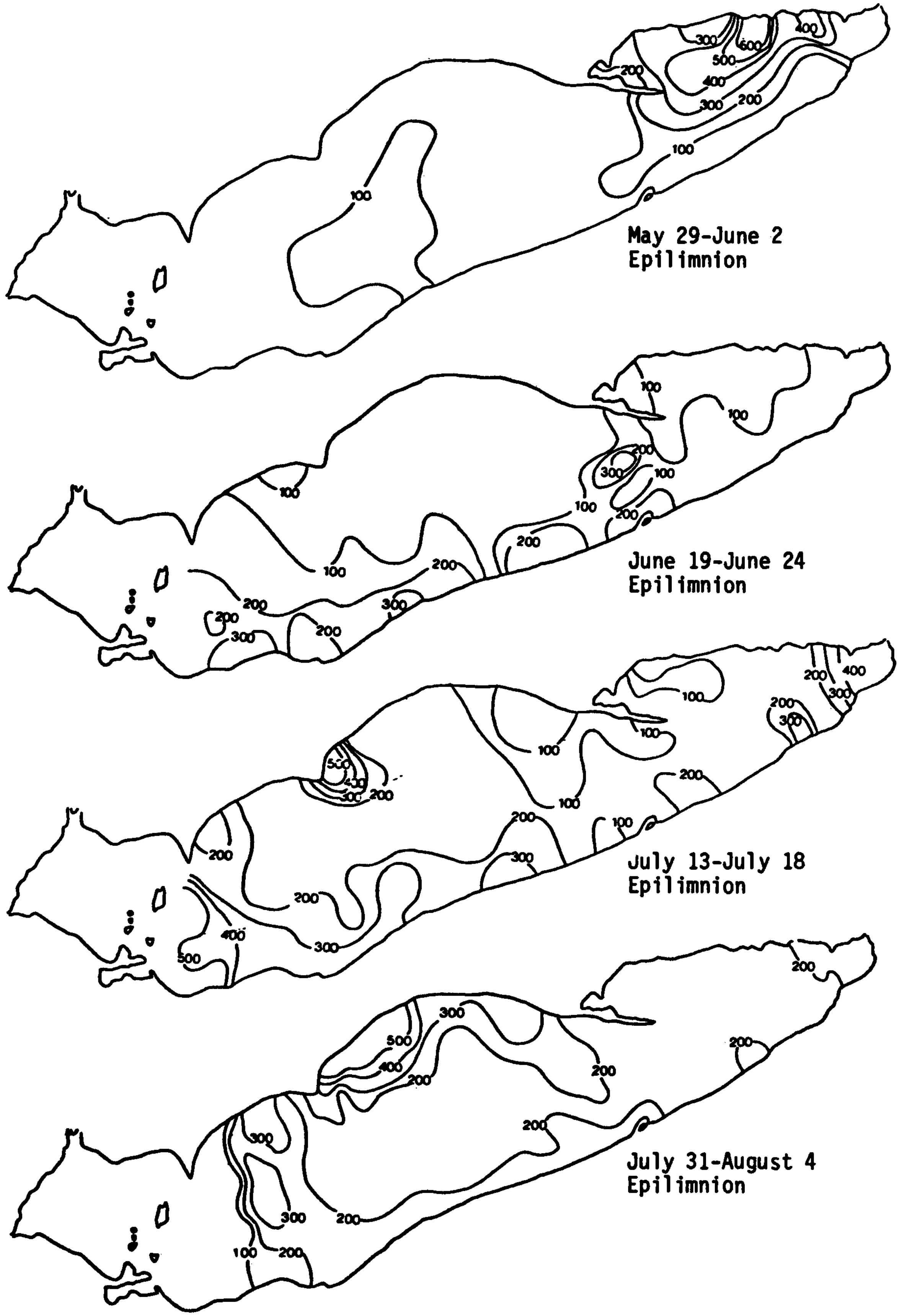


FIGURE 37. THE SEASONAL EPILIMNION DISSOLVED SILICA (ug/l) DISTRIBUTION PATTERNS FOR THE CENTRAL AND EASTERN BASINS OF LAKE ERIE FOR 1978 (CCIW-NWRI).

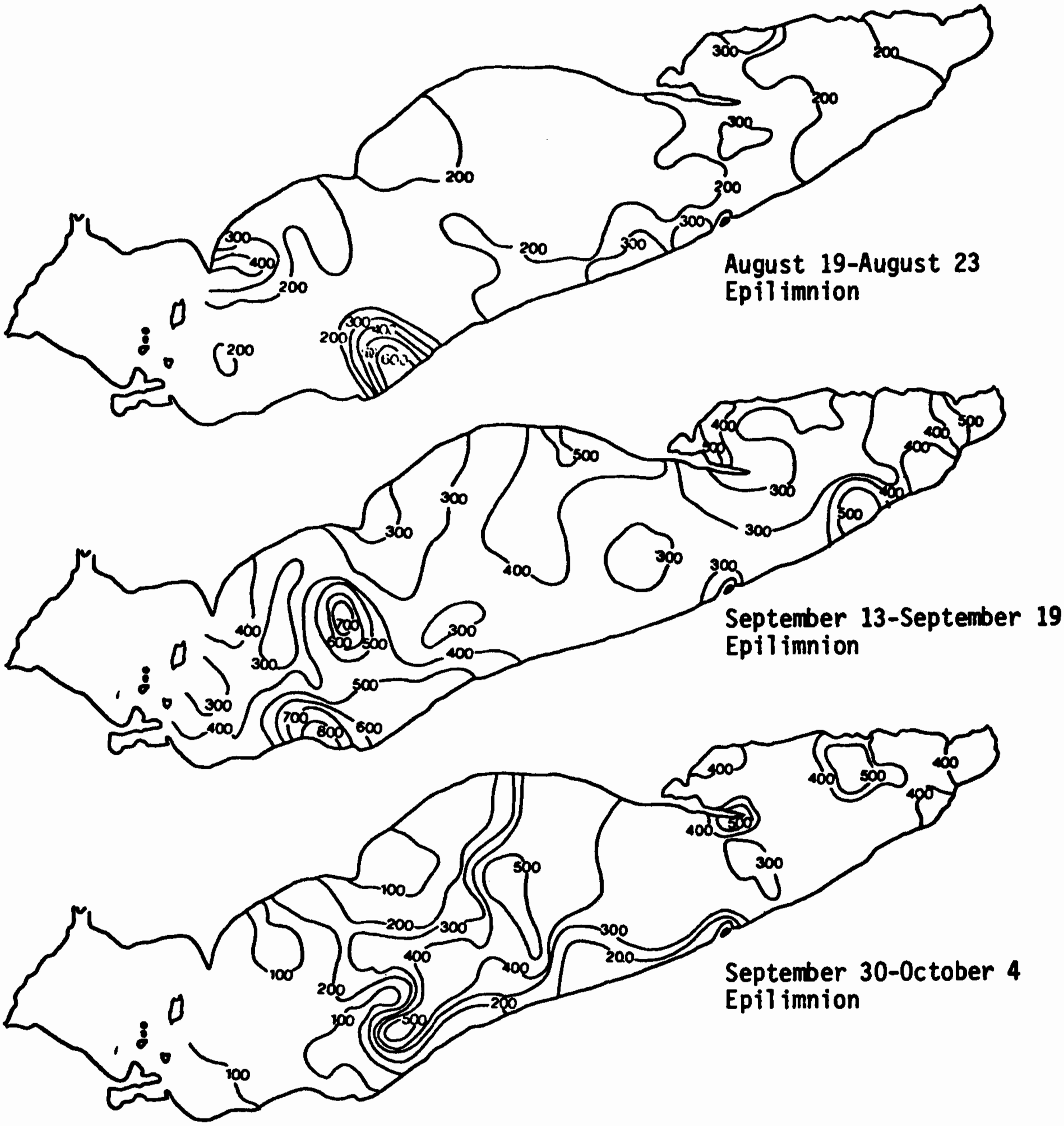


FIGURE 37. CONTINUED

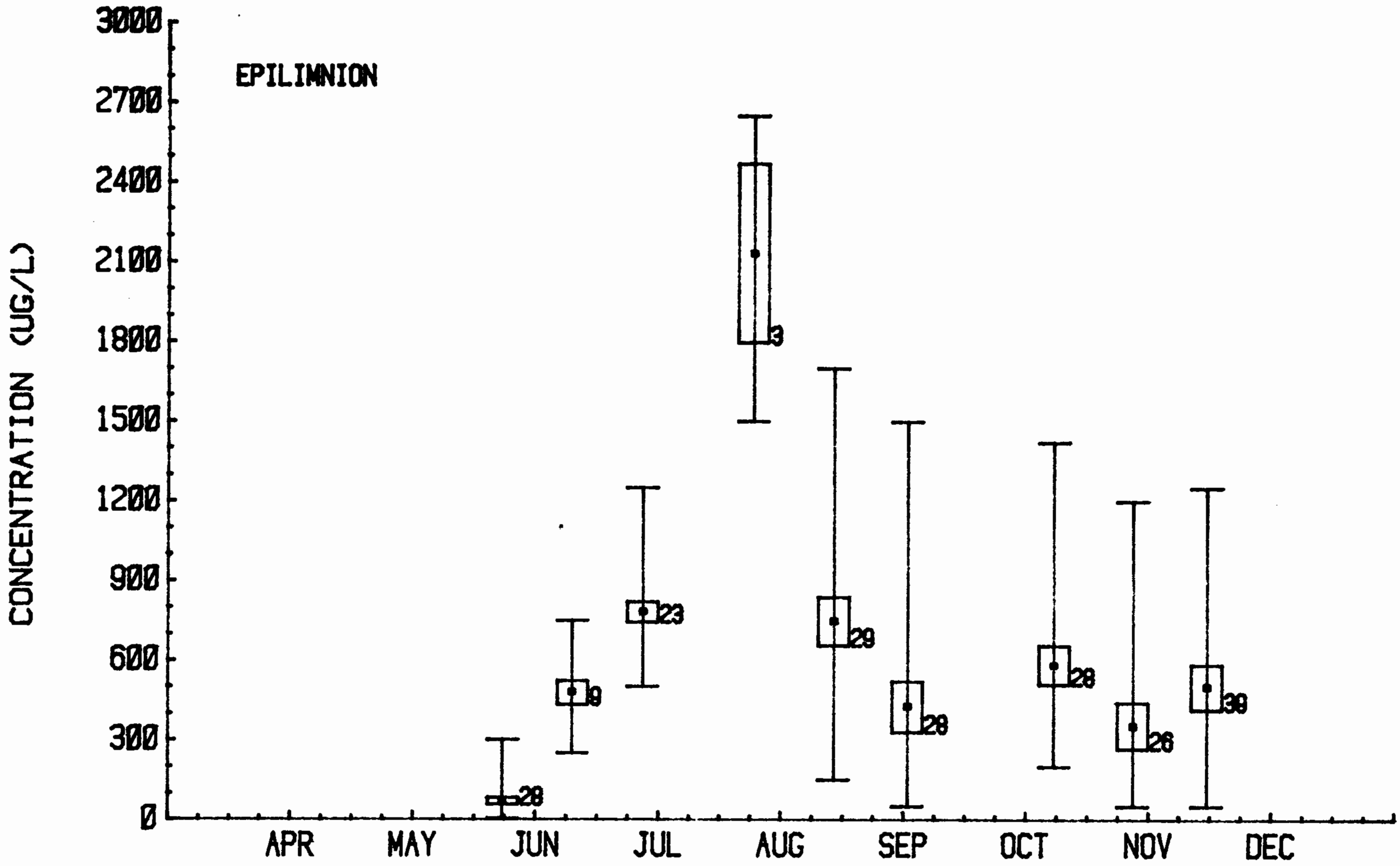


FIGURE 38. THE MEAN WESTERN BASIN DISSOLVED SILICA CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

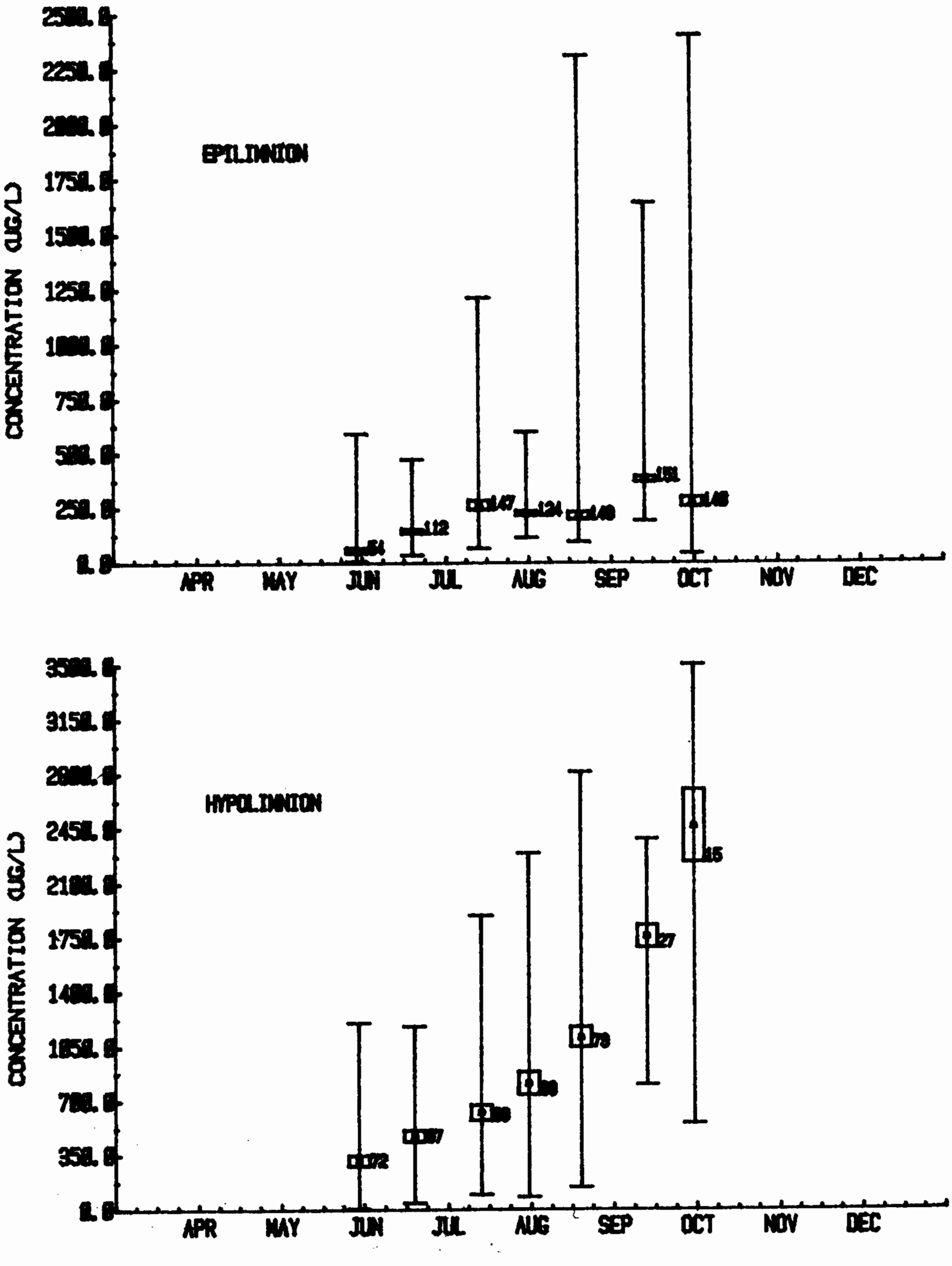


FIGURE 39. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION CONCENTRATIONS OF DISSOLVED SILICA FOR 1978 (CCIW-NWRI).

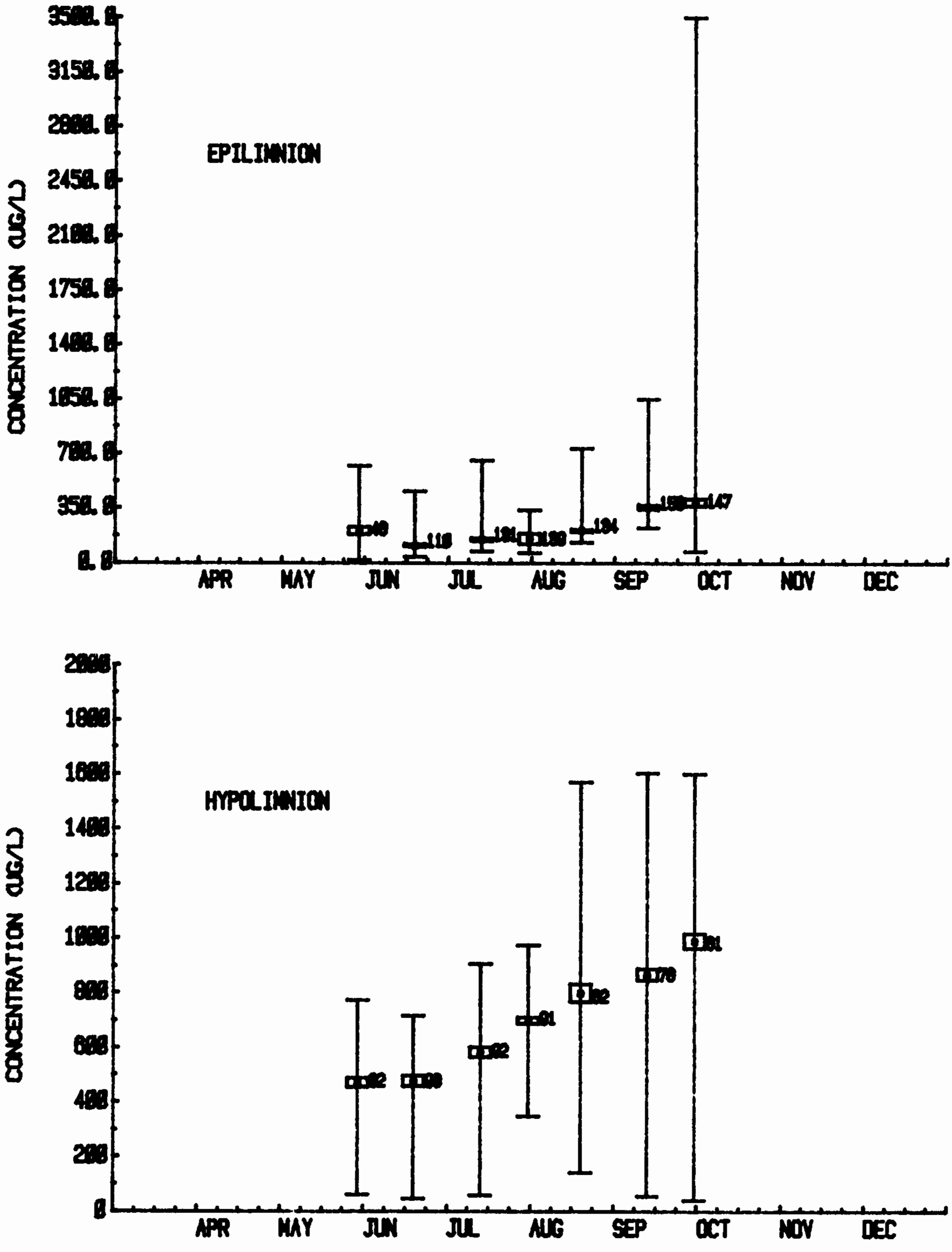


FIGURE 40. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION CONCENTRATIONS OF DISSOLVED SILICA FOR 1978 (CCIW-NWRI).

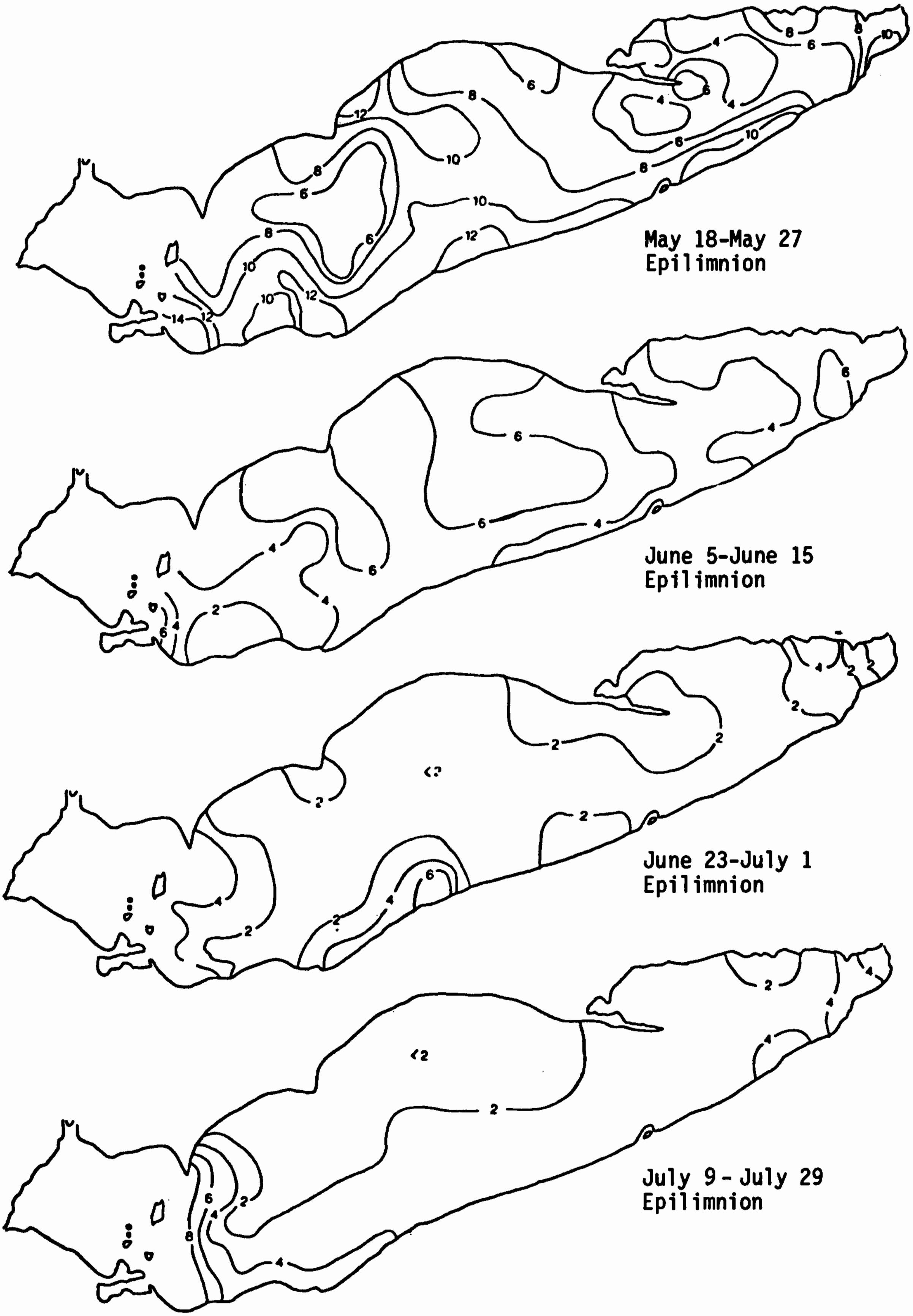
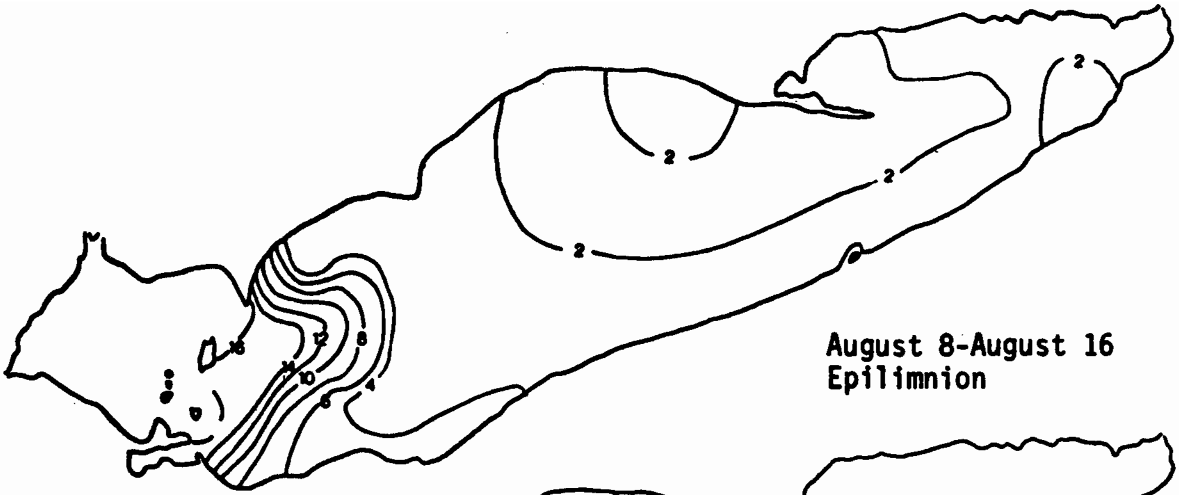
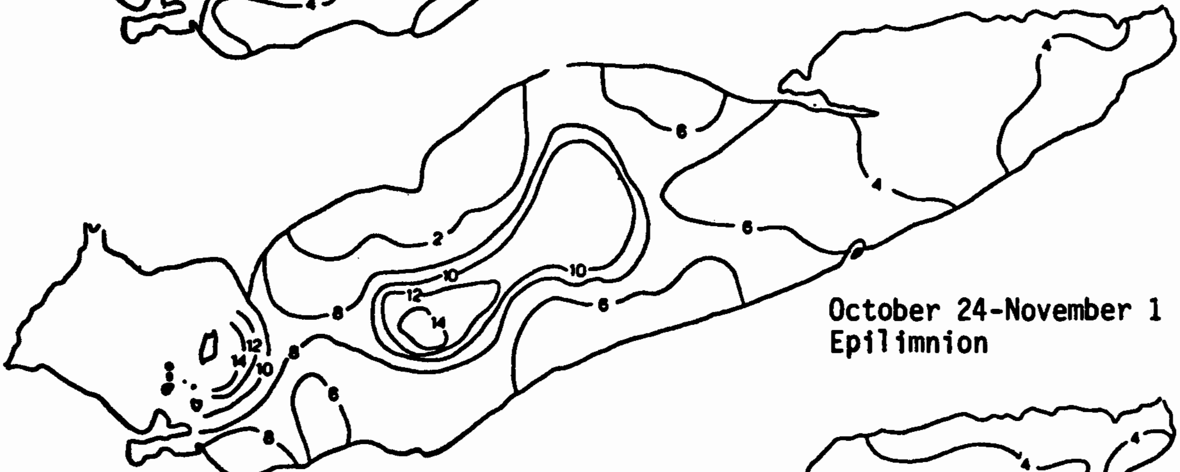


FIGURE 41. THE SEASONAL EPILIMNION CORRECTED CHLOROPHYLL a (ug/l) DISTRIBUTION PATTERNS FOR THE CENTRAL AND EASTERN BASINS OF LAKE ERIE FOR 1978 (USEPA-GLNPO).



August 8-August 16
Epilimnion

August 29-September 6
Epilimnion



October 24-November 1
Epilimnion

November 10-November 19
Epilimnion

FIGURE 41. Continued

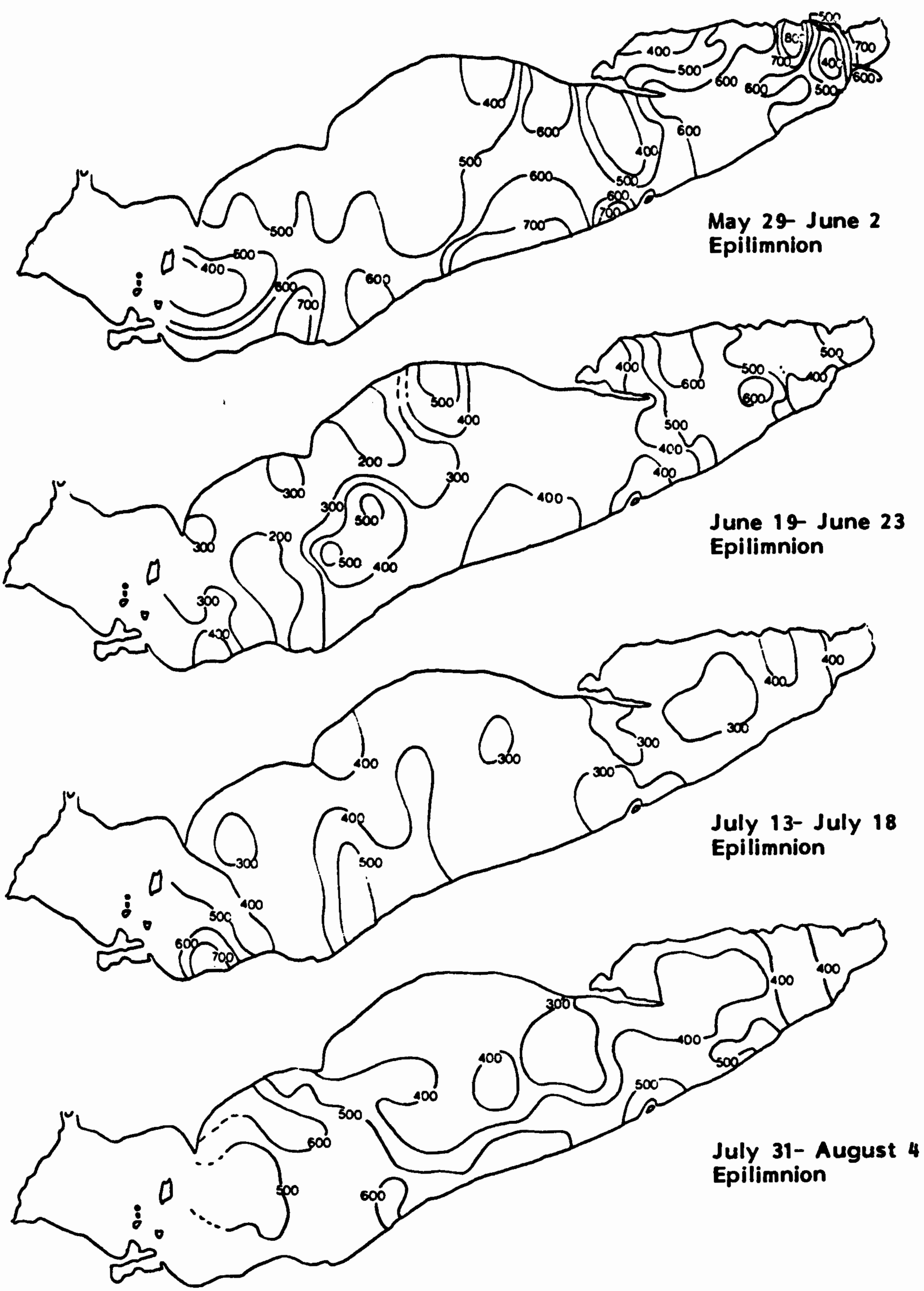


FIGURE 42. THE SEASONAL EPILIMNION PARTICULATE ORGANIC CARBON (ug/l) DISTRIBUTION PATTERNS FOR THE CENTRAL AND EASTERN BASINS OF LAKE ERIE FOR 1978 (CCIW-NWRI).

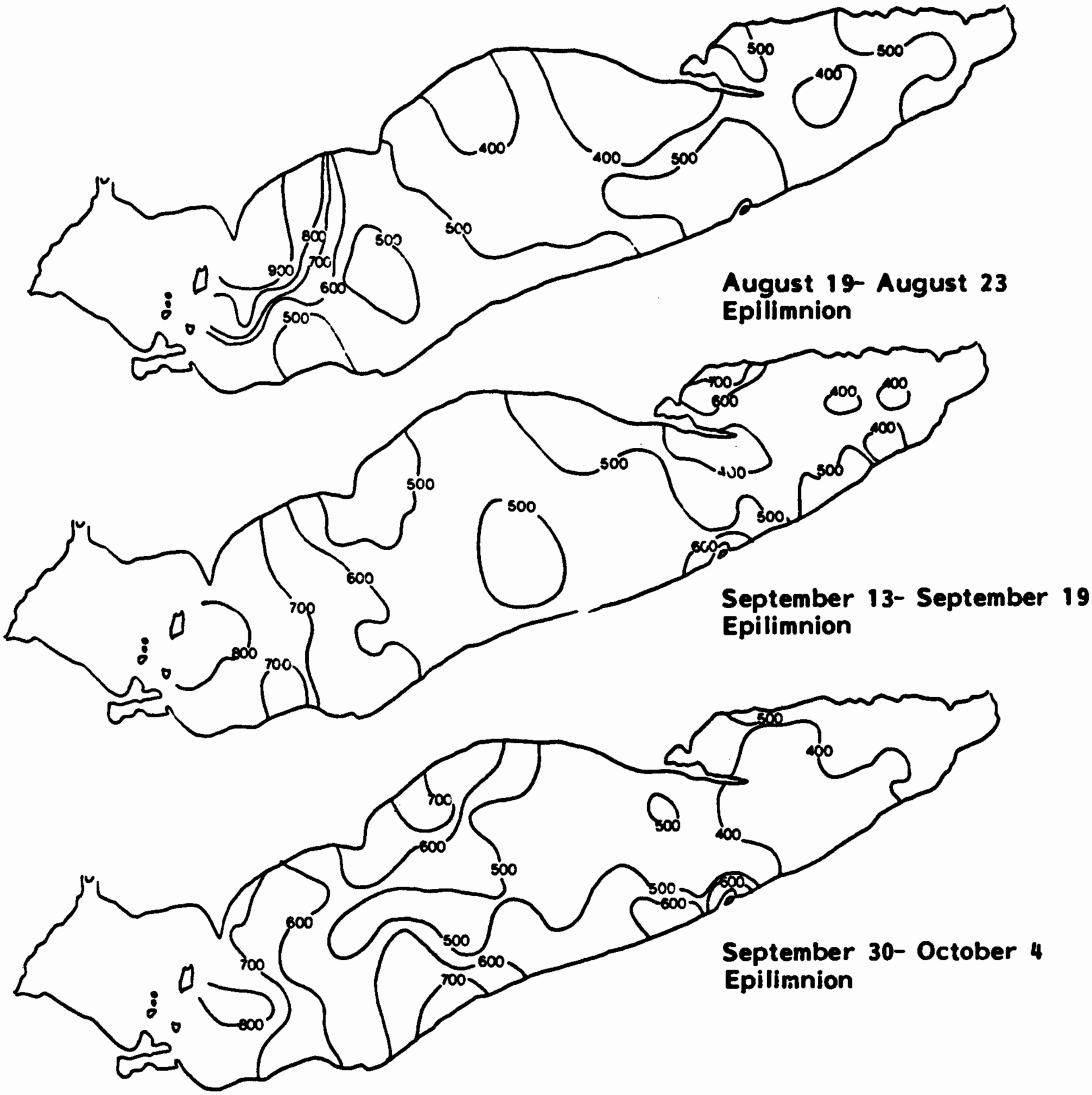


FIGURE 42. CONTINUED

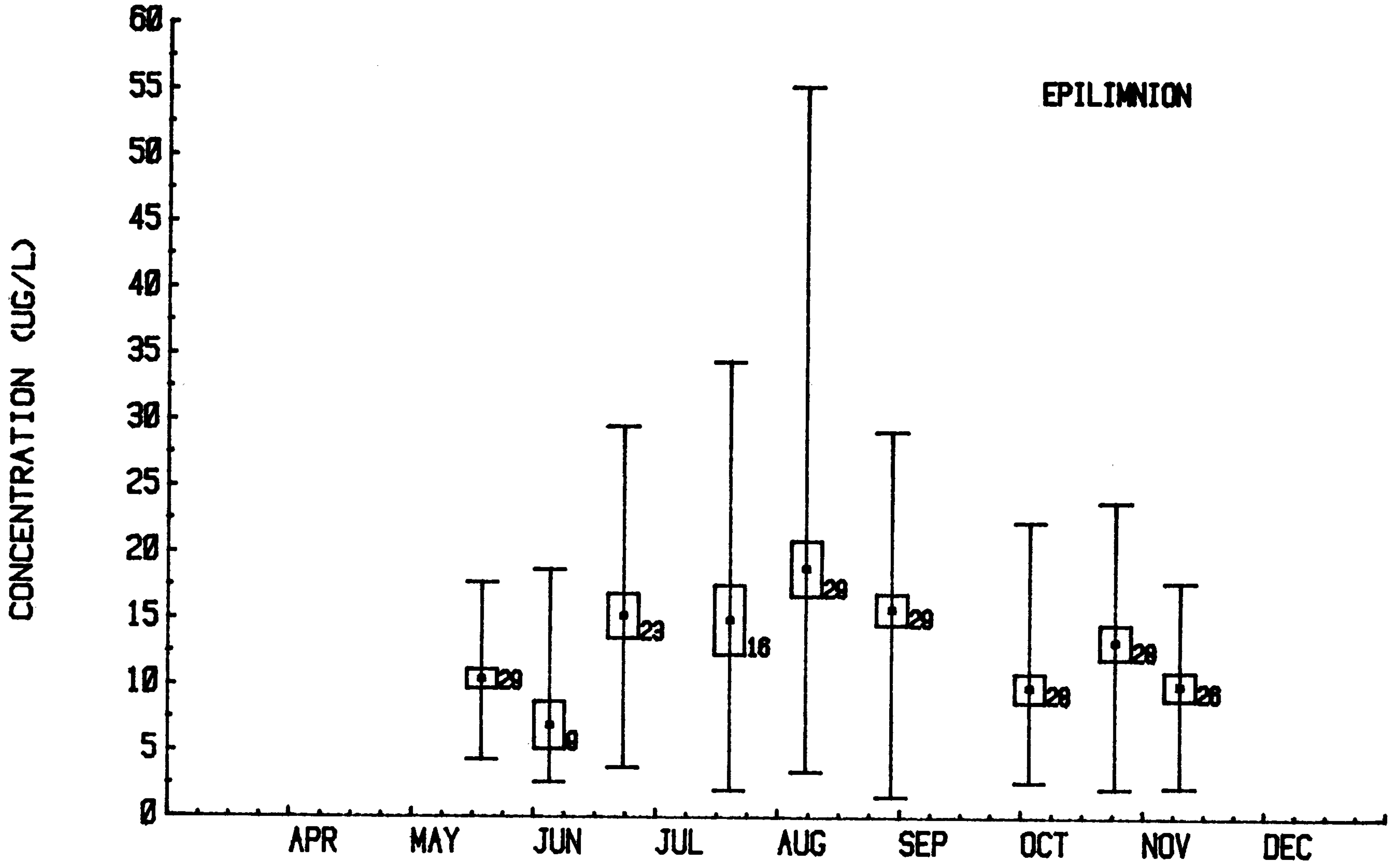
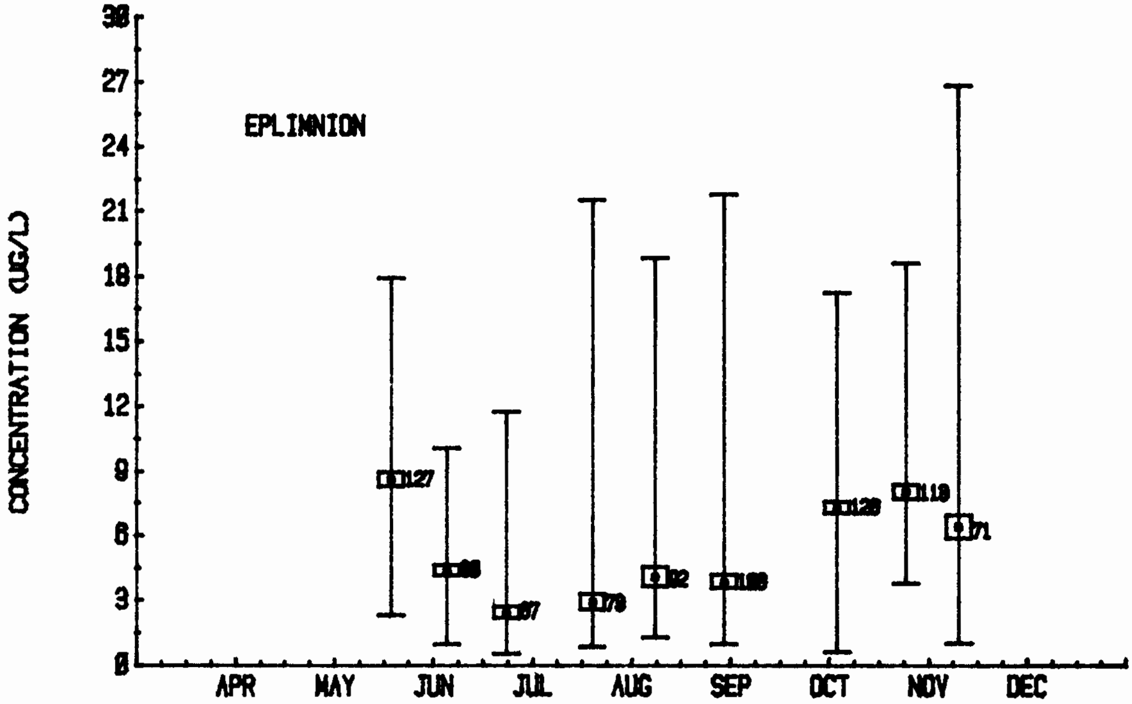


FIGURE 43. THE MEAN WESTERN BASIN CORRECTED CHLOROPHYLL A CONCENTRATIONS FOR 1978 (USEPA-GLNPO).



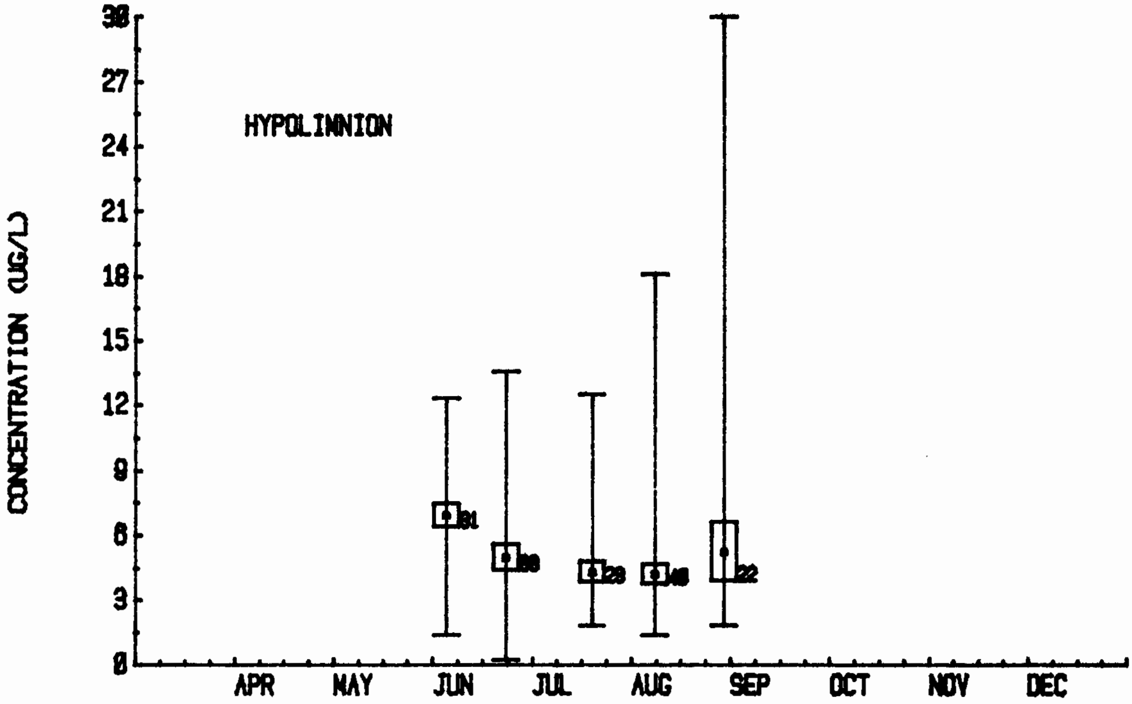


FIGURE 44. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION CORRECTED CHLOROPHYLL A CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

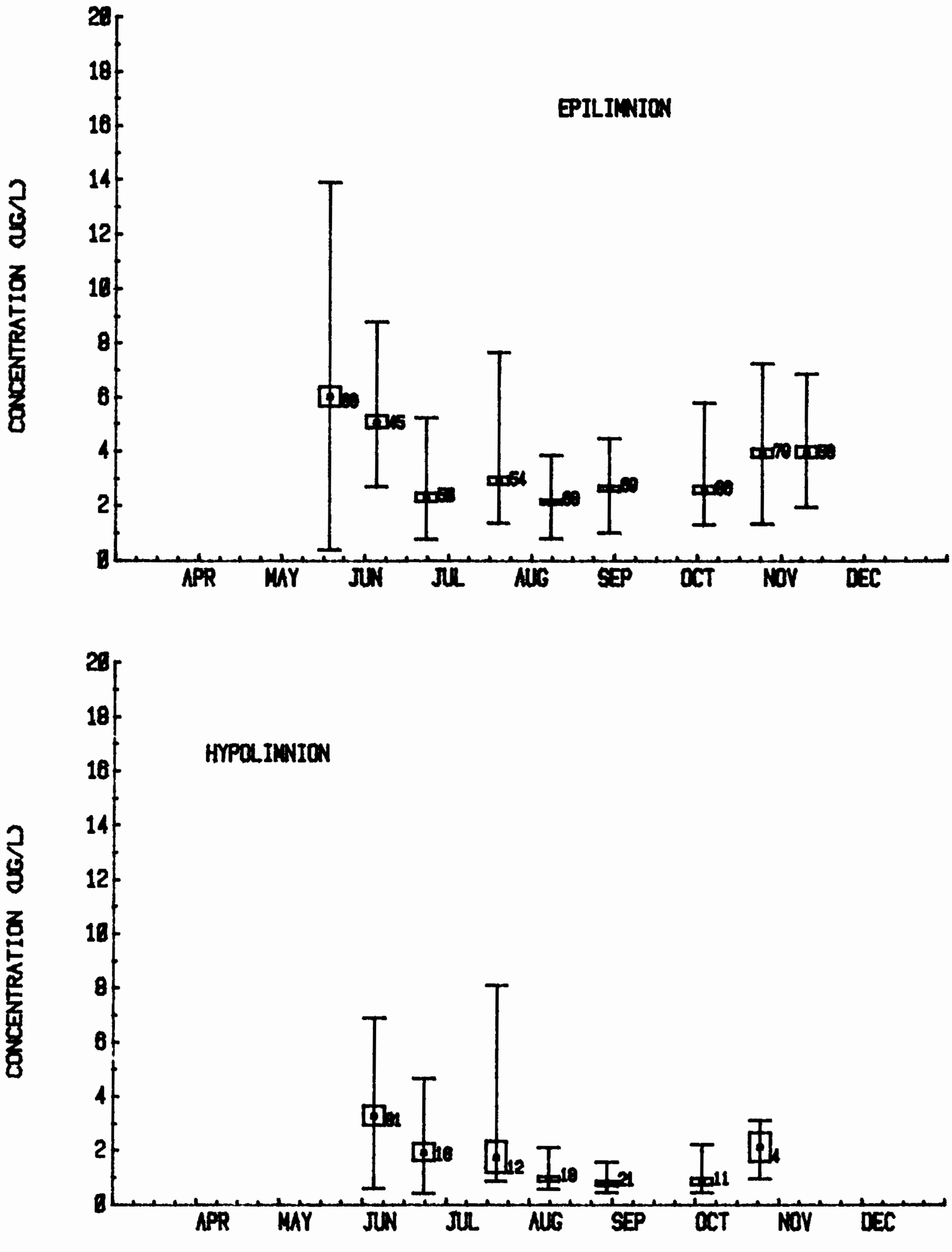


FIGURE 45. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION CORRECTED CHLOROPHYLL A CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

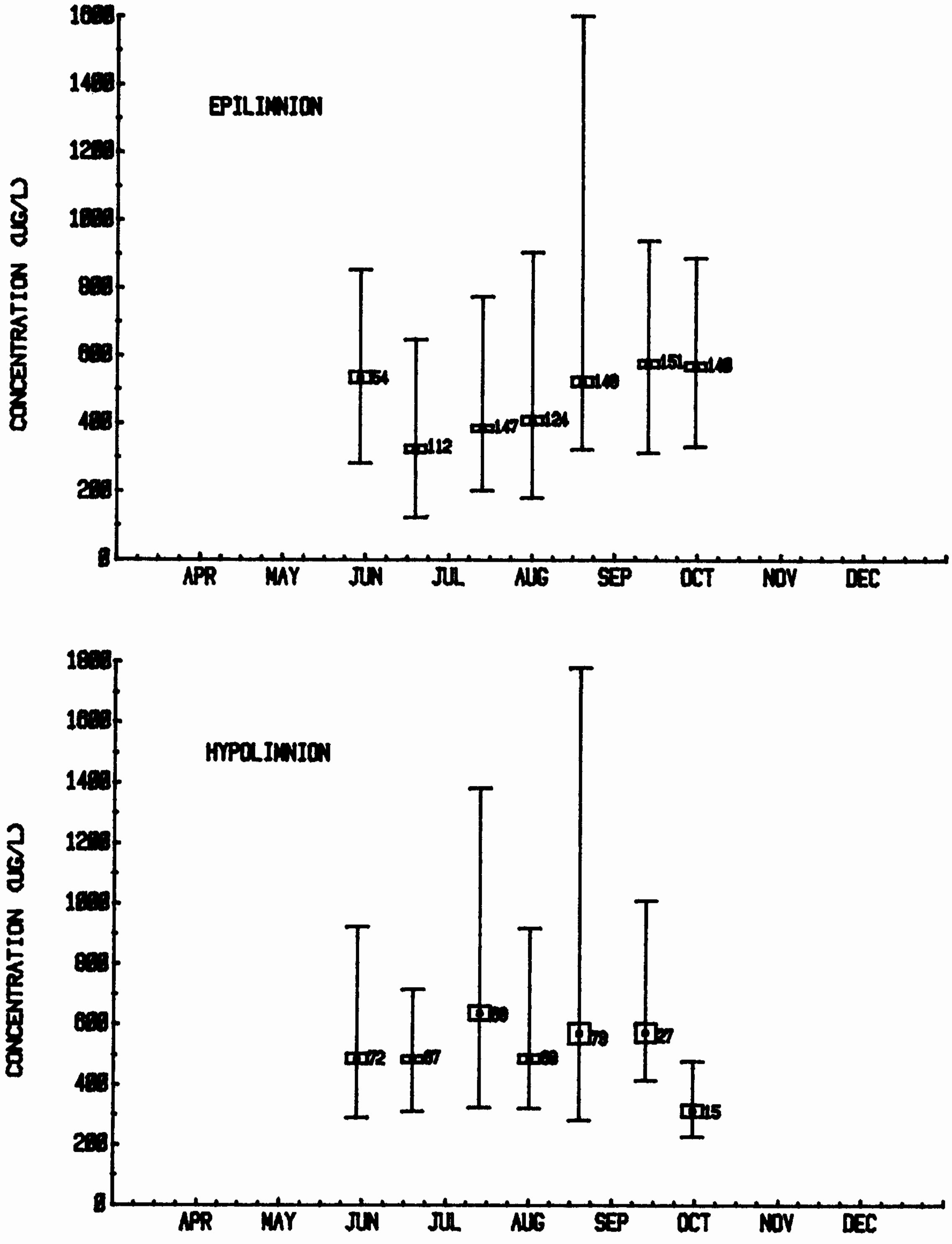


FIGURE 46. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION PARTICULATE ORGANIC CARBON CONCENTRATIONS FOR 1978 (CCIW-NWRI).

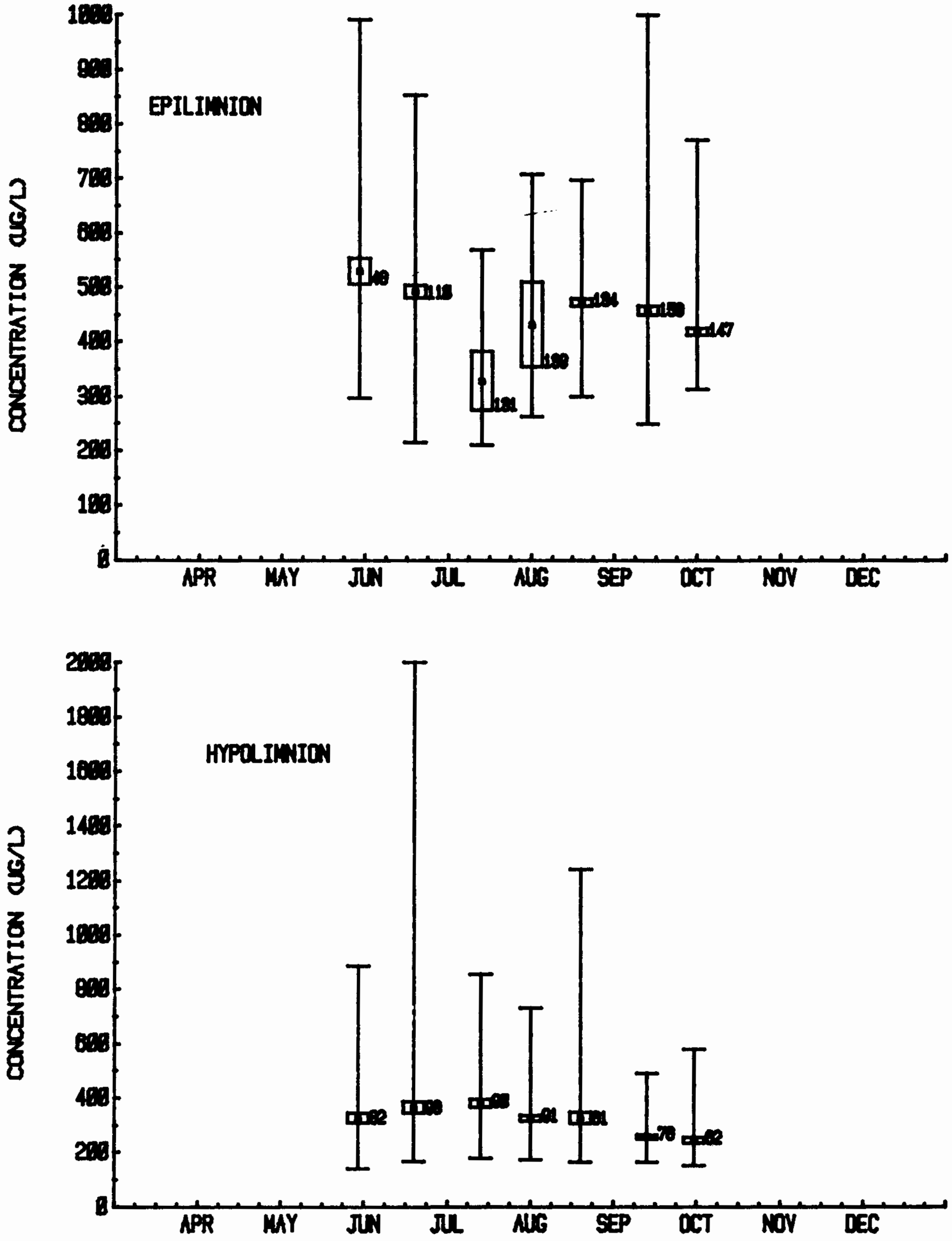


FIGURE 47. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION PARTICULATE ORGANIC CARBON CONCENTRATIONS FOR 1978 (CCIW-NWRI).

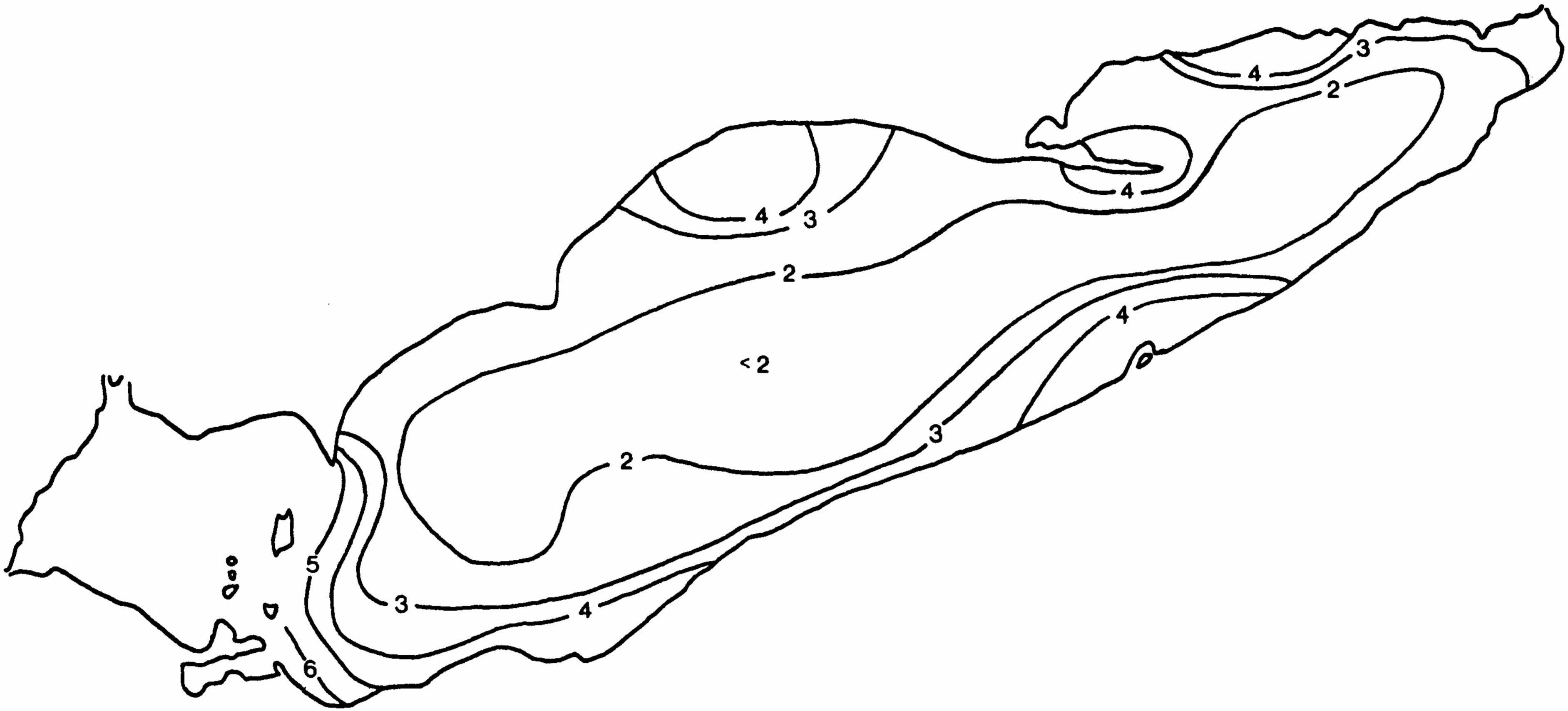


FIGURE 48. THE 1978 SEASONAL MEAN DISTRIBUTION PATTERN OF TOTAL SUSPENDED SOLIDS (mg/l) FOR CENTRAL AND EASTERN BASINS OF LAKE ERIE (USEPA-GNNPO).

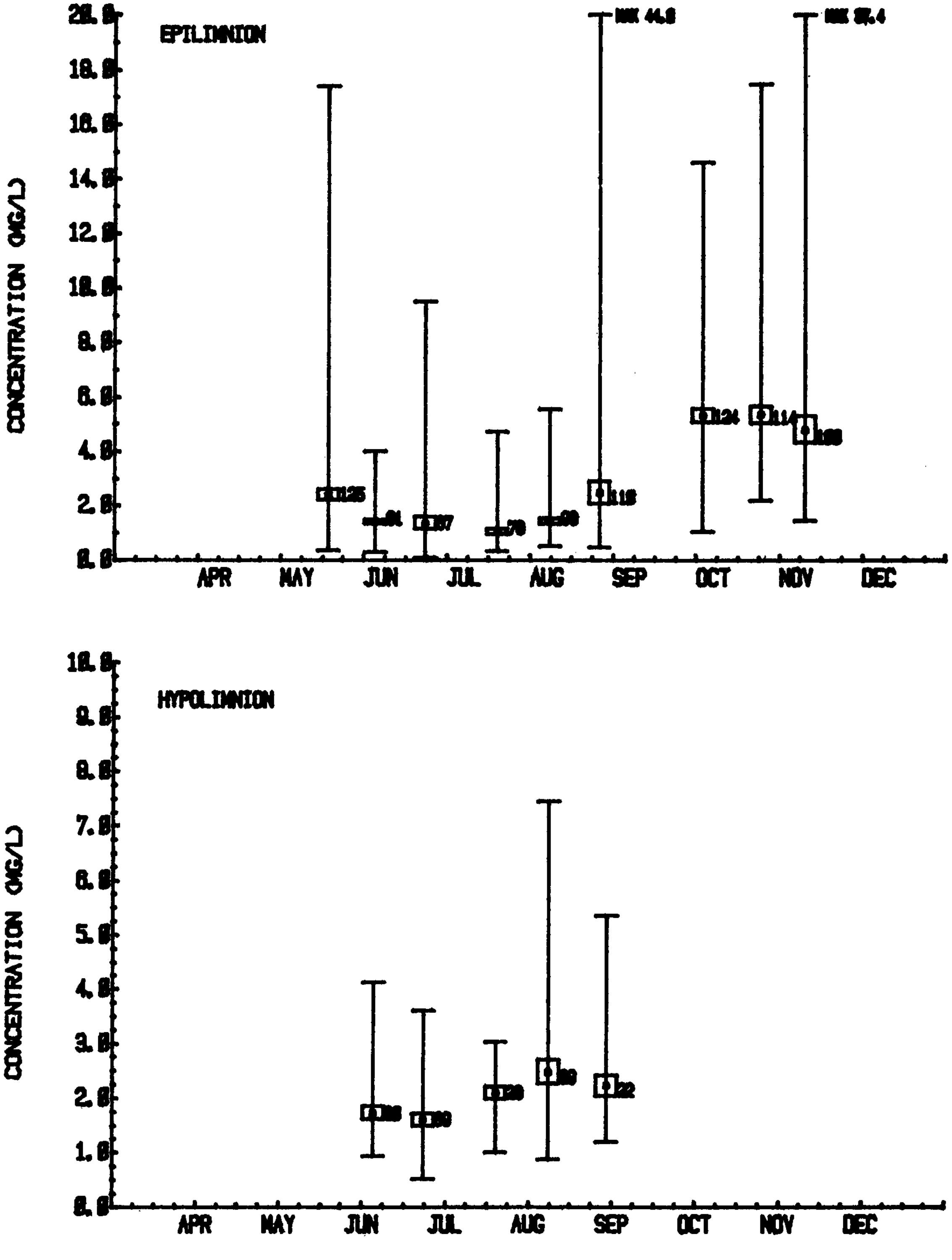


FIGURE 49. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION TOTAL SUSPENDED SOLIDS CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

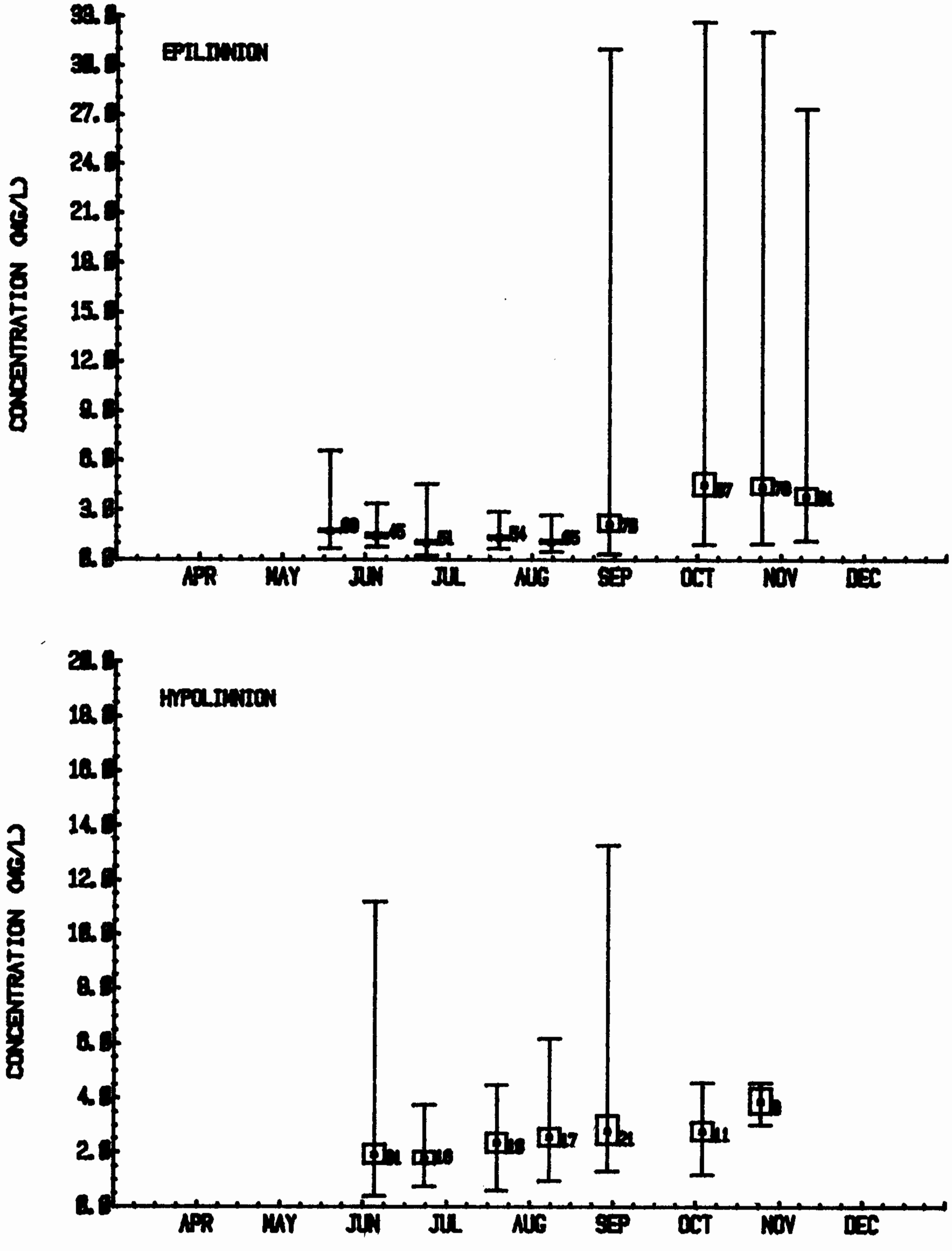


FIGURE 50. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION TOTAL SUSPENDED SOLIDS CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

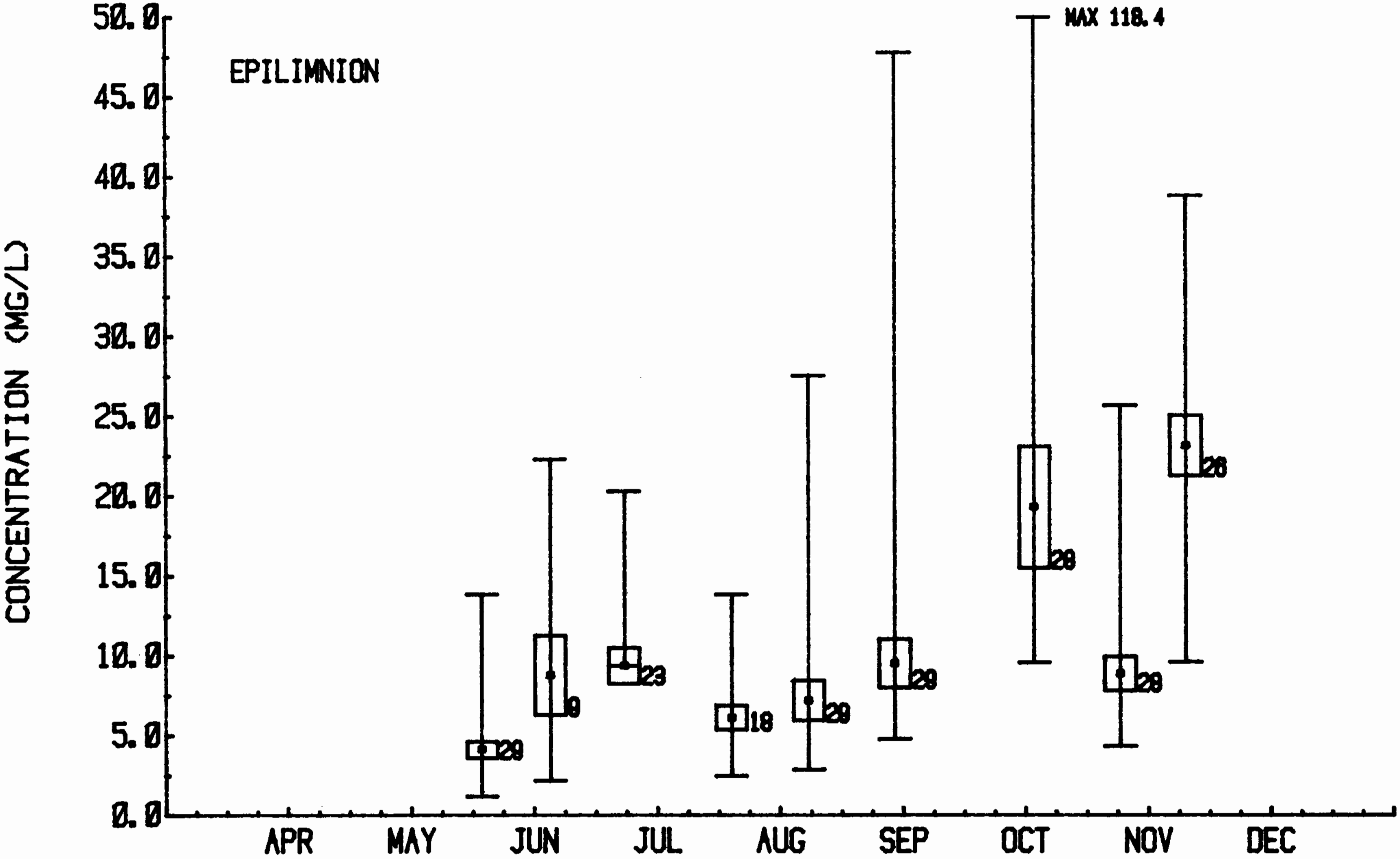


FIGURE 51. THE MEAN WESTERN BASIN TOTAL SUSPENDED SOLIDS CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

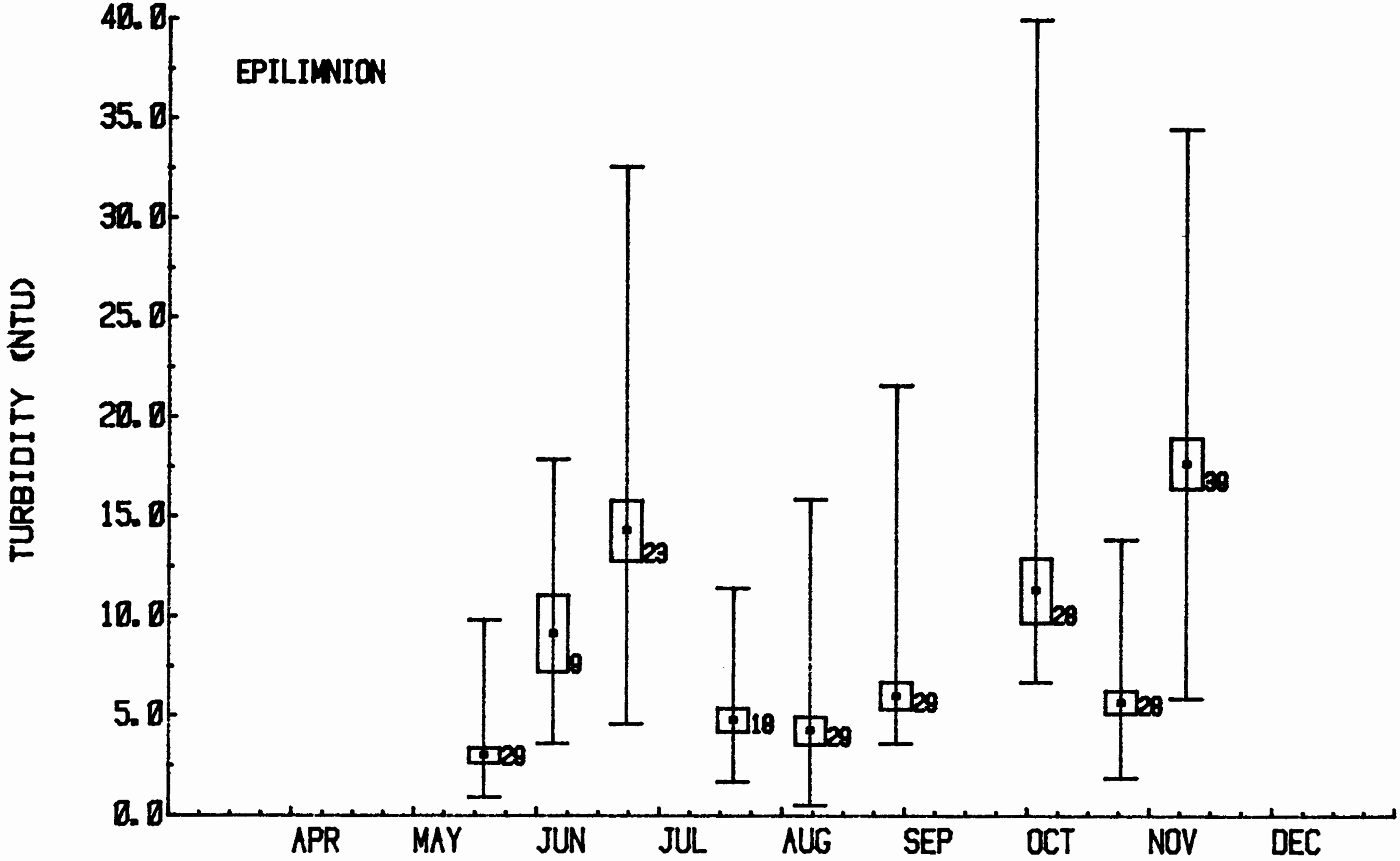


FIGURE 52. THE MEAN WESTERN BASIN TURBIDITY VALUES FOR 1978 (USEPA-GLNPO).

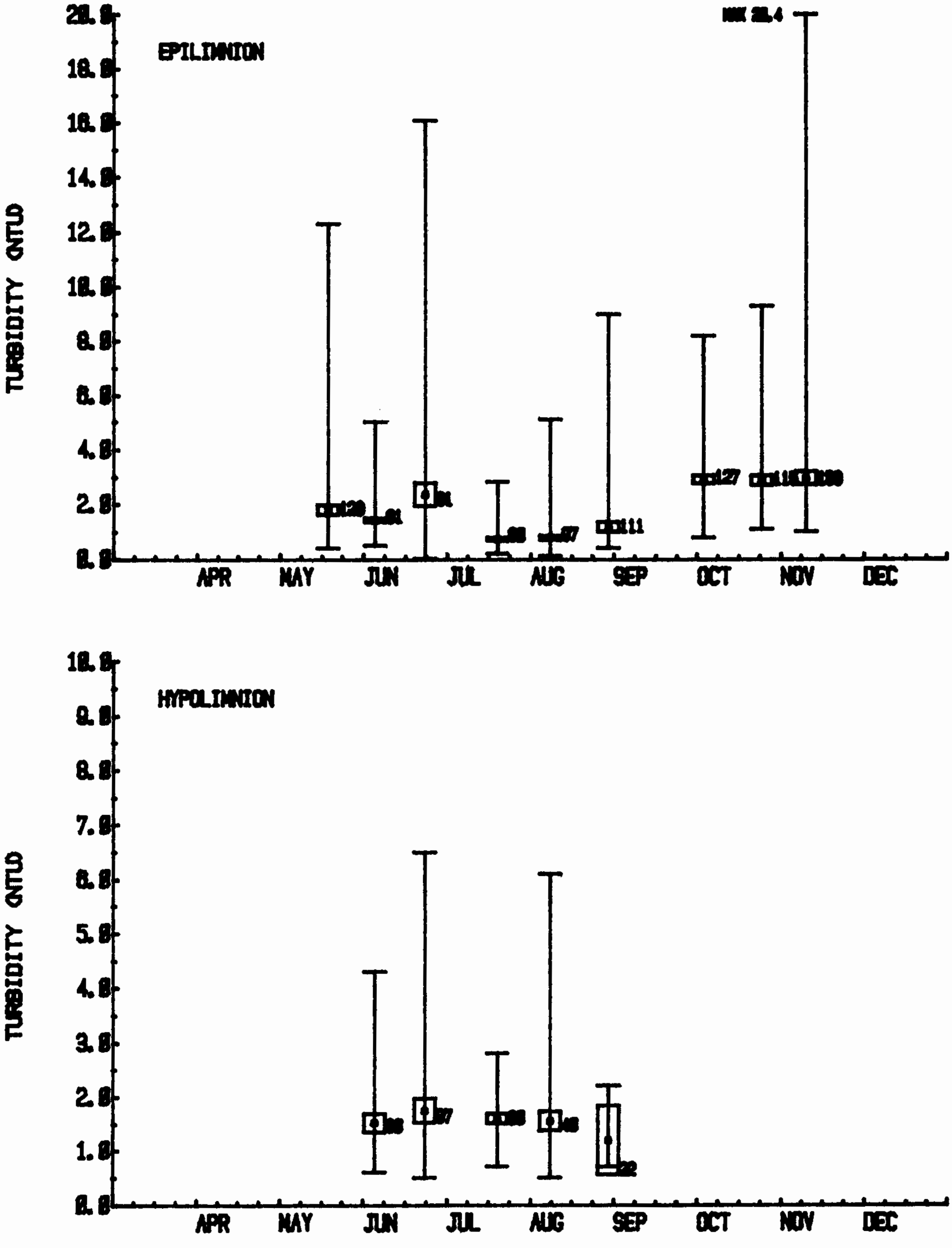


FIGURE 53. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION TURBIDITY VALUES FOR 1978 (USEPA-GLNPO).

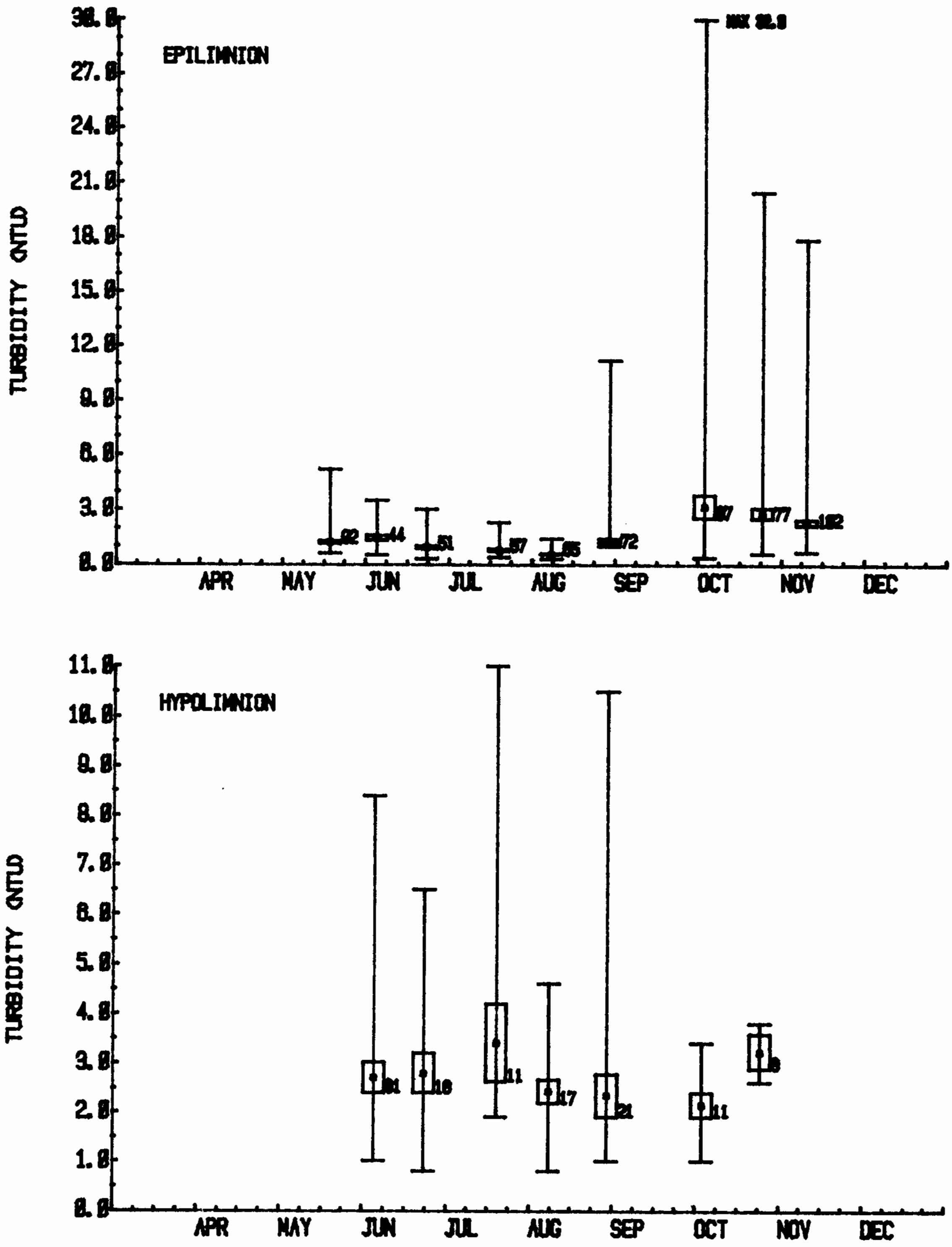


FIGURE 54. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION TURBIDITY VALUES FOR 1978 (USEPA-GLNPO).

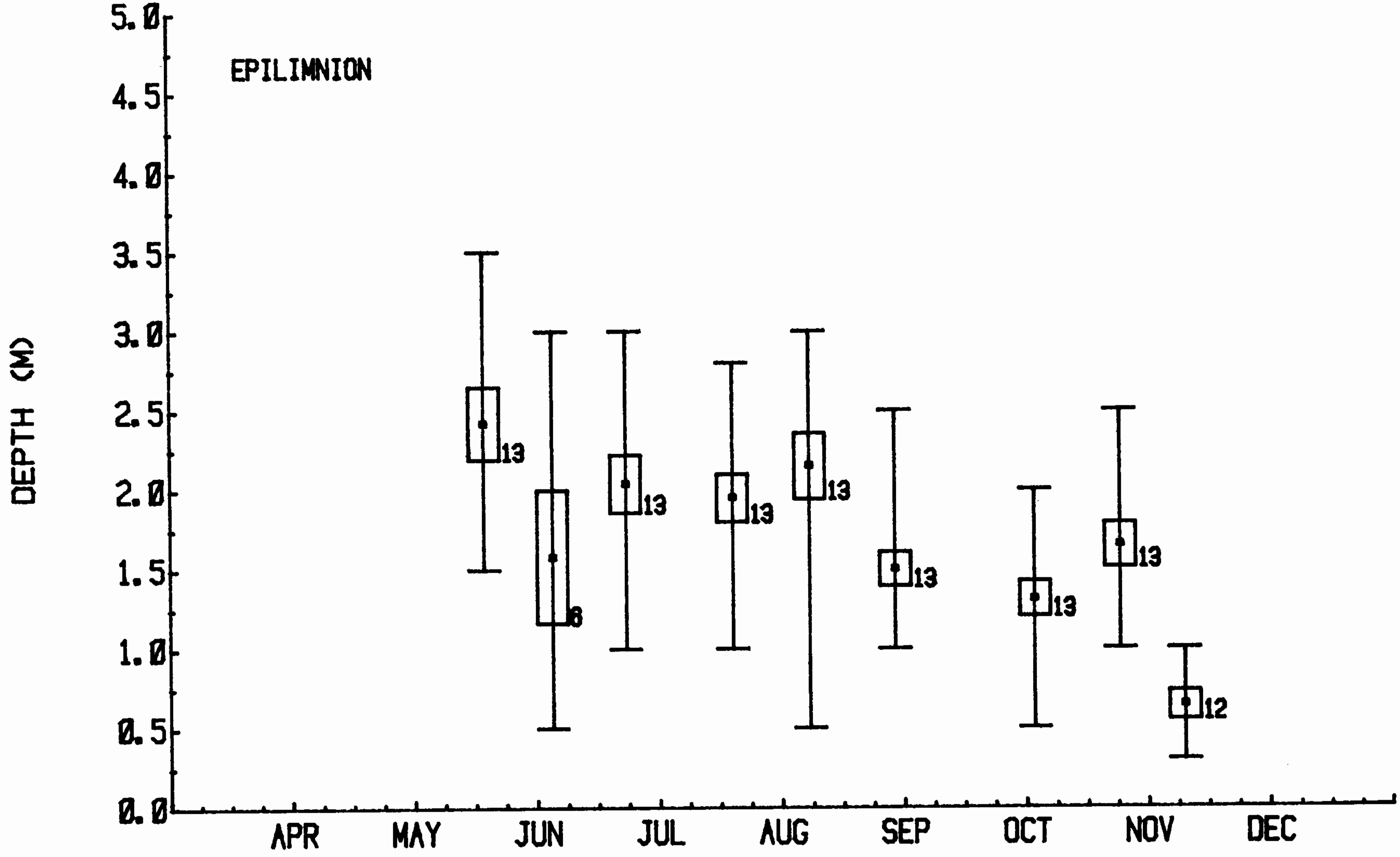


FIGURE 55a. THE MEAN WESTERN BASIN SECCHI VALUES
FOR 1978 (USEPA-GLNPO).

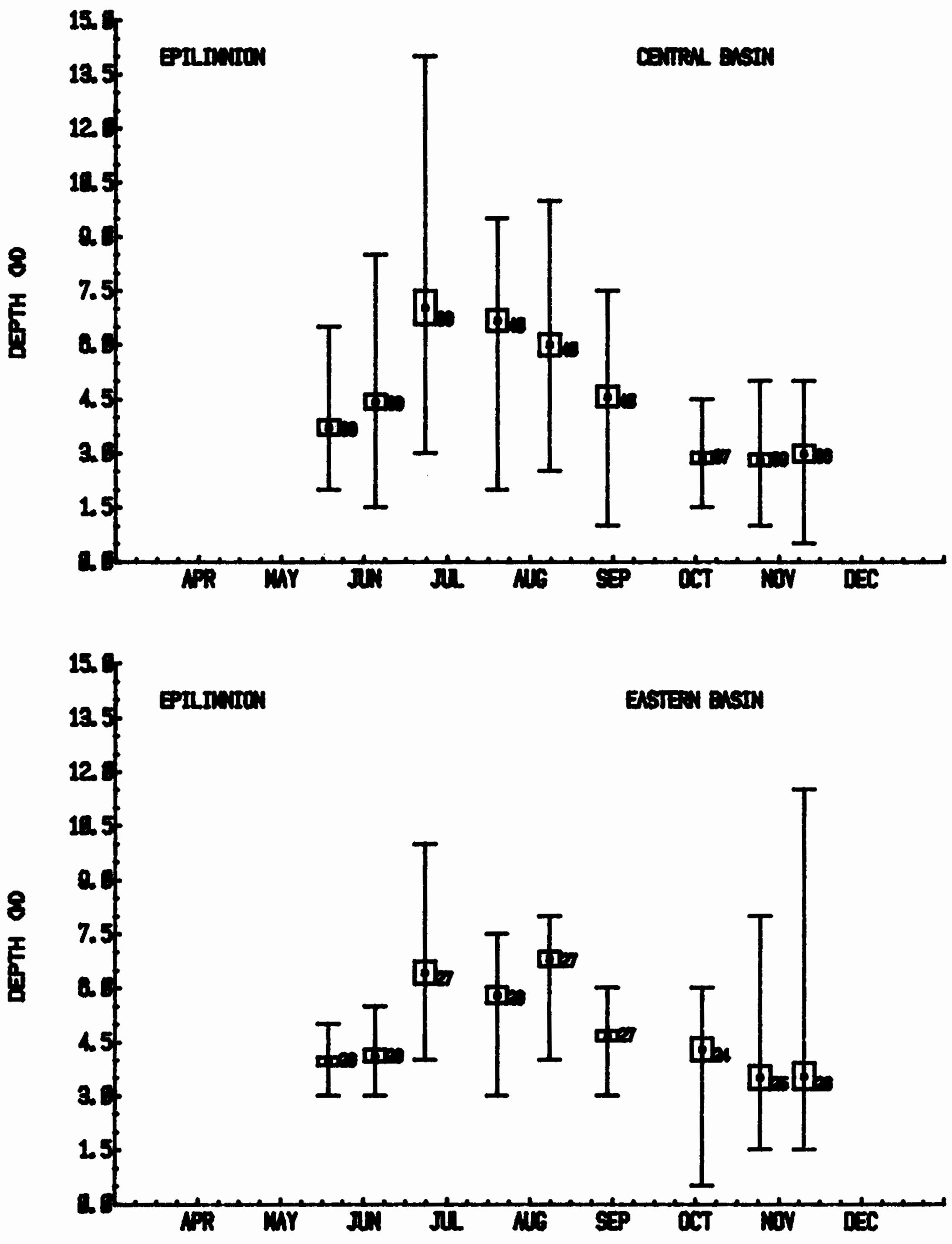


FIGURE 55b. THE MEAN CENTRAL AND EASTERN BASIN SECCHI VALUES FOR 1978 (USEPA-GLNPO).

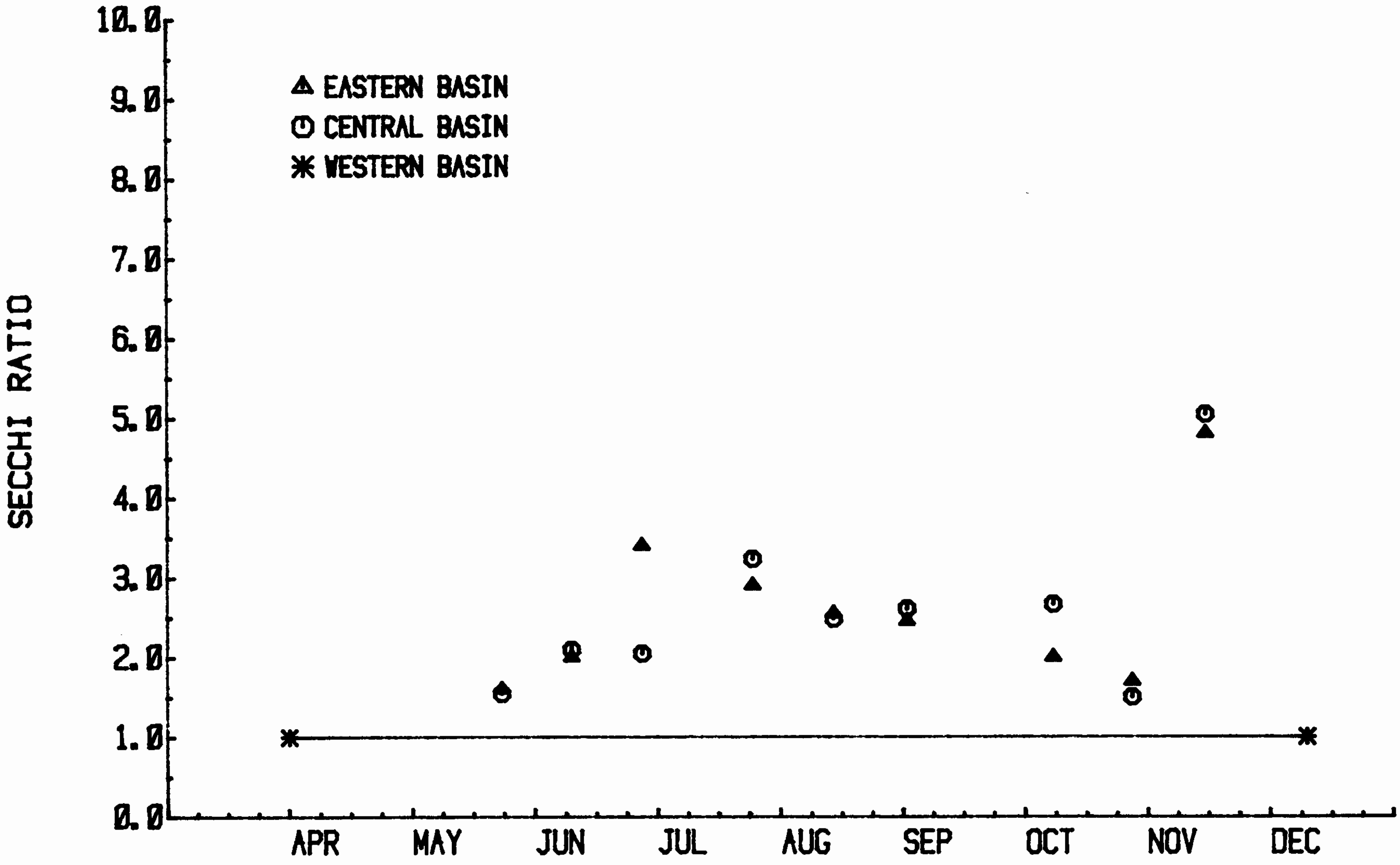


FIGURE 56. THE CENTRAL AND EASTERN BASIN SECCHI RATIOS BASED UPON A NORMILIZATION OF THE 1978 WESTERN BASIN VALUES.

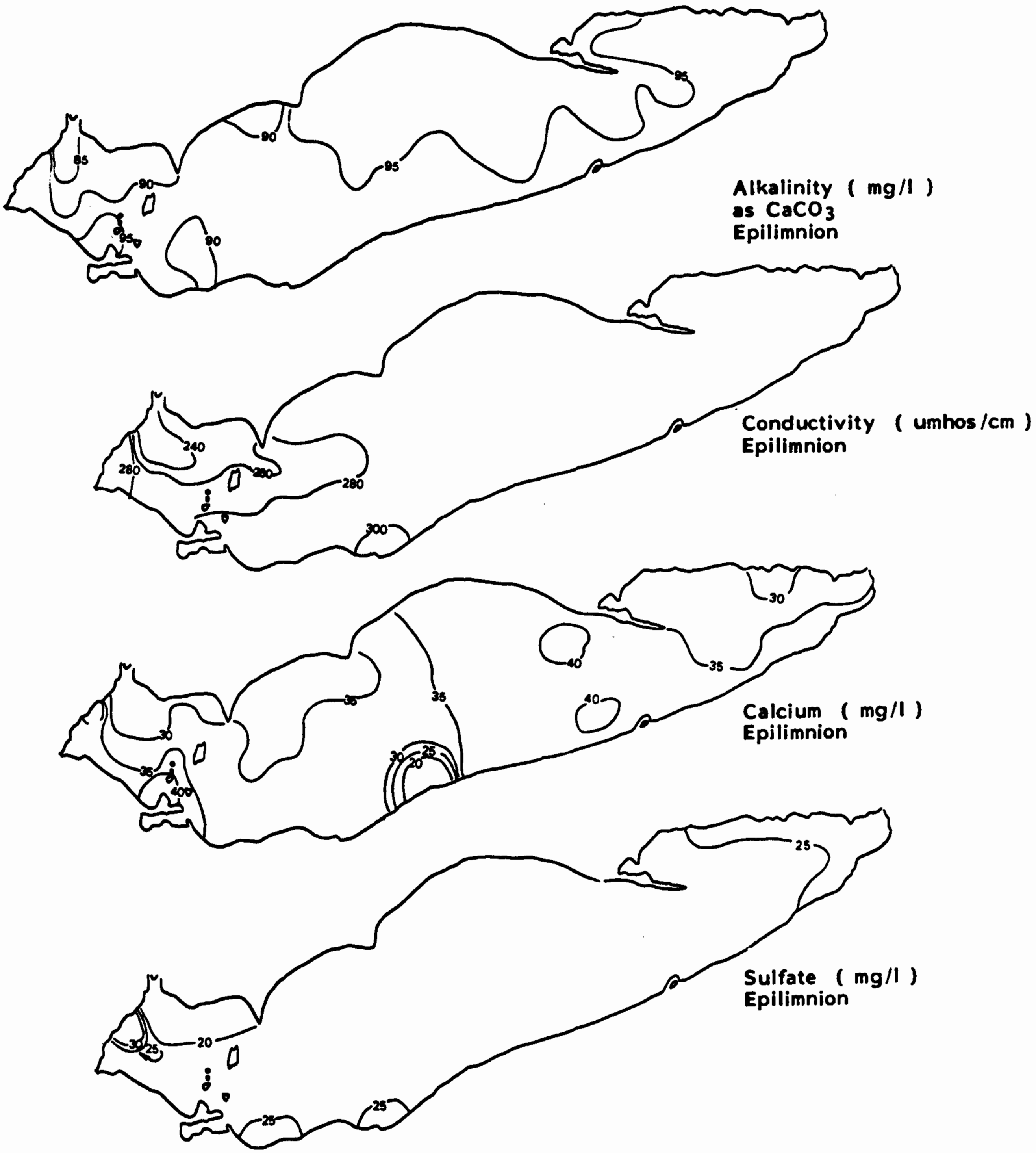


FIGURE 57. THE DISTRIBUTION PATTERNS FOR EPILIMNION CONCENTRATIONS OF PRINCIPAL IONS MEASURED DURING JUNE 1978 (USEPA-GLNPO).

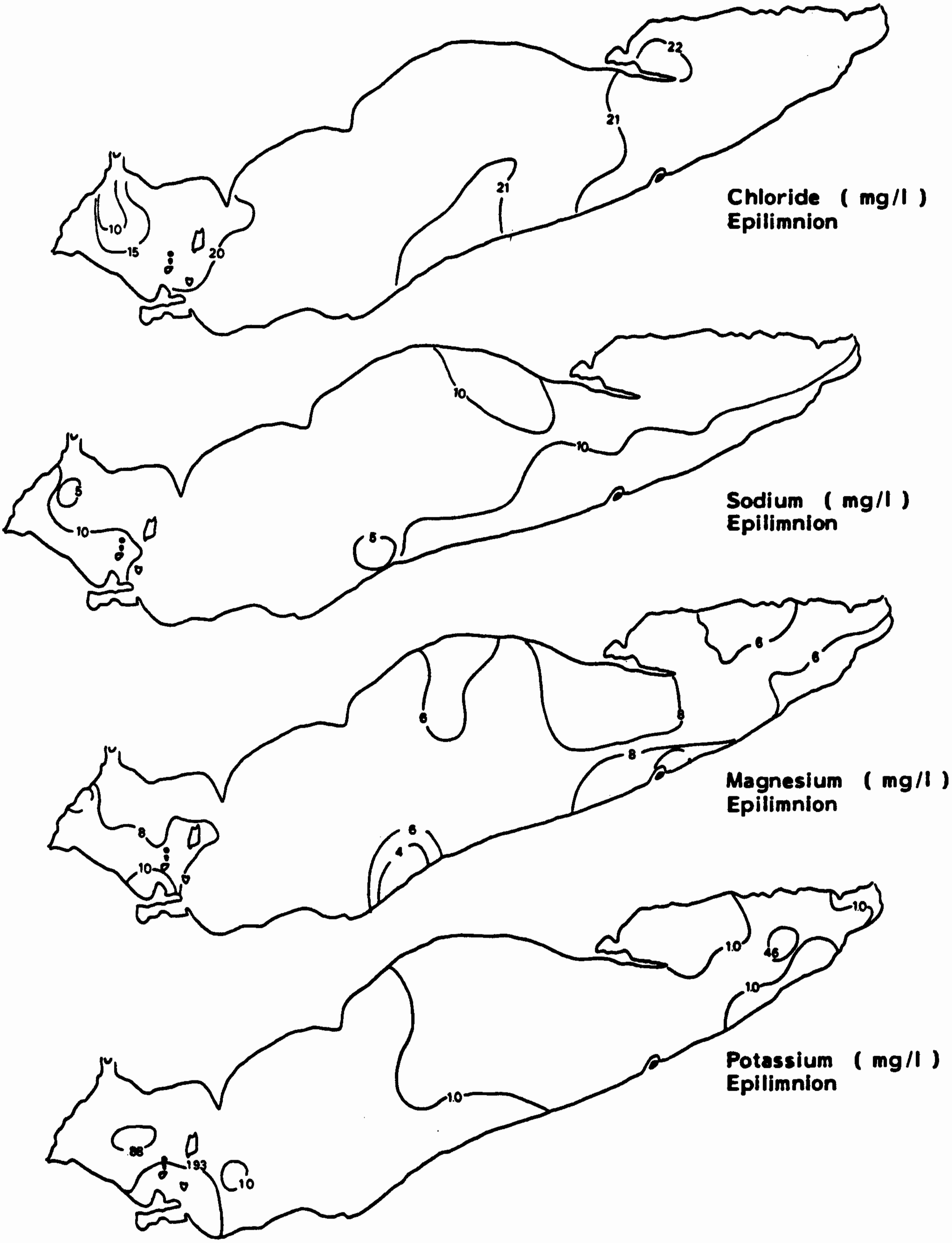


FIGURE 57. Continued

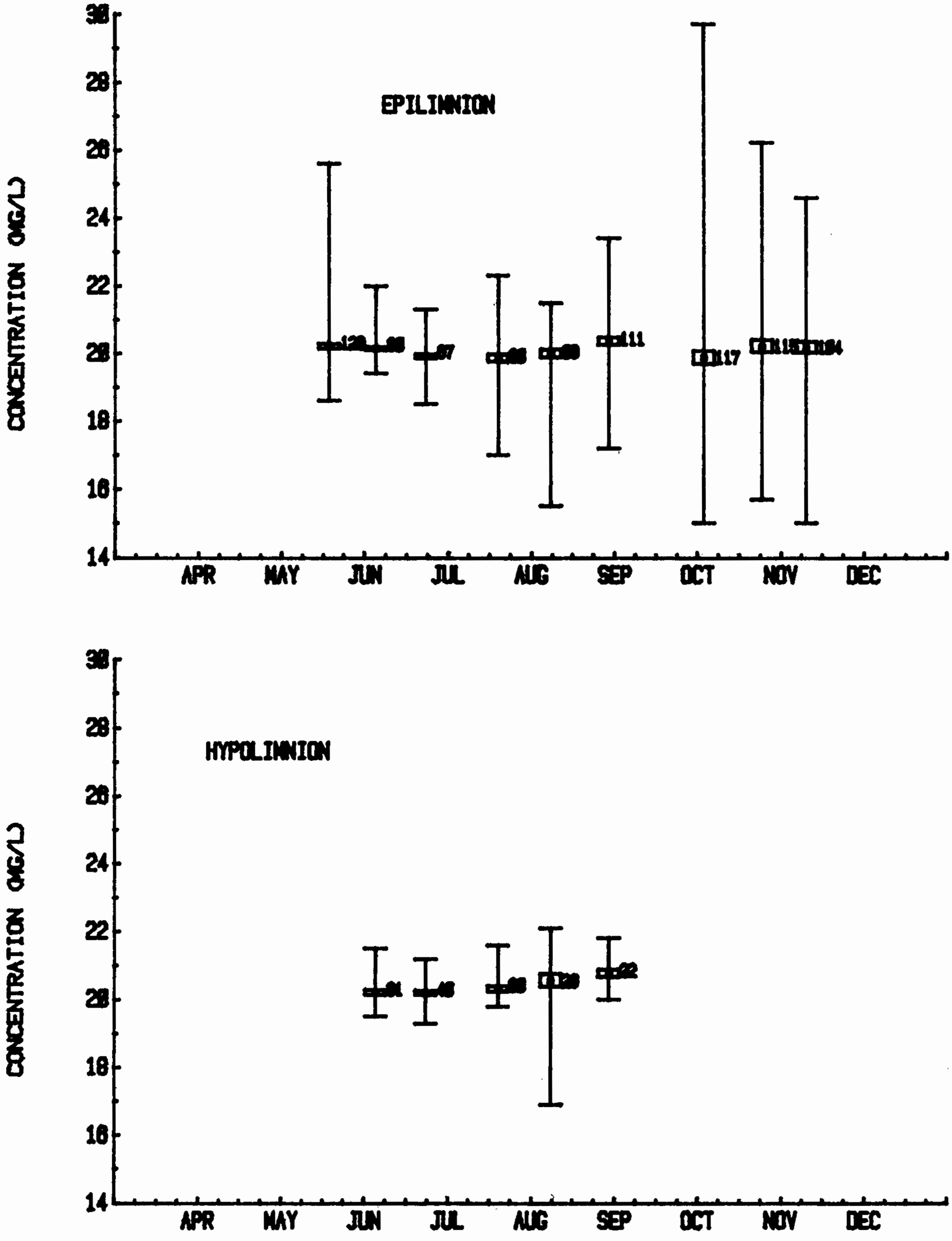
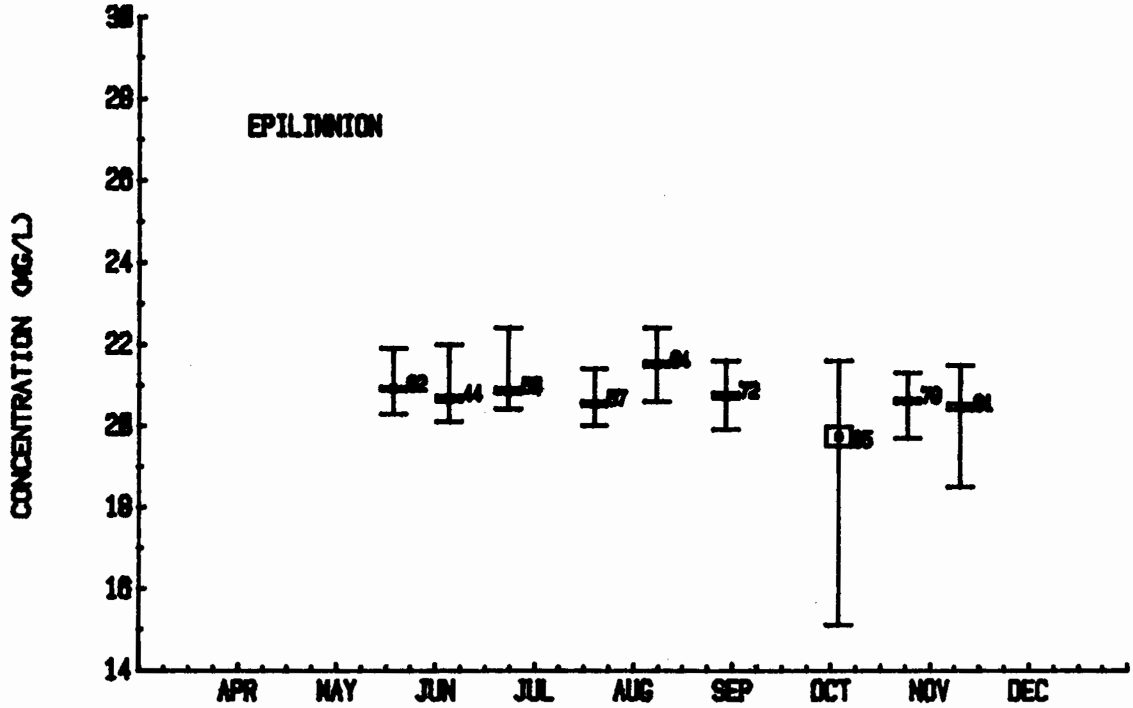


FIGURE 58. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION CHLORIDE CONCENTRATIONS FOR 1978 (USEPA-GLNPO).



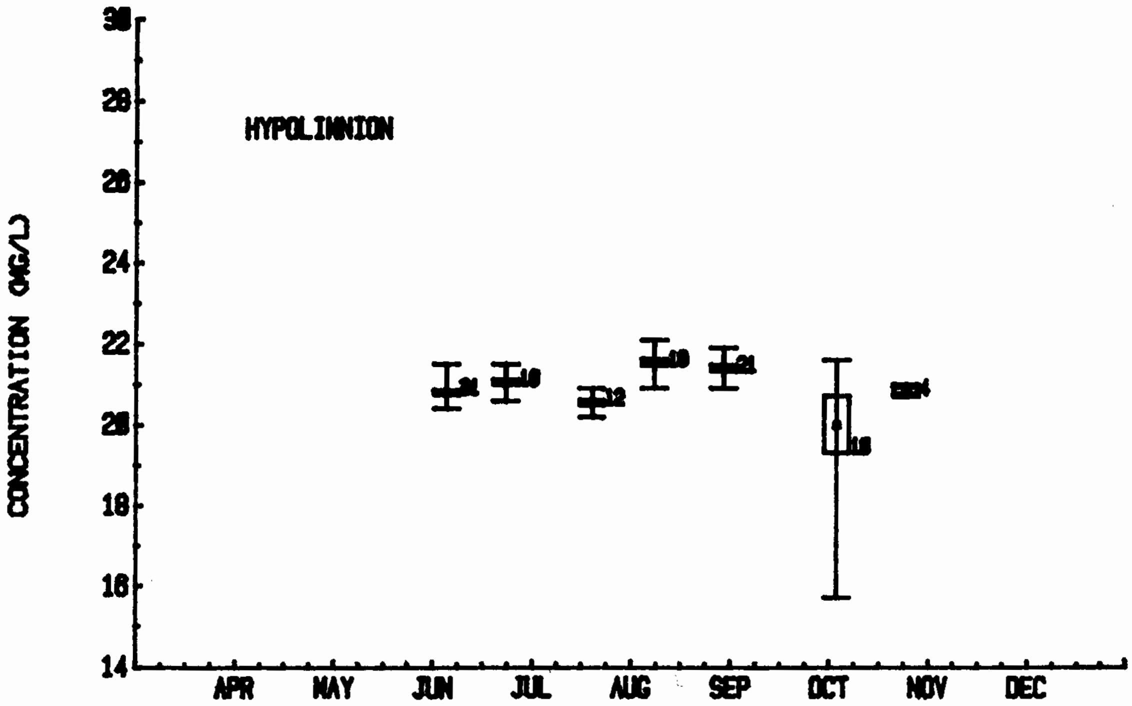


FIGURE 59. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION CHLORIDE CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

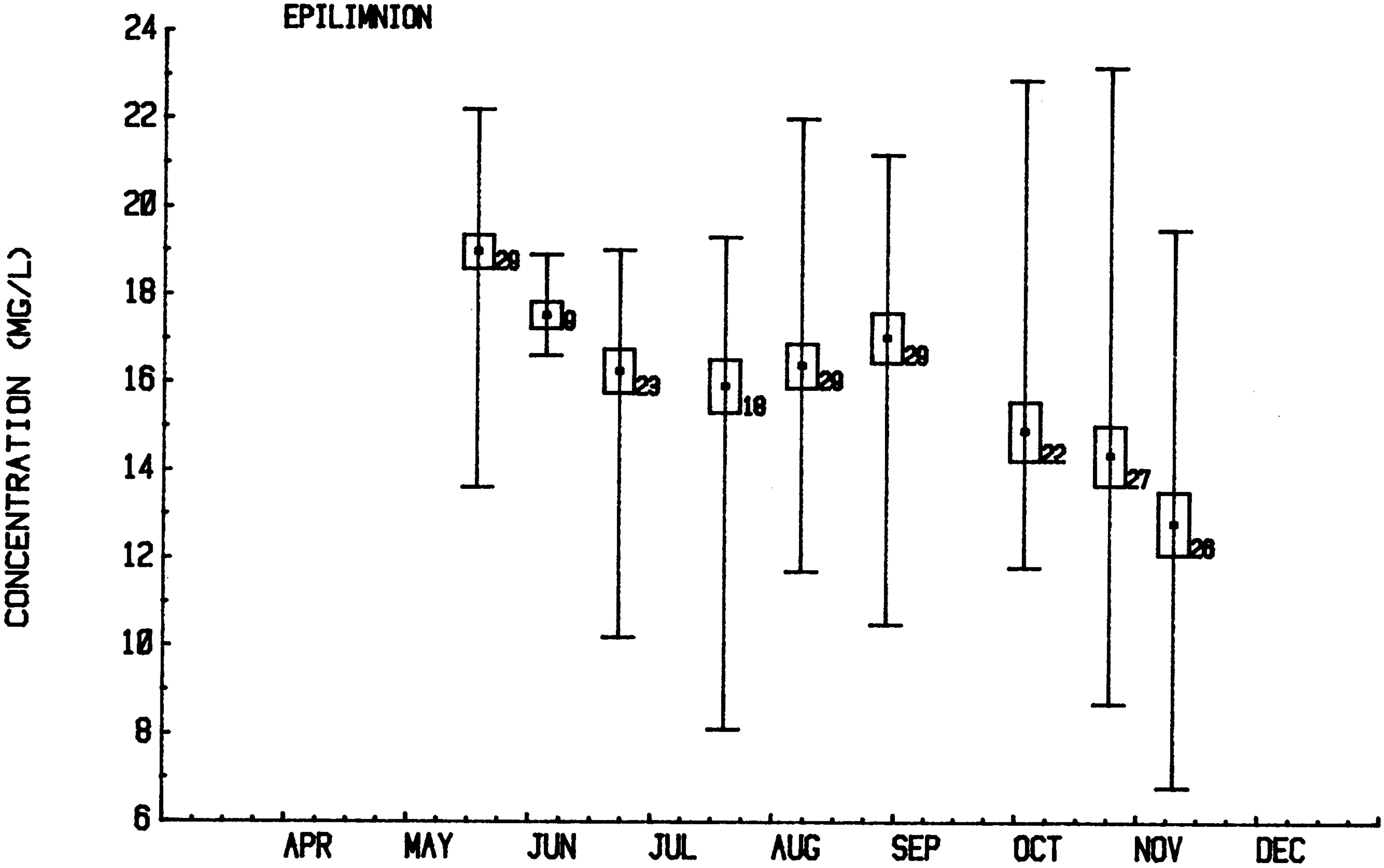


FIGURE 60. THE MEAN WESTERN BASIN CHLORIDE CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

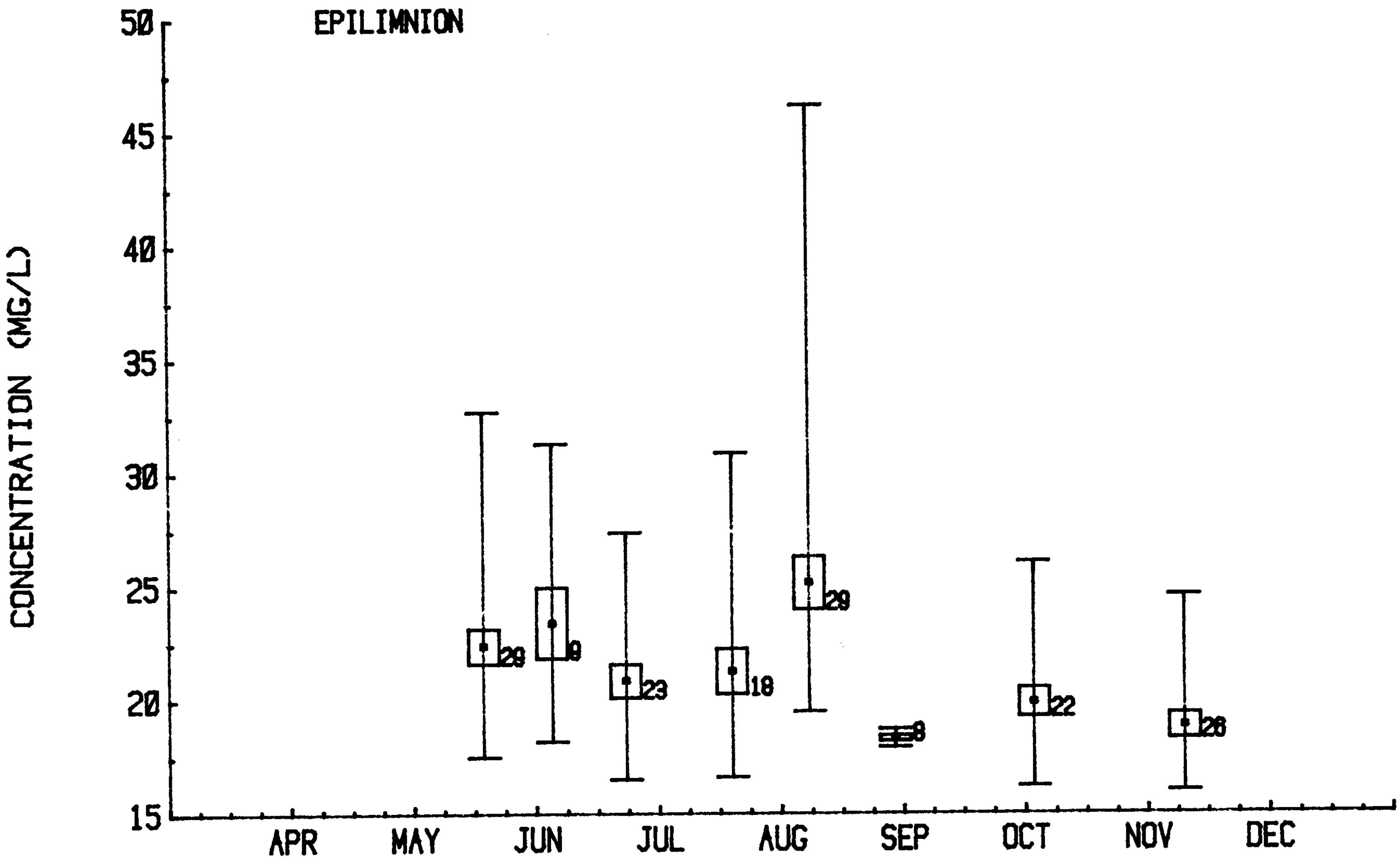


FIGURE 61. THE MEAN WESTERN BASIN SULFATE CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

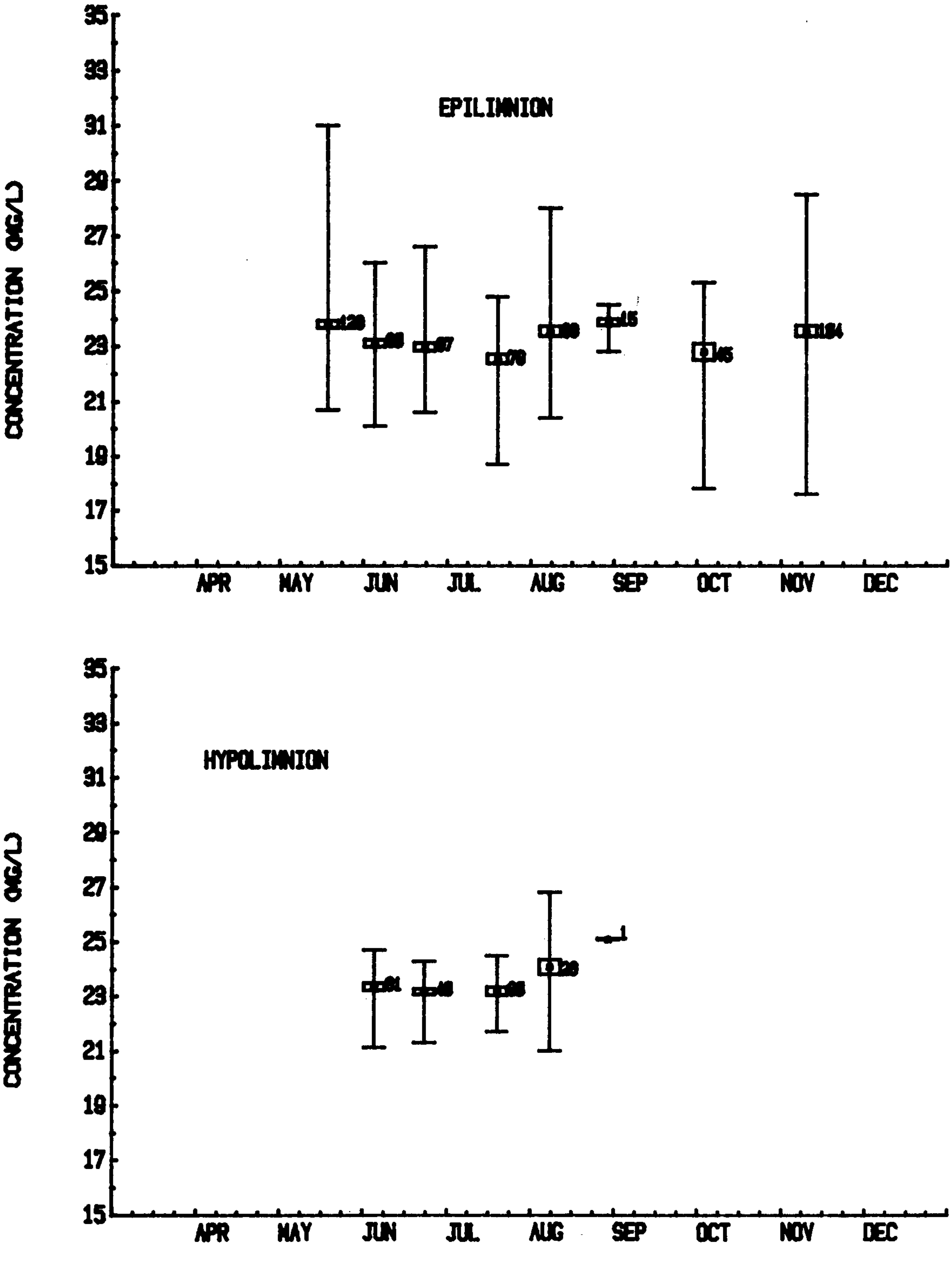
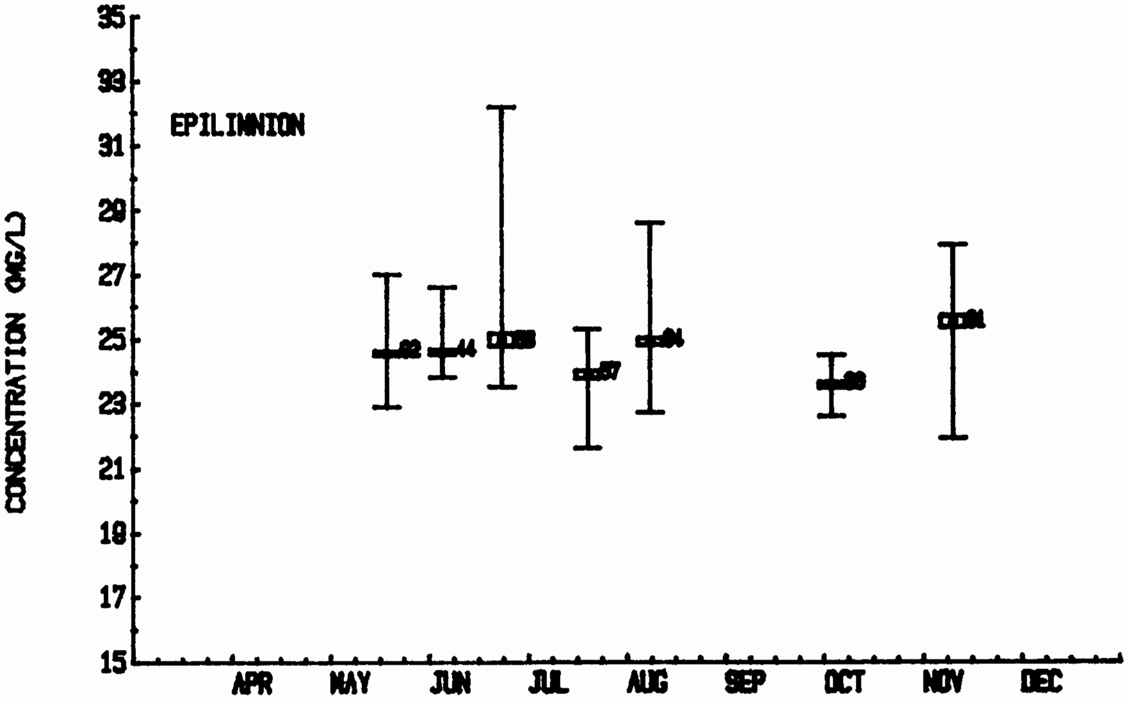


FIGURE 62. THE MEAN CENTRAL BASIN EPILIMNION AND HYPOLIMNION SULFATE CONCENTRATIONS FOR 1978 (USEPA-GLNPO).



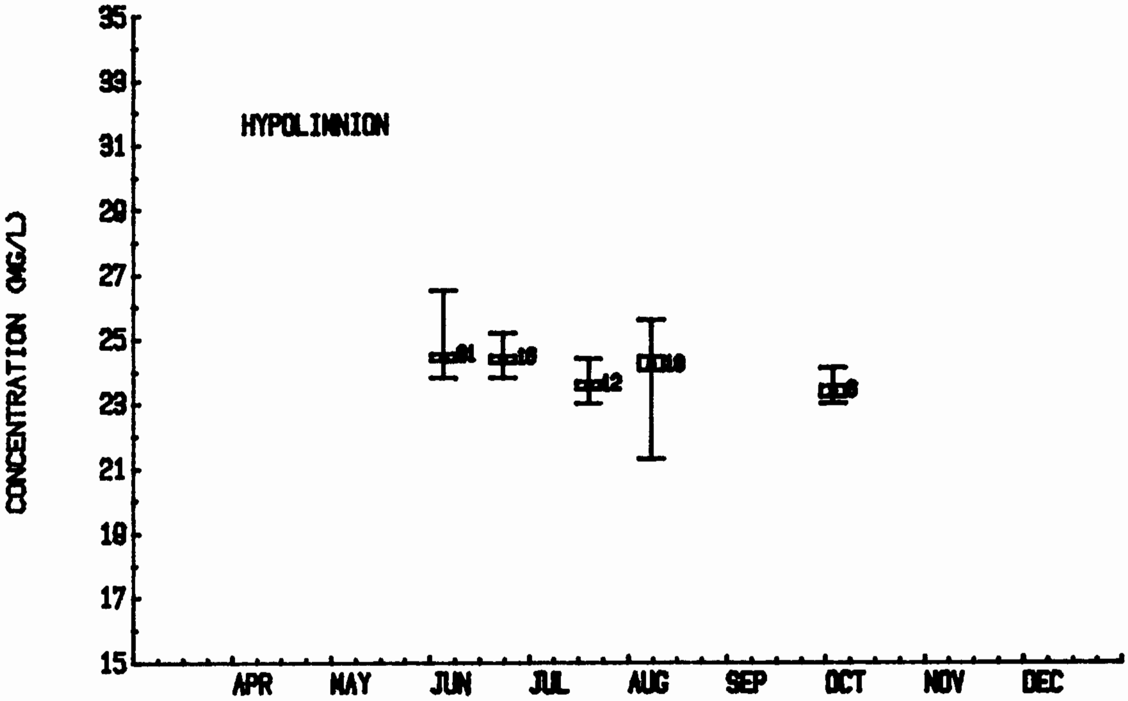


FIGURE 63. THE MEAN EASTERN BASIN EPILIMNION AND HYPOLIMNION SULFATE CONCENTRATIONS FOR 1978 (USEPA-GLNPO).

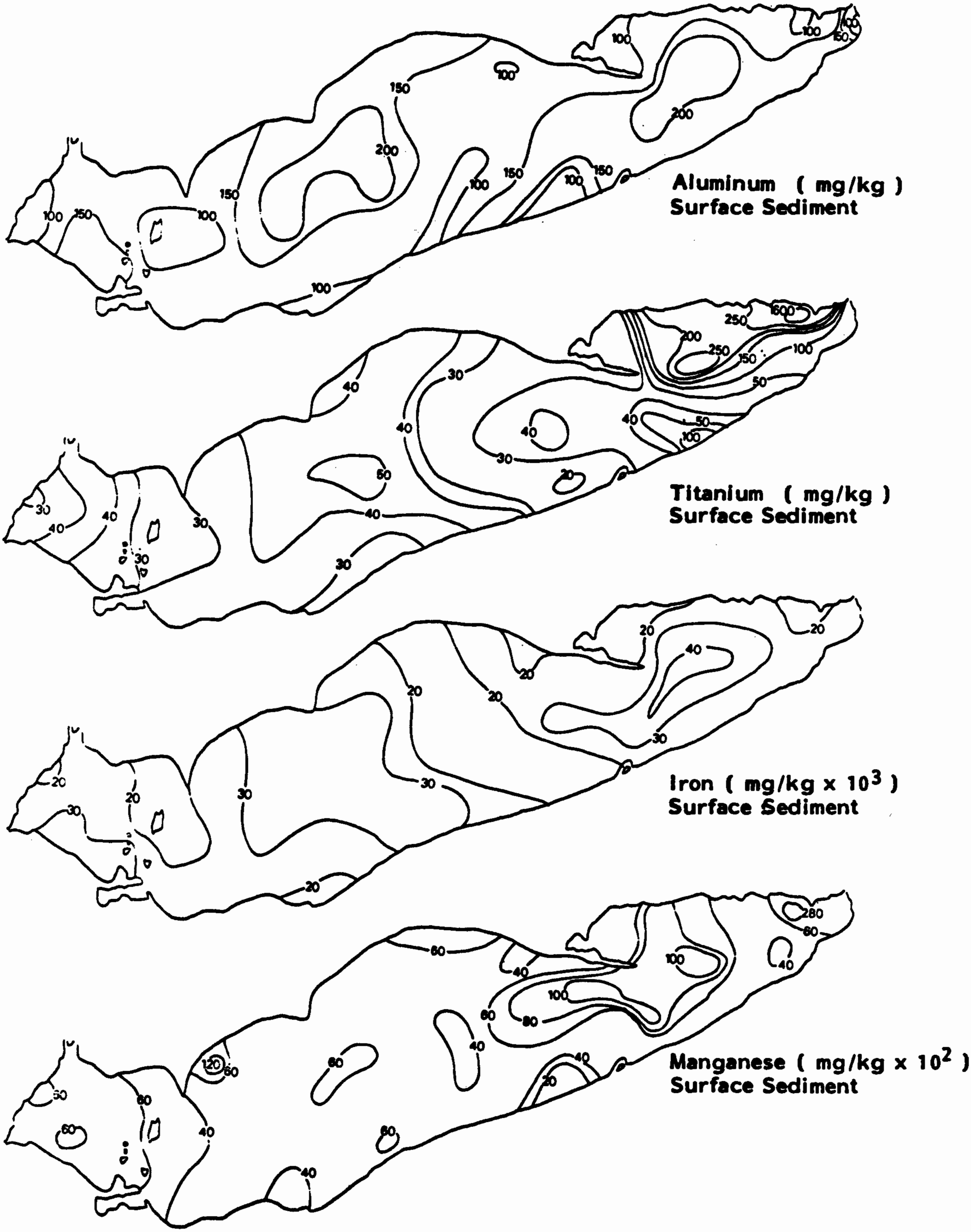


FIGURE 64. THE 1979 DISTRIBUTION PATTERNS OF SURFICIAL SEDIMENT METAL CONCENTRATIONS IN LAKE ERIE (USEPA-GLNPO).

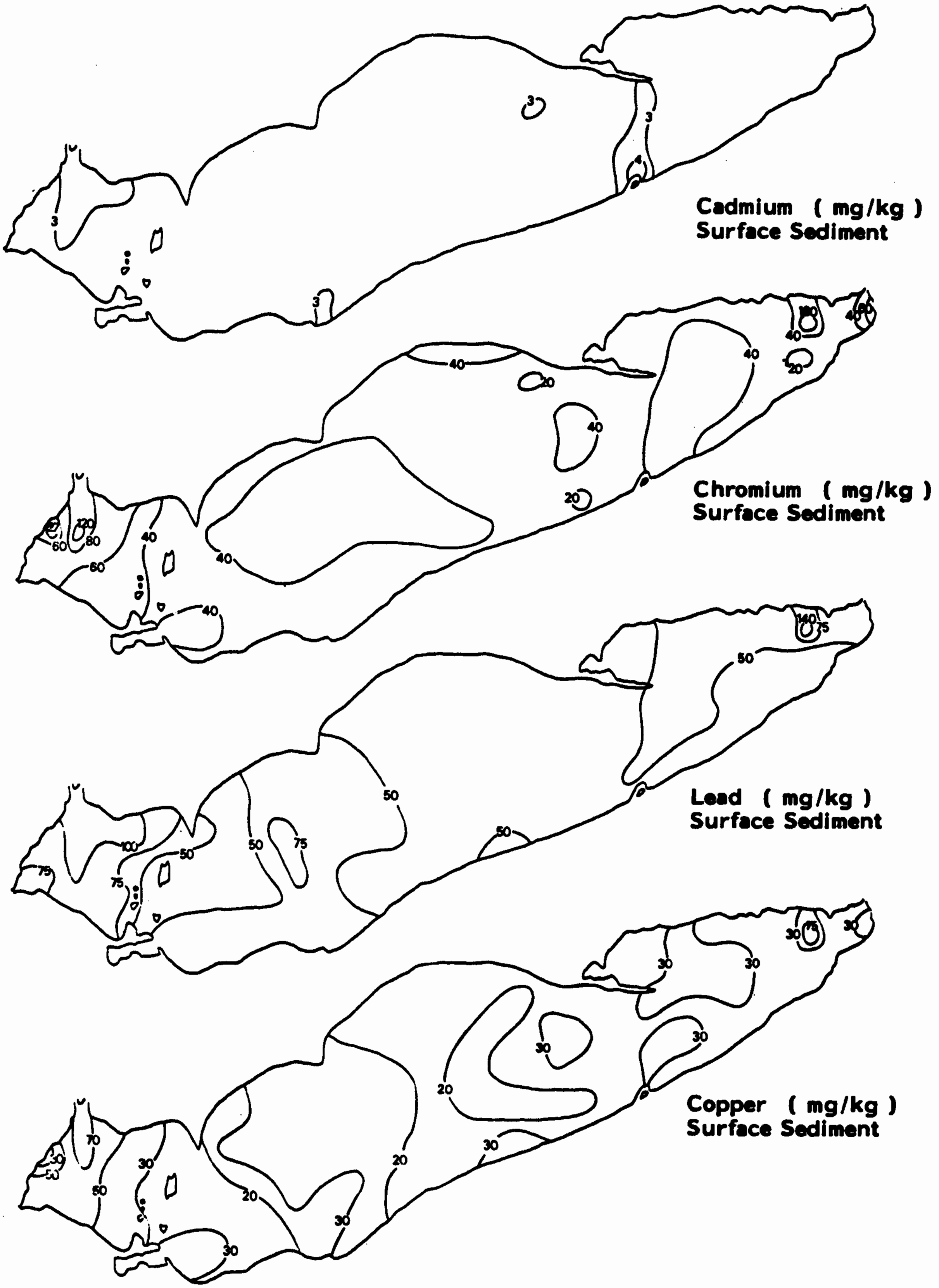


FIGURE 64. CONTINUED

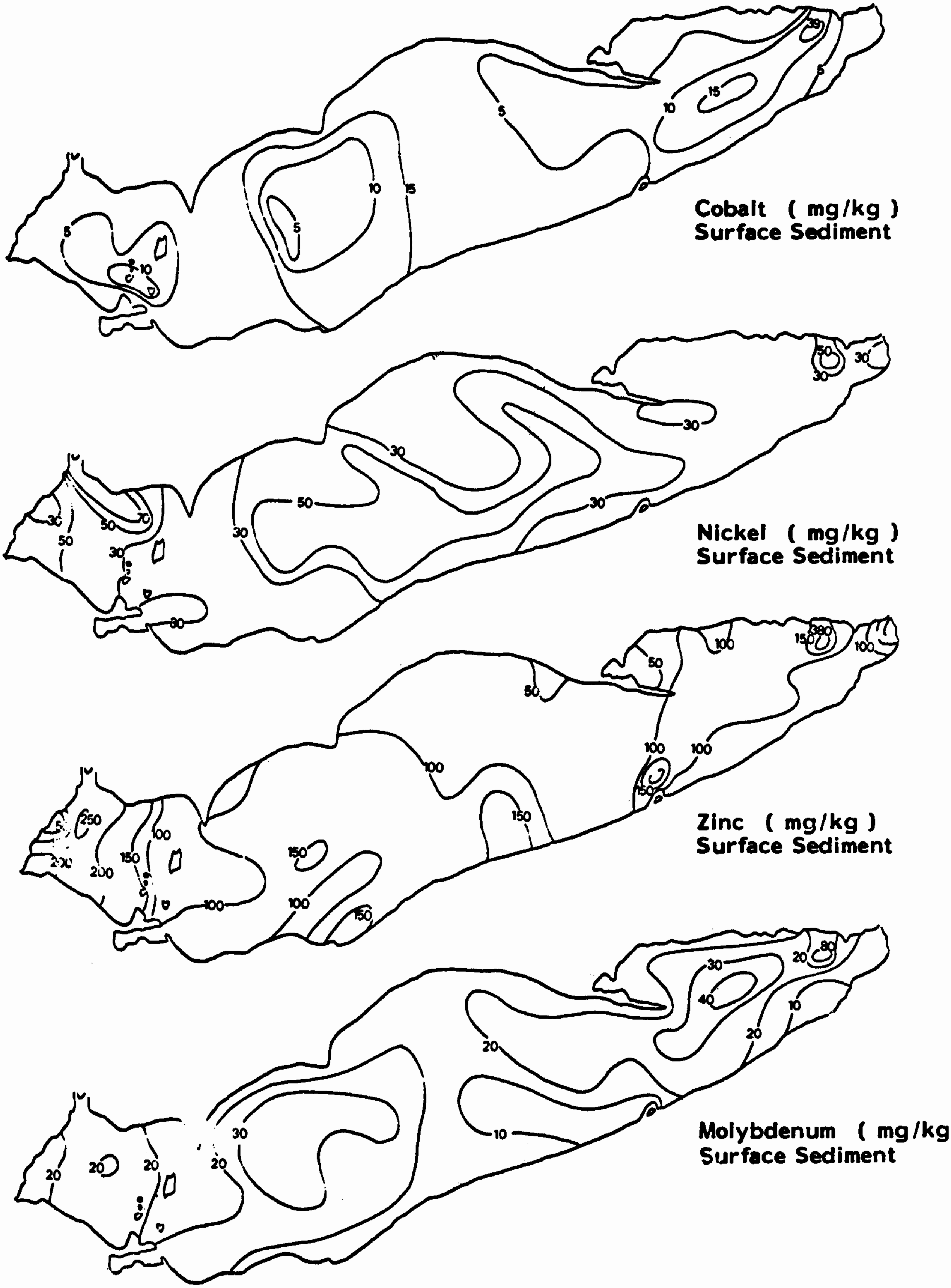


FIGURE 64. CONTINUED

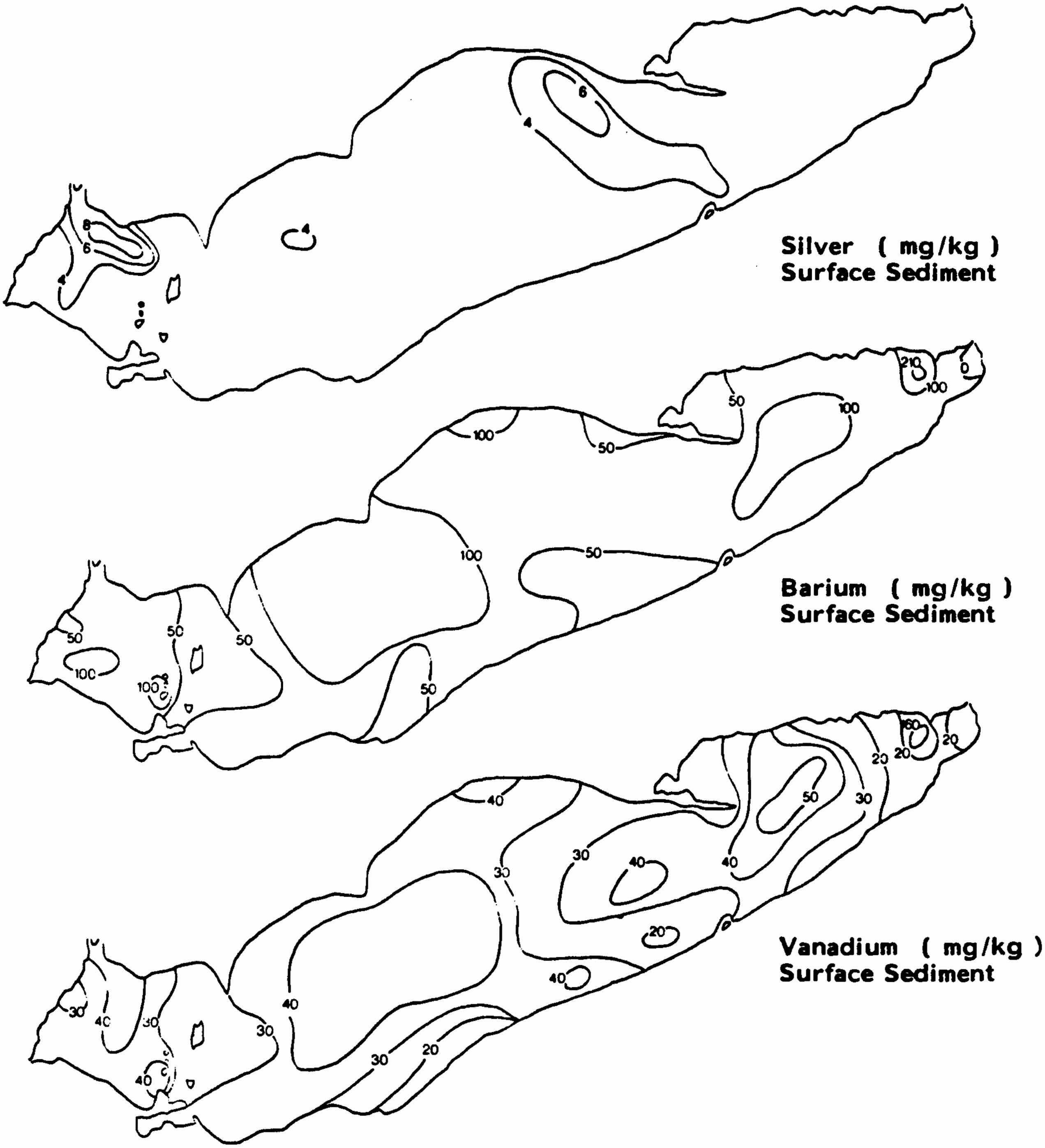


FIGURE 64. CONTINUED

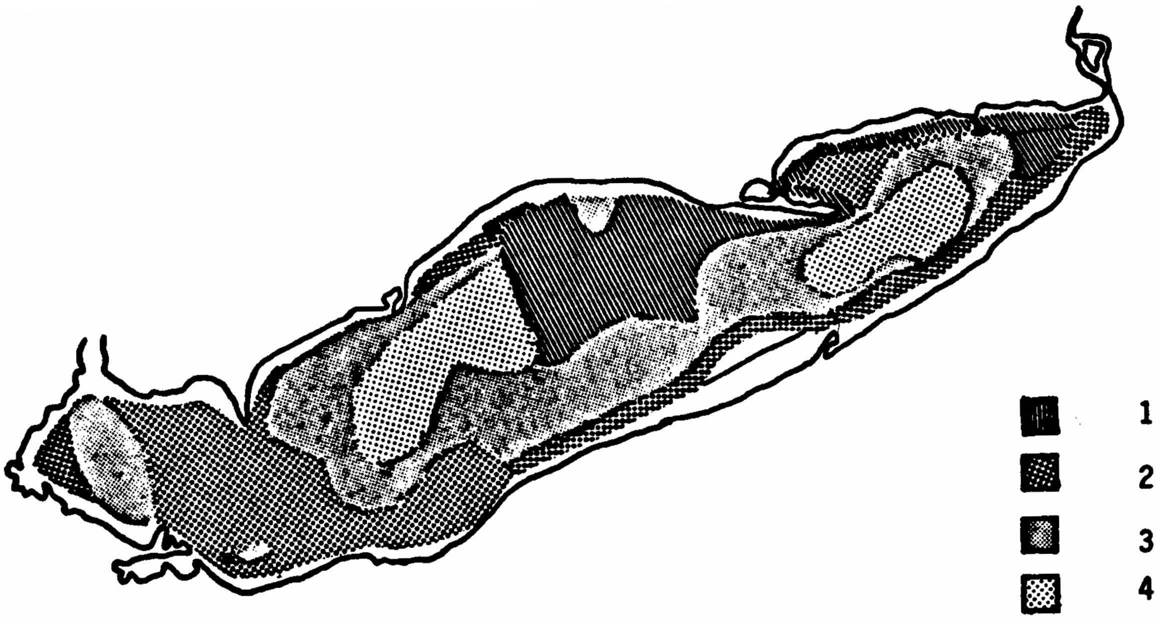


FIGURE 65a. THE DISTRIBUTION PATTERN OF METAL CONCENTRATIONS BASED UPON CLUSTER ANALYSIS FOR LAKE ERIE SURFICIAL SEDIMENTS IN 1979.

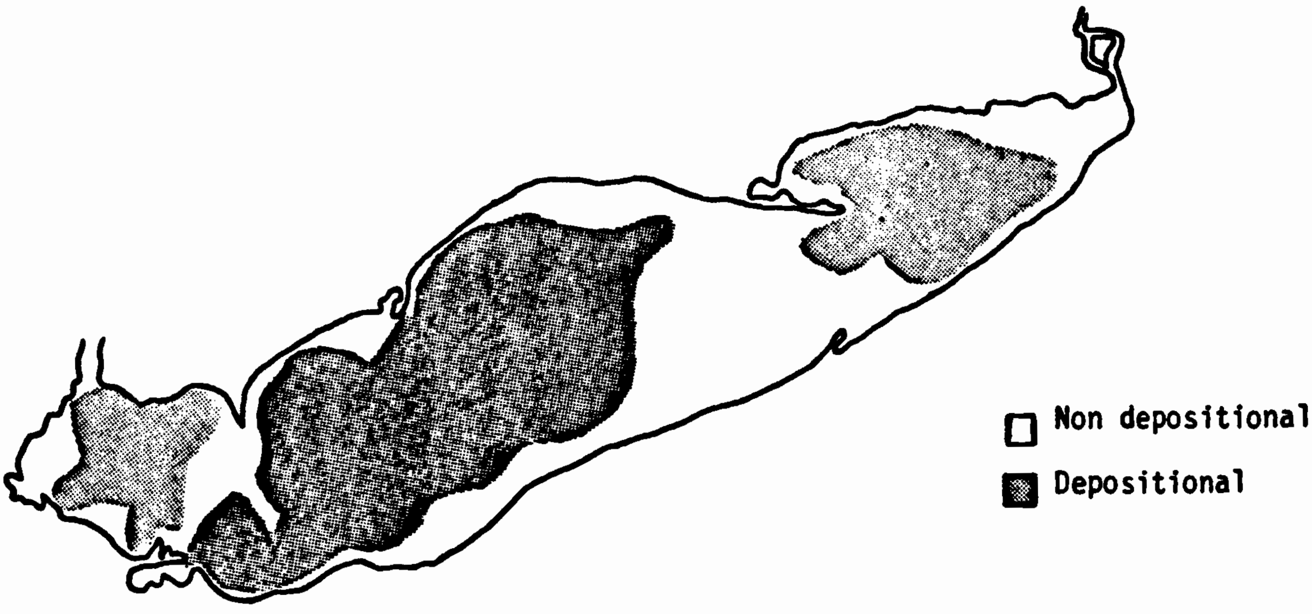


FIGURE 65b. THE MAJOR SEDIMENT DEPOSITIONAL AREAS IN LAKE ERIE (THOMAS, ET AL, 1976).

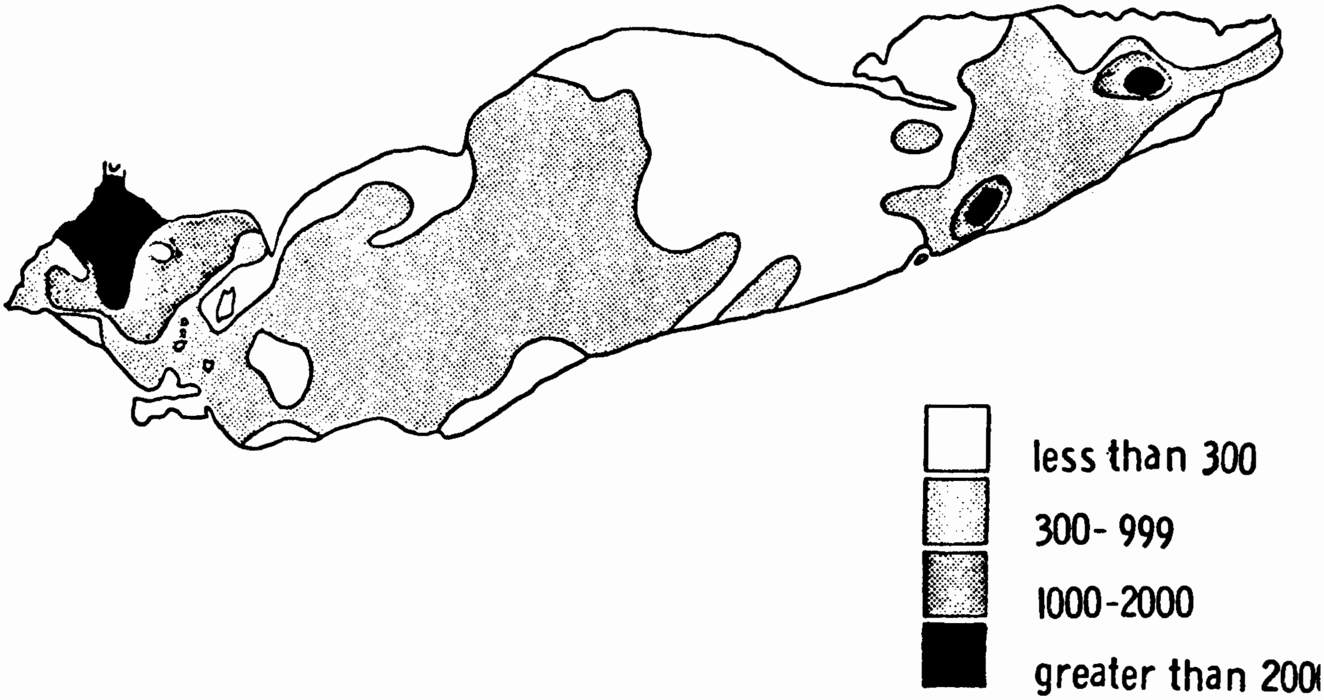


FIGURE 66a. THE DISTRIBUTION PATTERN OF MERCURY CONCENTRATIONS (mg/kg) IN THE SURFICIAL SEDIMENTS OF LAKE ERIE DURING 1970 (THOMAS AND JAQUET, 1976).

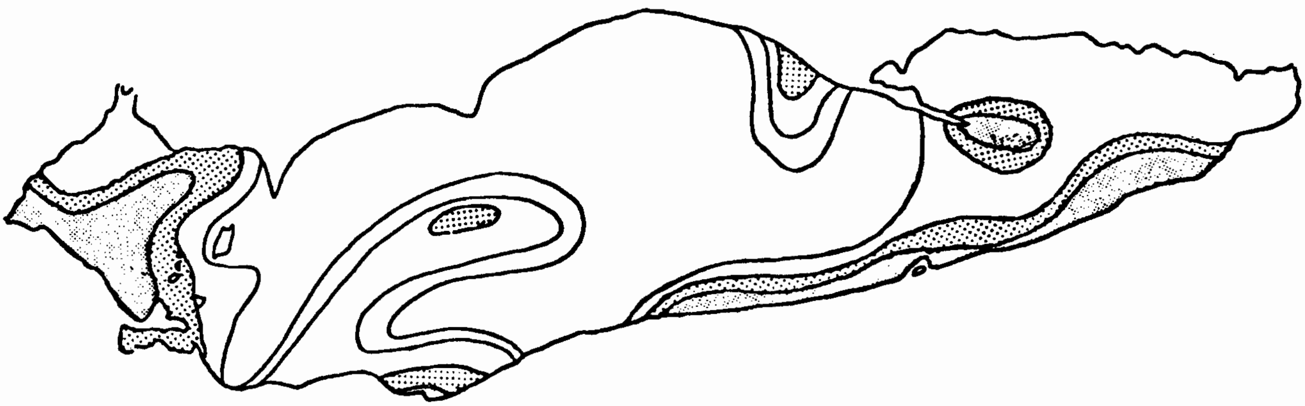


FIGURE 66b. THE DISTRIBUTION PATTERN OF MERCURY CONCENTRATIONS (mg/kg) IN THE SURFICIAL SEDIMENTS OF LAKE ERIE DURING 1979.

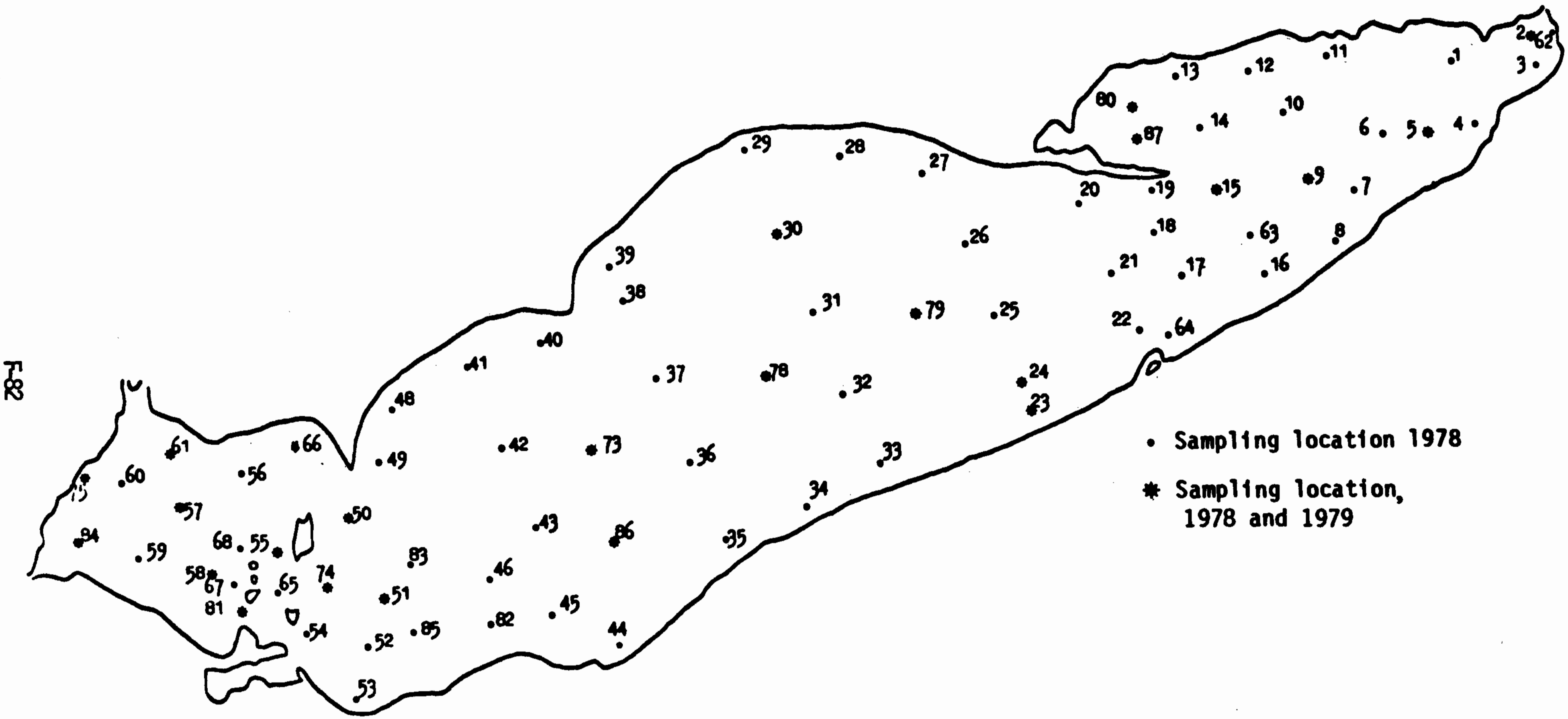


FIGURE 67. PHYTOPLANKTON SAMPLING LOCATIONS FOR 1978 AND THE MODIFIED 1979 COLLECTION SITES (USEPA-GLNPO).

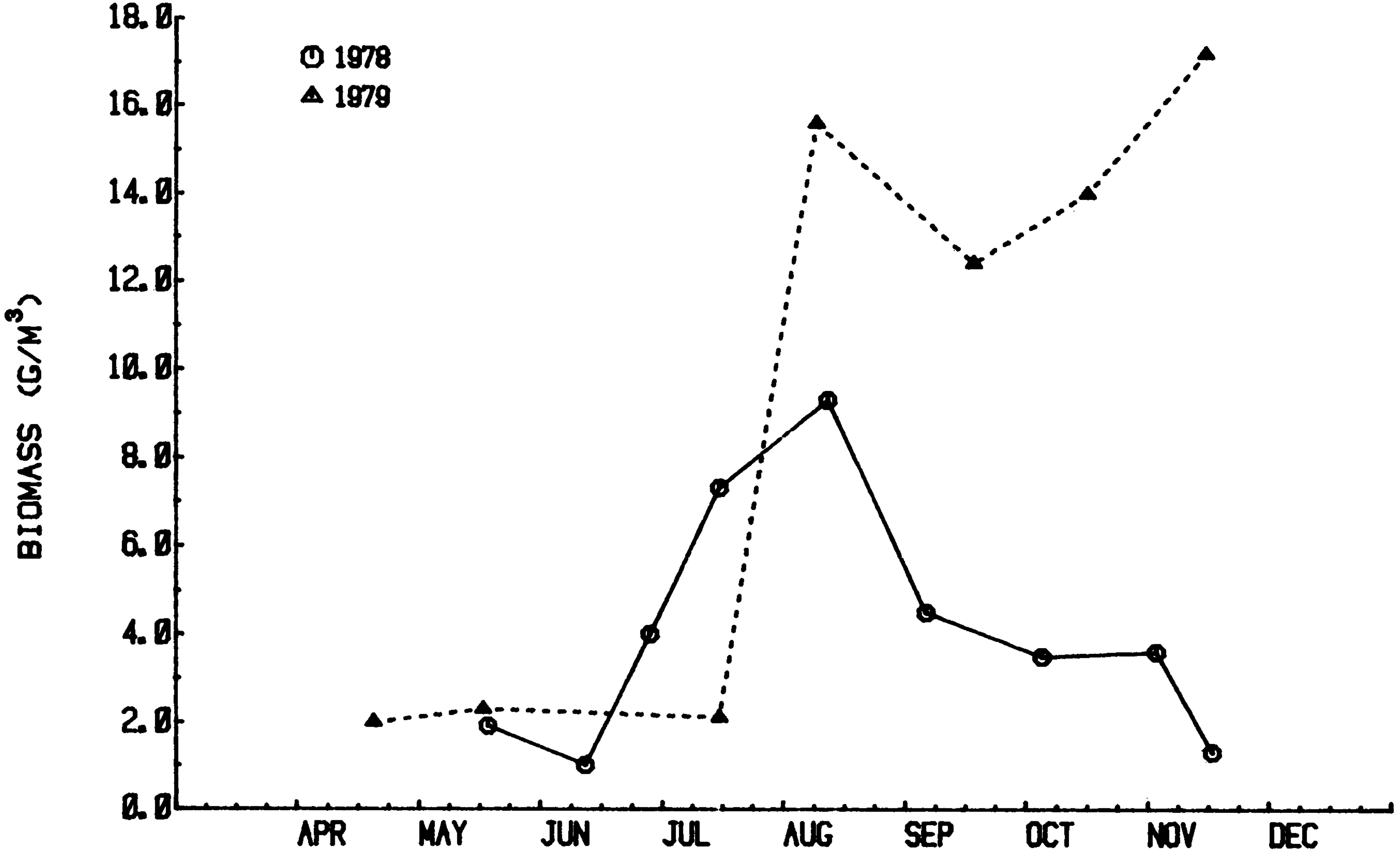


FIGURE 68. SEASONAL FLUCTUATIONS IN WESTERN BASIN TOTAL PHYTOPLANKTON BIOMASS FOR 1978 AND 1979 (USEPA-GLNPO).

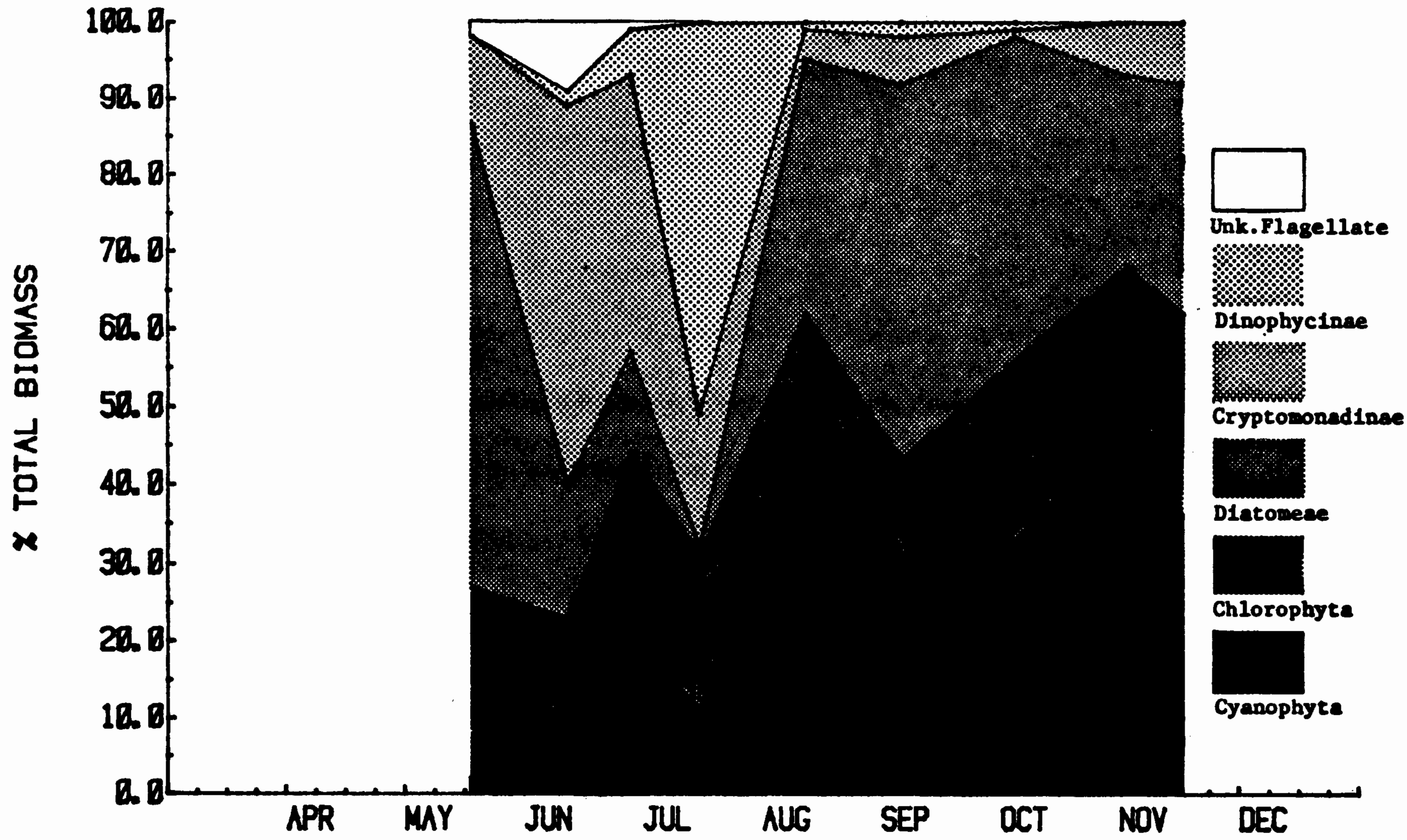


FIGURE 69. SEASONAL FLUCTUATIONS IN WESTERN BASIN PHYTOPLANKTON COMPOSITION FOR 1978 (USEPA-GLNPO).

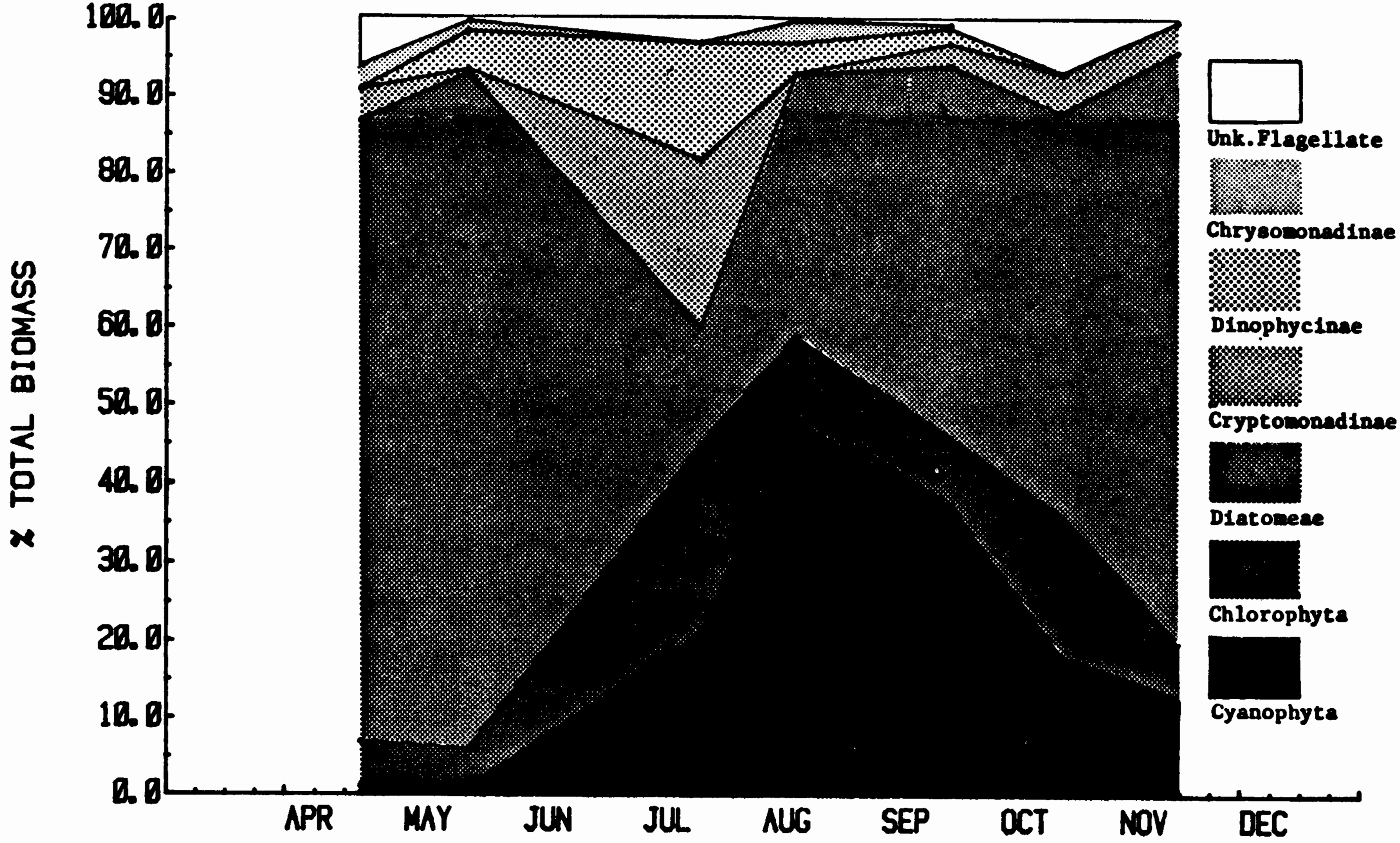


FIGURE 70. SEASONAL FLUCTUATIONS IN WESTERN BASIN PHYTOPLANKTON COMPOSITION FOR 1979 (USEPA-GLNPO).

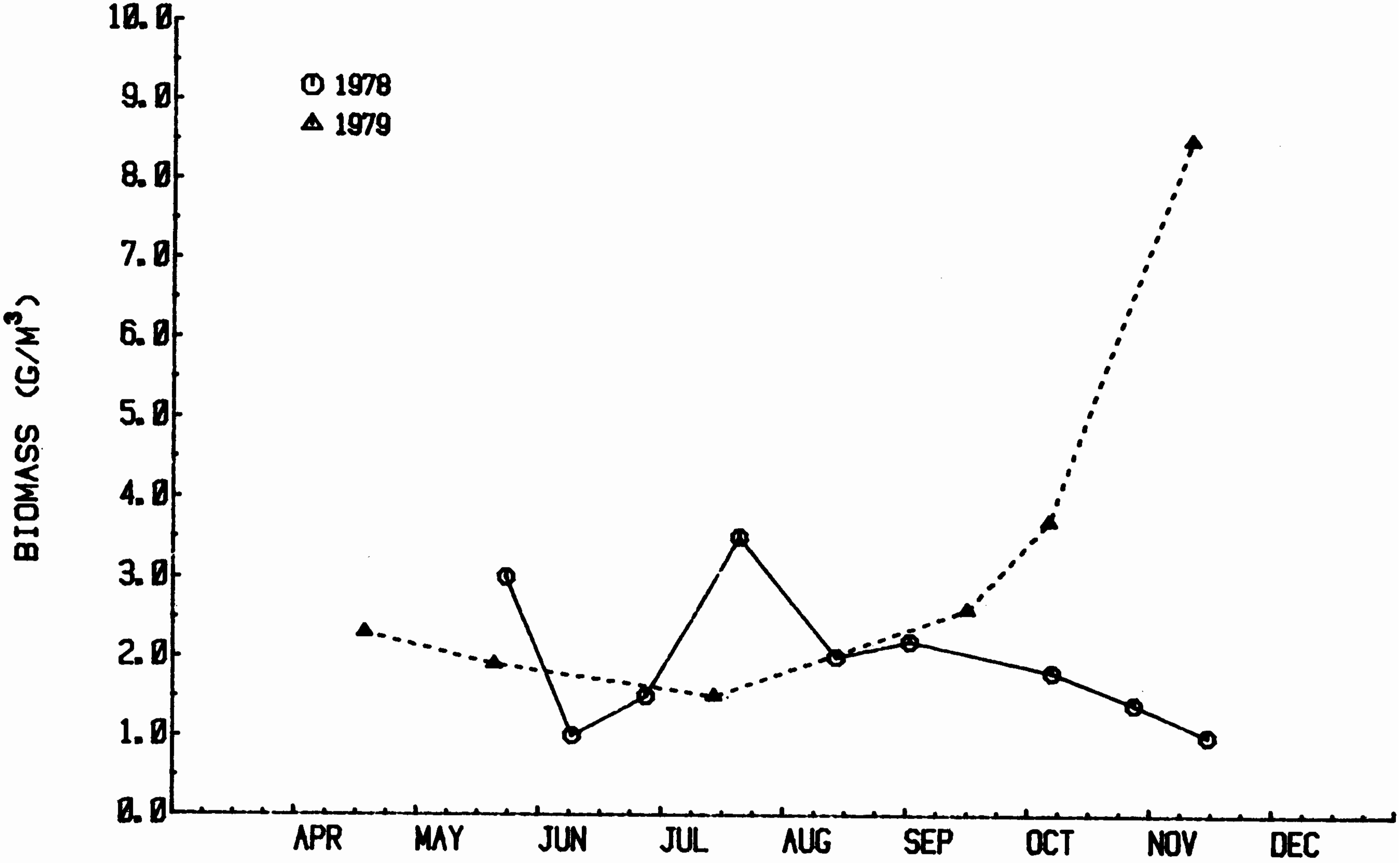


FIGURE 71. SEASONAL FLUCTUATIONS IN CENTRAL BASIN TOTAL PHYTOPLANKTON BIOMASS FOR 1978 AND 1979 (USEPA-GLNPO).

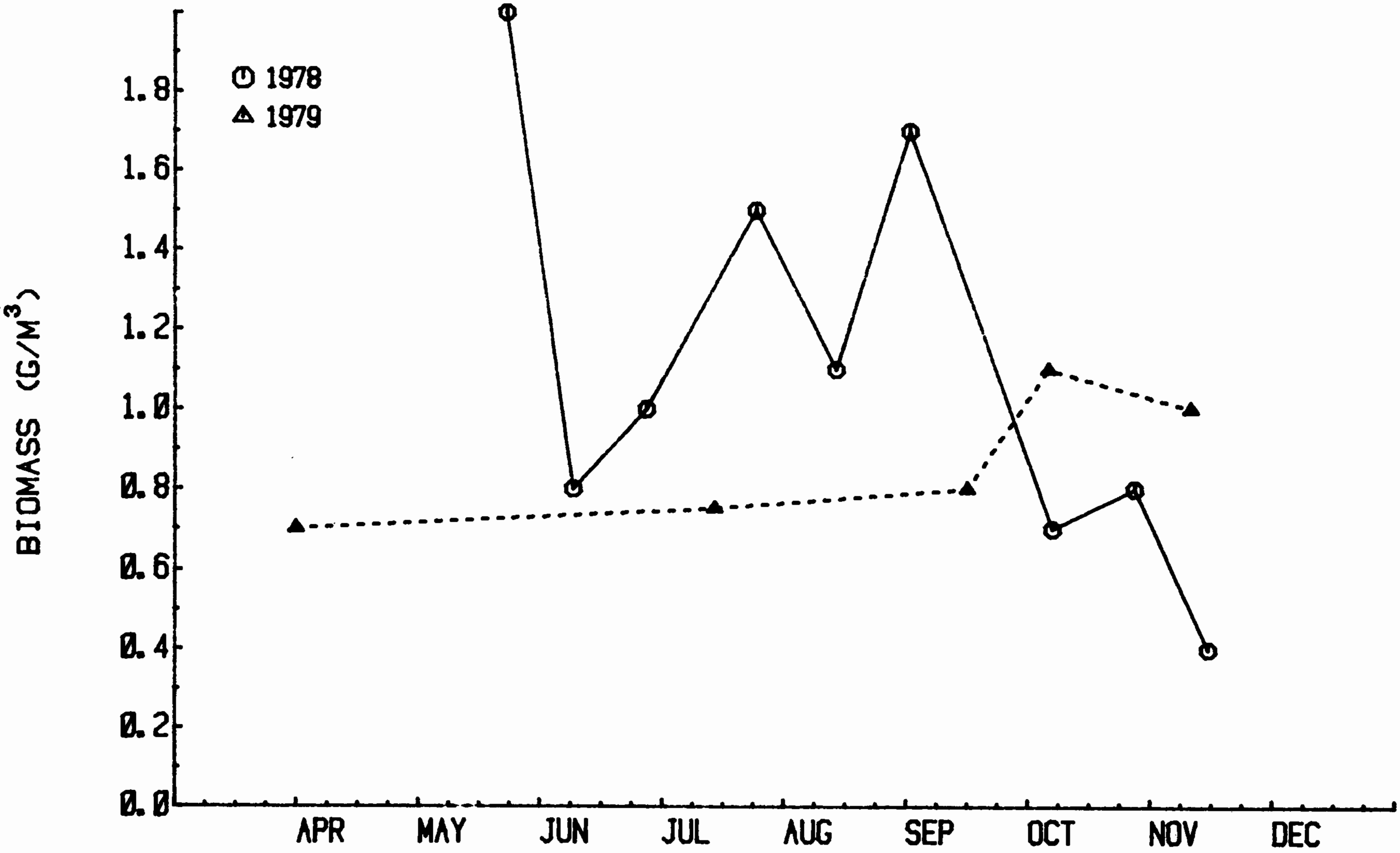


FIGURE 72. SEASONAL FLUCTUATIONS IN EASTERN BASIN TOTAL PHYTOPLANKTON BIOMASS FOR 1978 AND 1979 (USEPA-GLNPO).

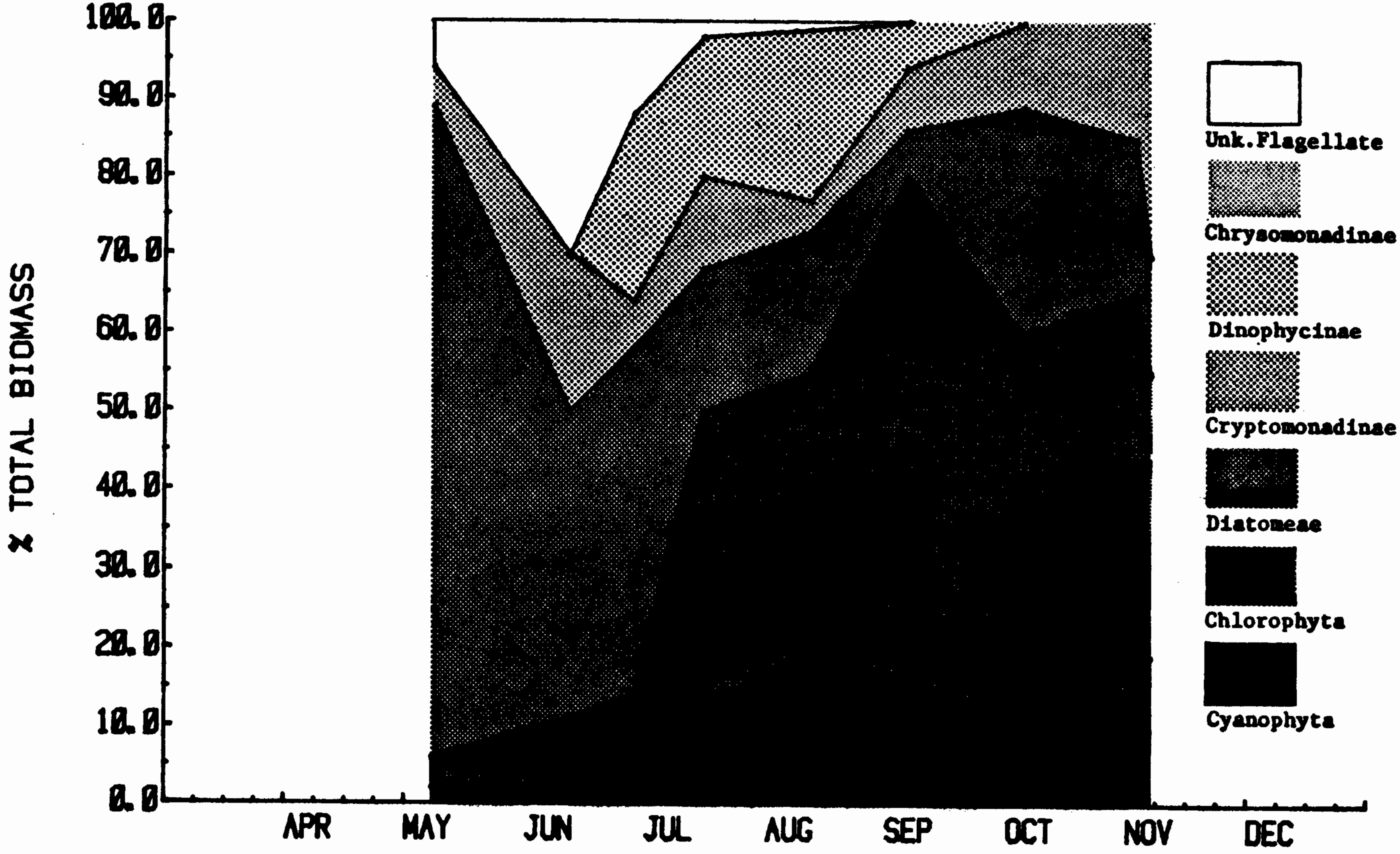


FIGURE 73. SEASONAL FLUCTUATIONS IN CENTRAL BASIN PHYTOPLANKTON COMPOSITION FOR 1978 (USEPA-GLNPO).

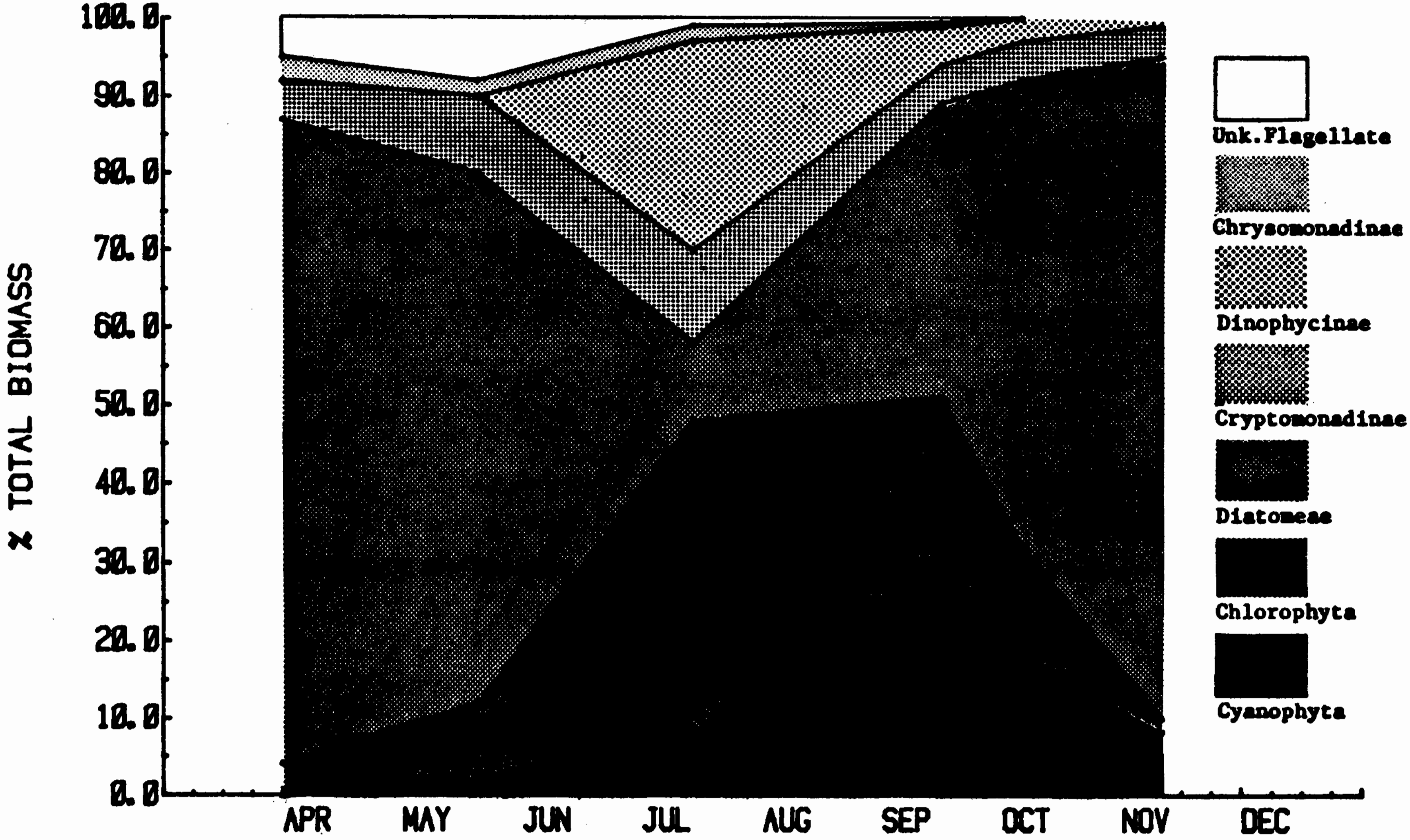


FIGURE 74. SEASONAL FLUCTUATIONS IN CENTRAL BASIN PHYTOPLANKTON COMPOSITION FOR 1979 (USEPA-GLNPO).

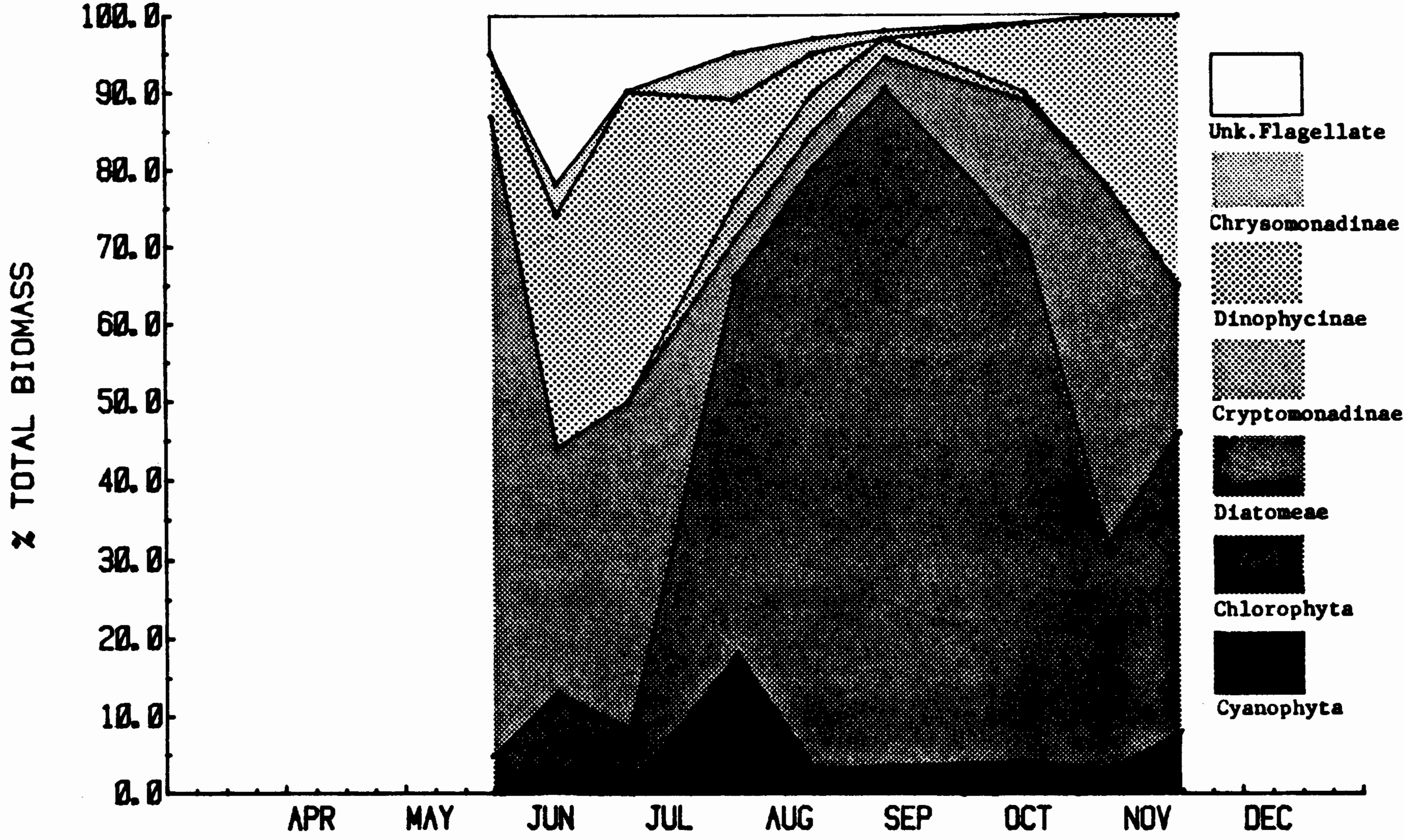


FIGURE 75. SEASONAL FLUCTUATIONS IN EASTERN BASIN PHYTOPLANKTON COMPOSITION FOR 1978 (USEPA-GLNPO).

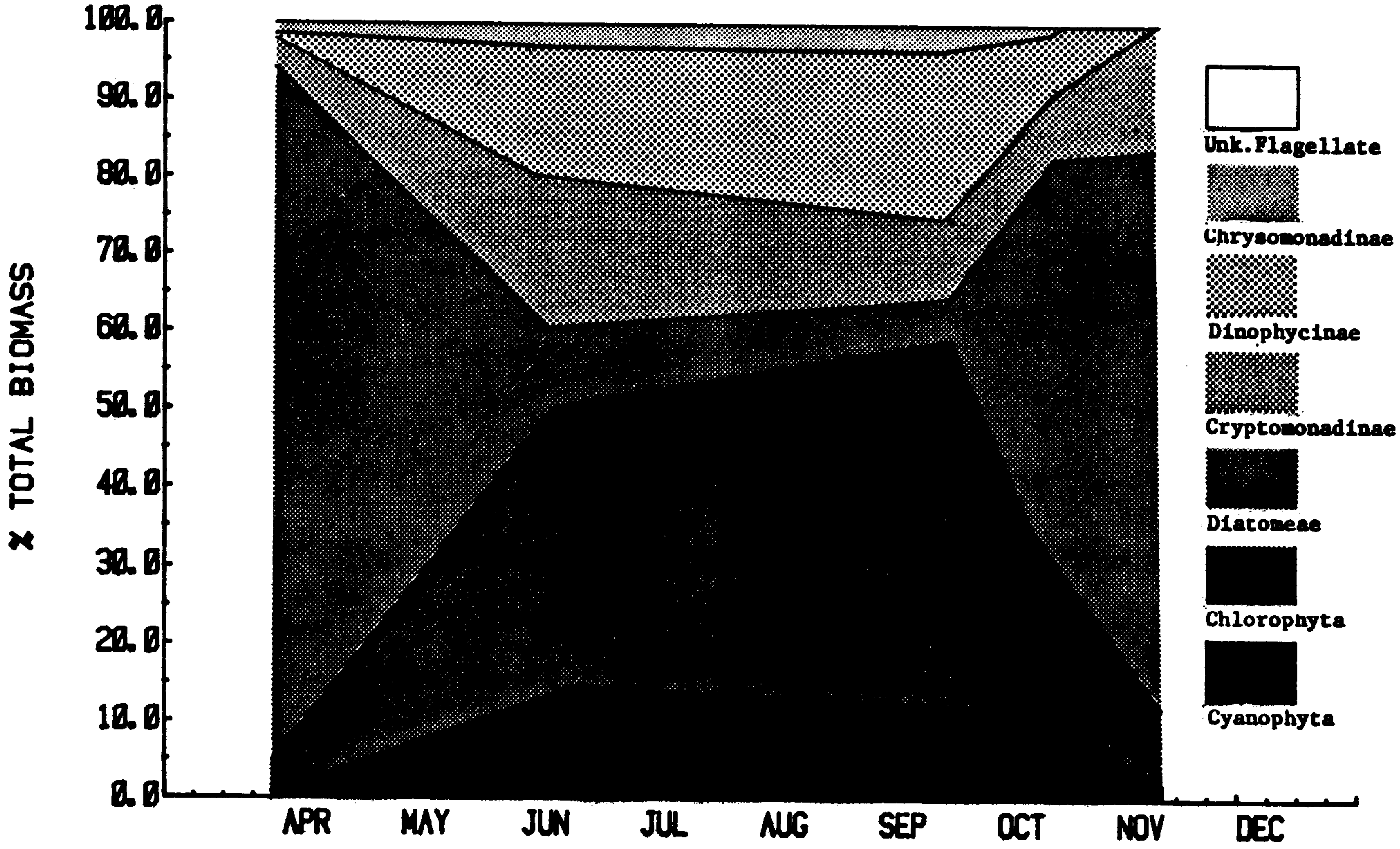


FIGURE 76. SEASONAL FLUCTUATIONS IN EASTERN BASIN PHYTOPLANKTON COMPOSITION FOR 1979 (USEPA-GLNPO).

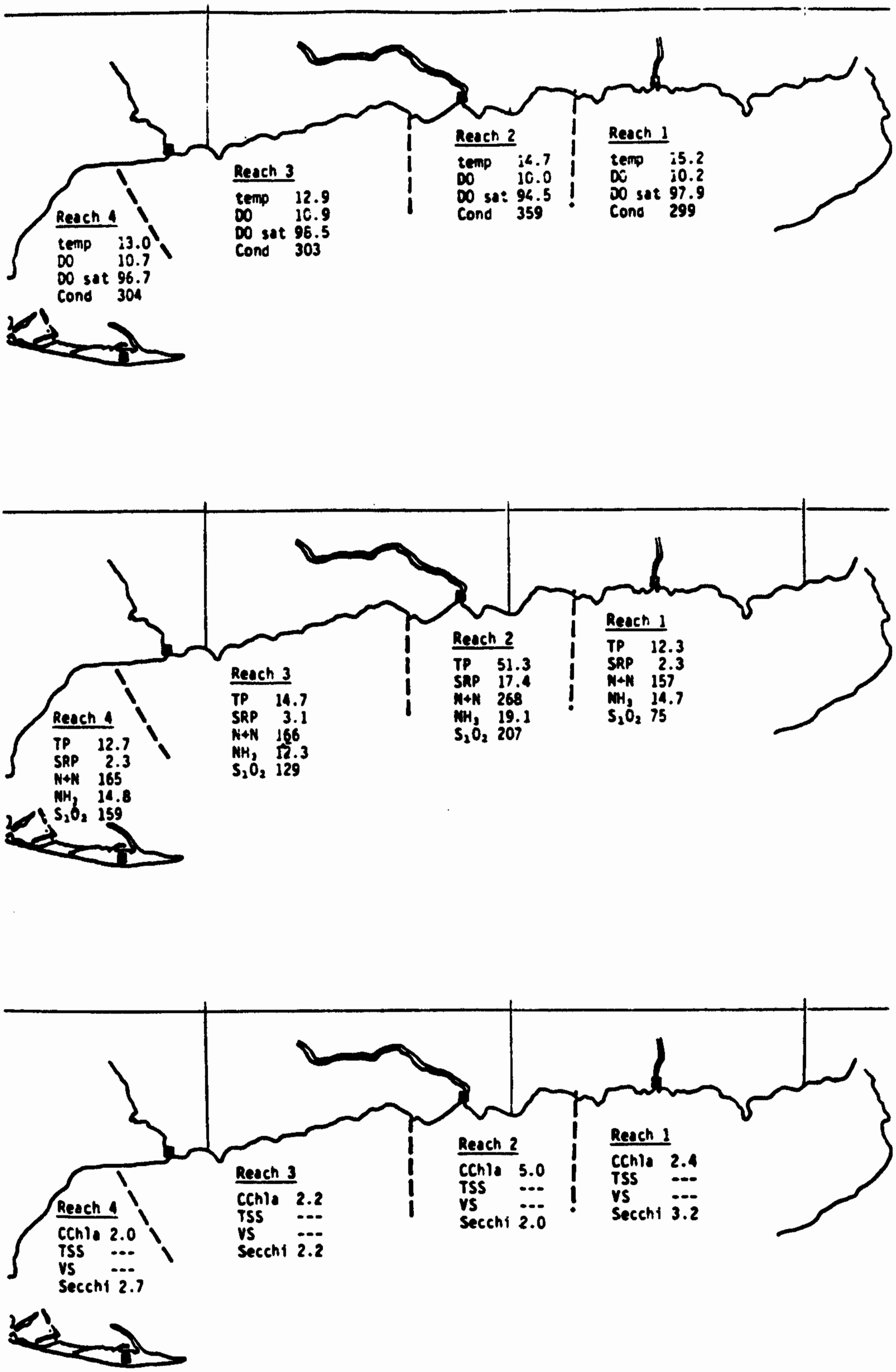


FIGURE 77. MEAN CONCENTRATIONS FOR THE 1978 AND 1979 NEARSHORE DATA BASE SUMMARIZED FOR EACH DESIGNATED REACH AREA.

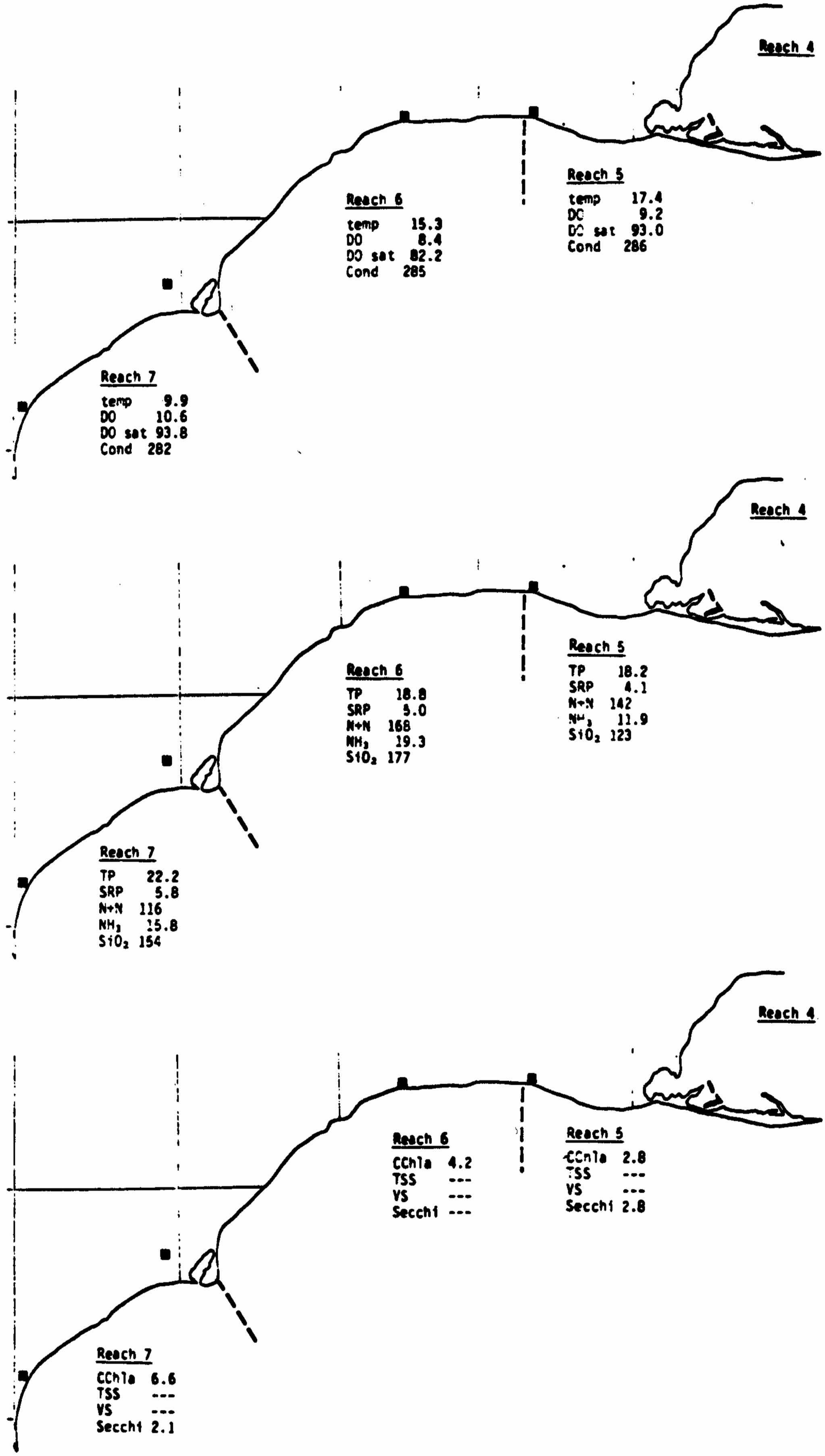
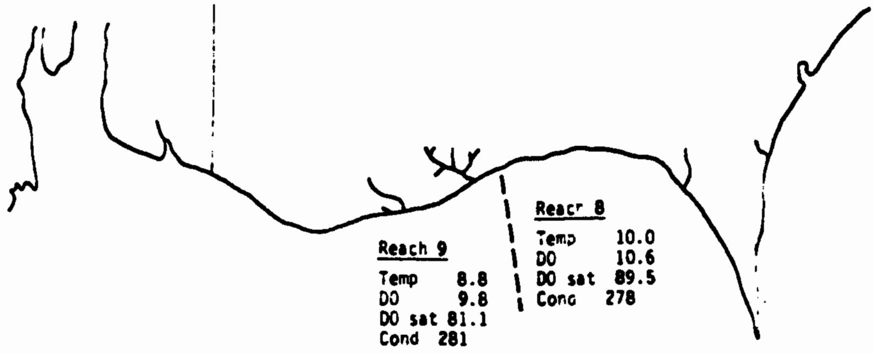
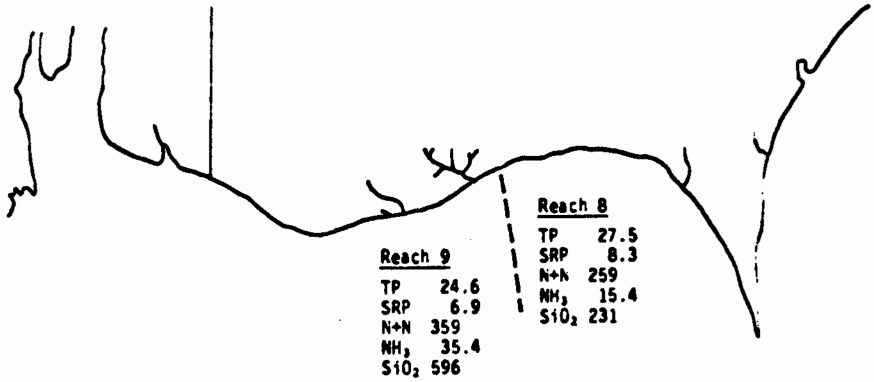


FIGURE 77. CONTINUED





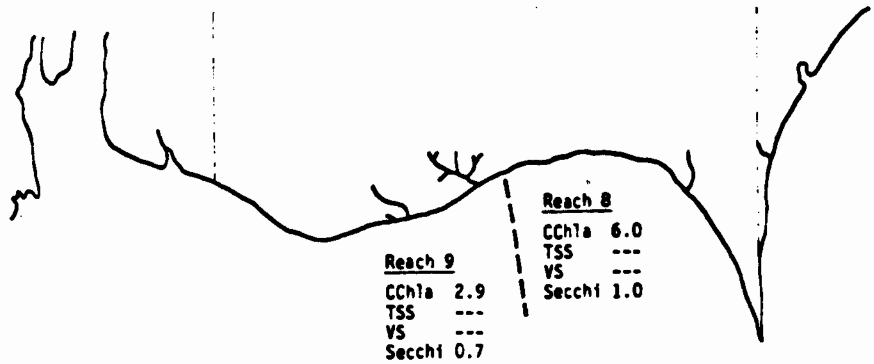


FIGURE 77. CONTINUED

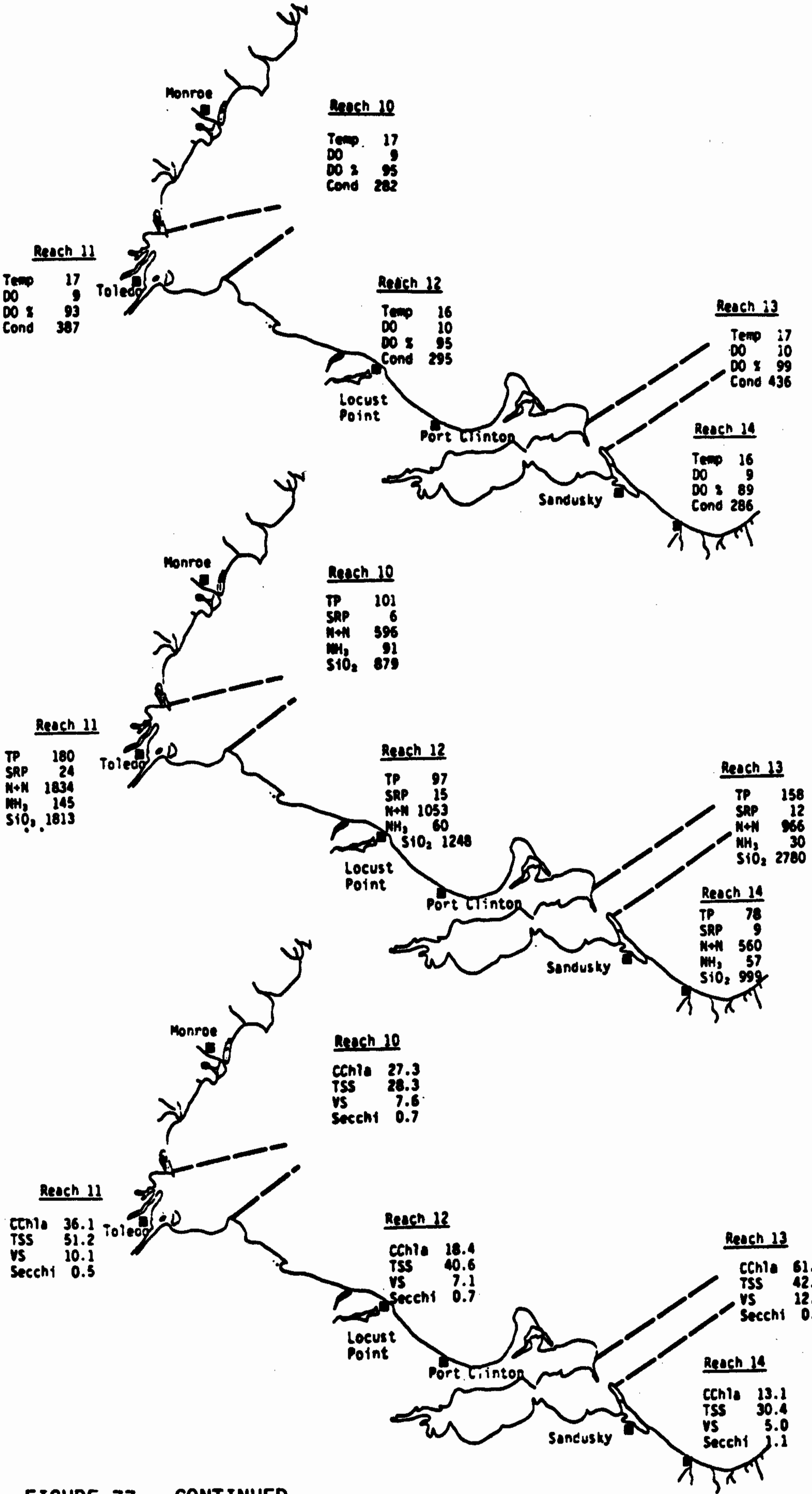


FIGURE 77. CONTINUED

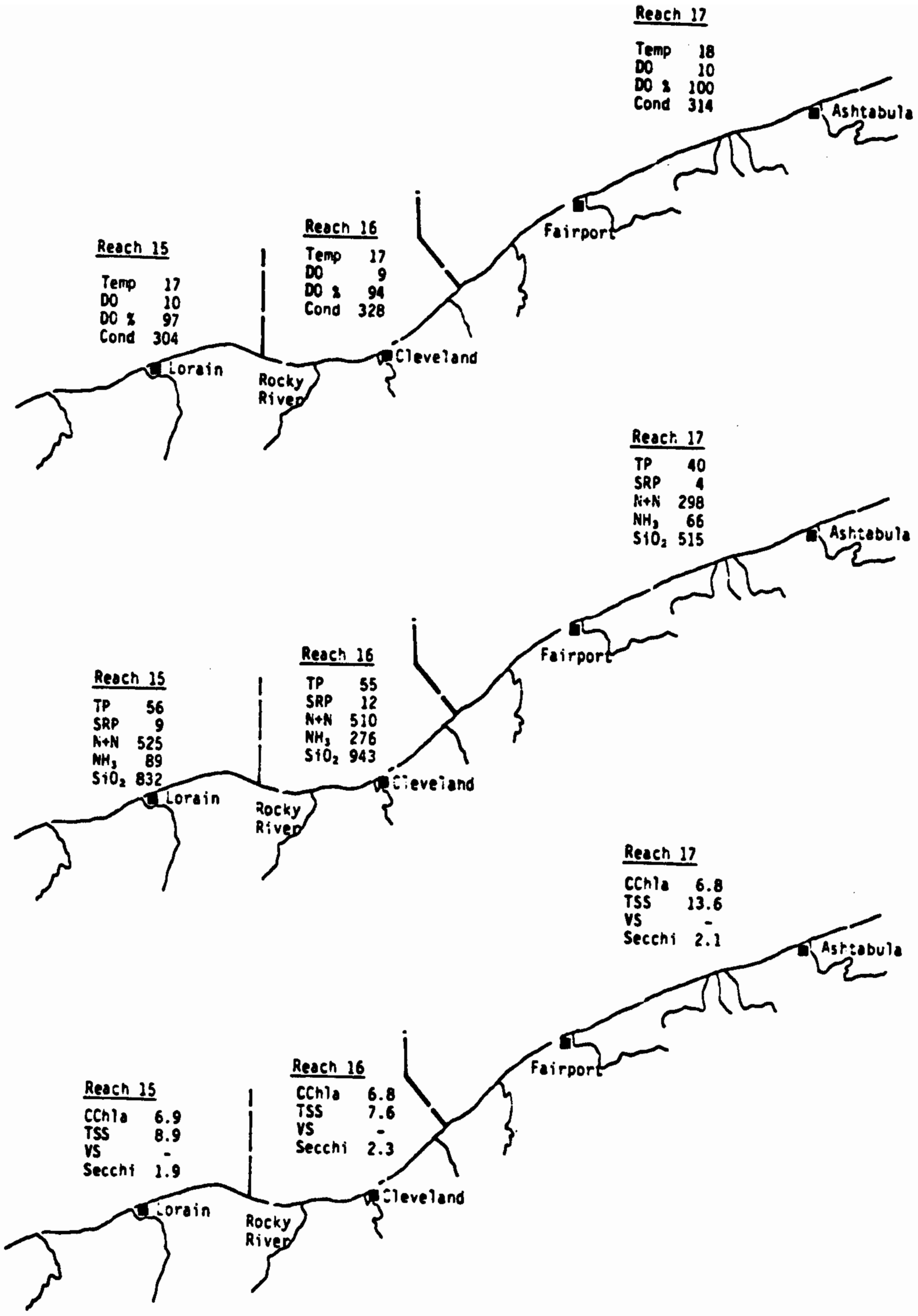


FIGURE 77. CONTINUED

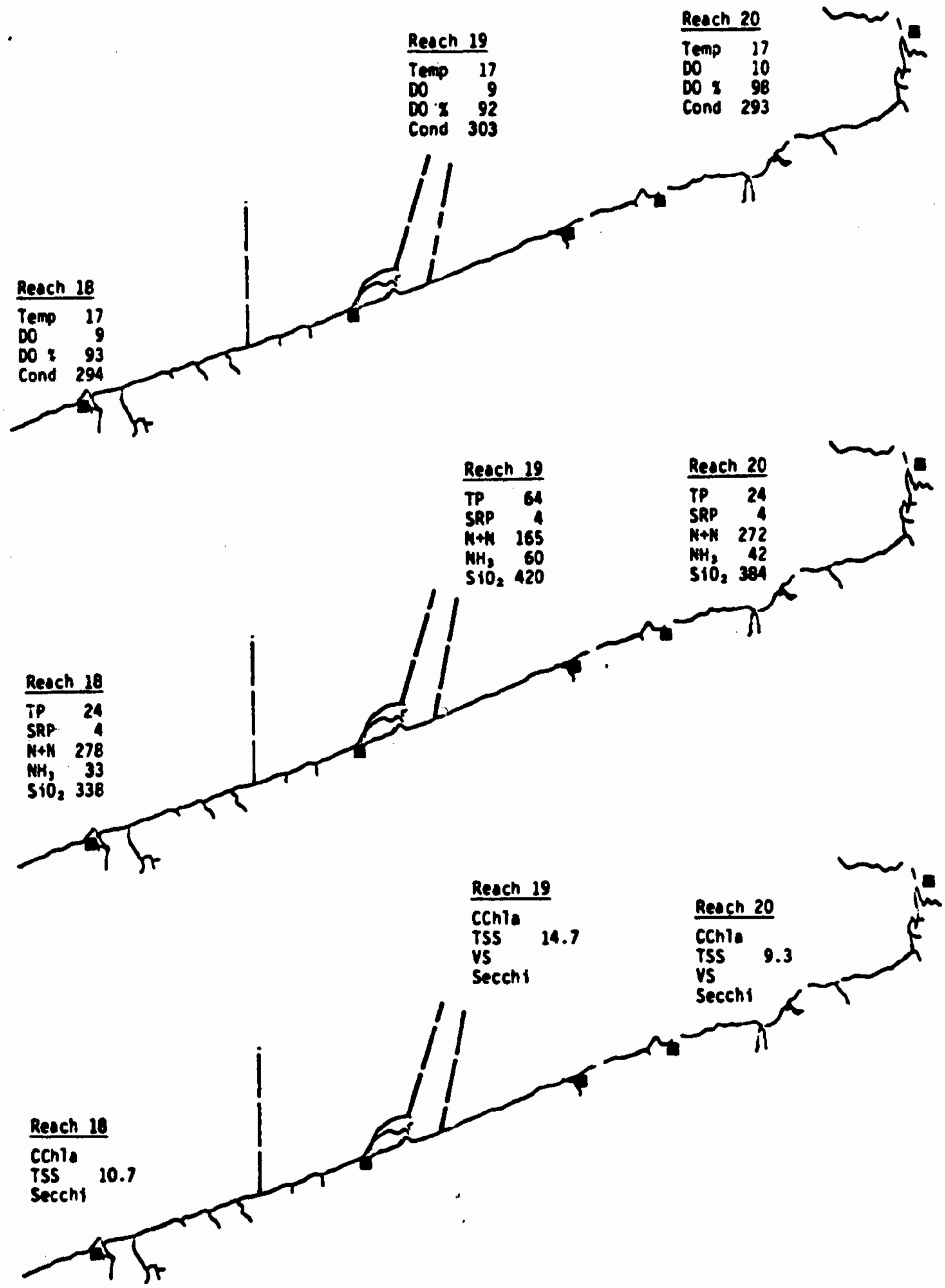


FIGURE 77. CONTINUED

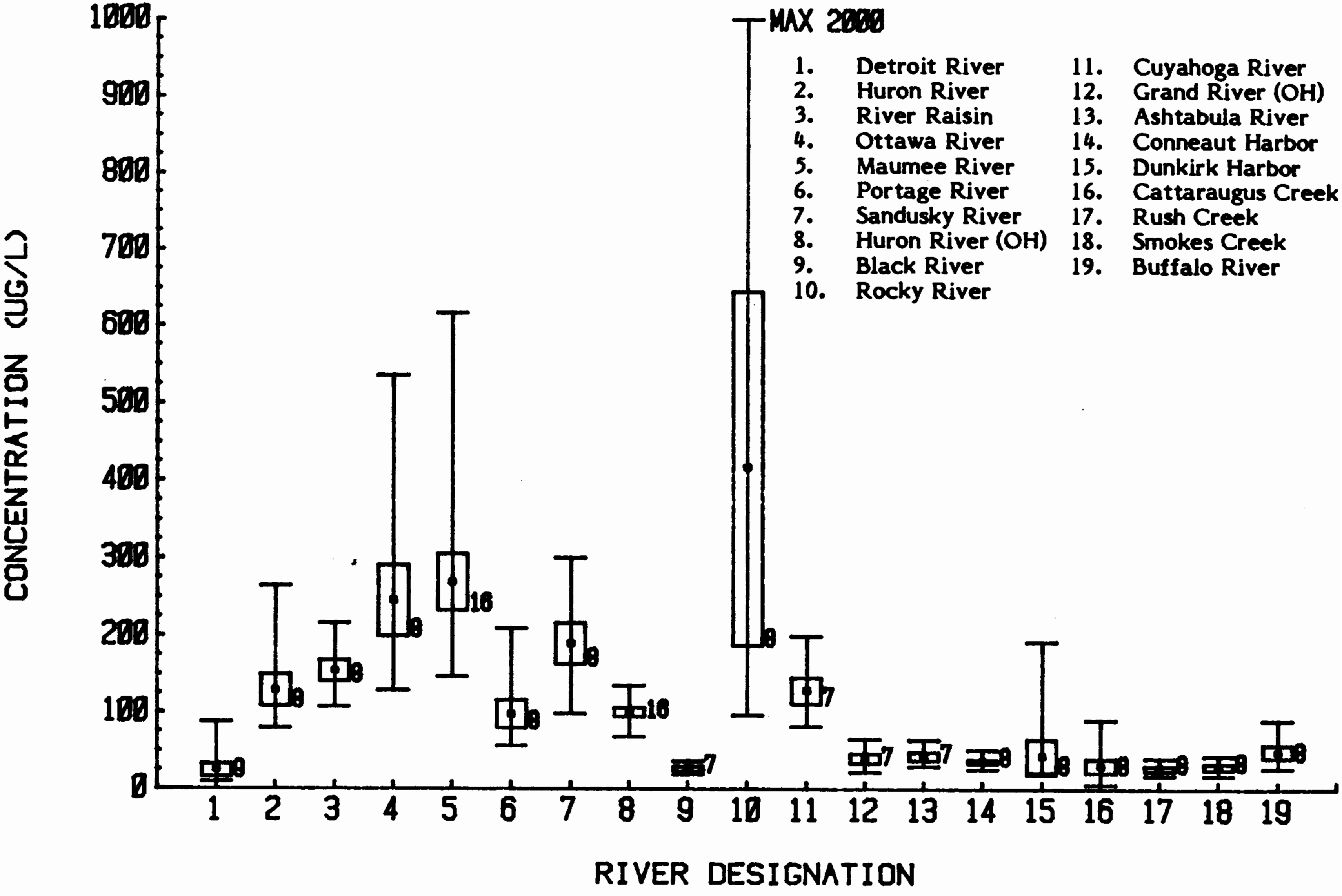


FIGURE 78. SOUTH SHORE RIVER AND HARBOR MEAN TOTAL PHOSPHORUS CONCENTRATIONS SUMMARIZED FOR 1978 - 1979.

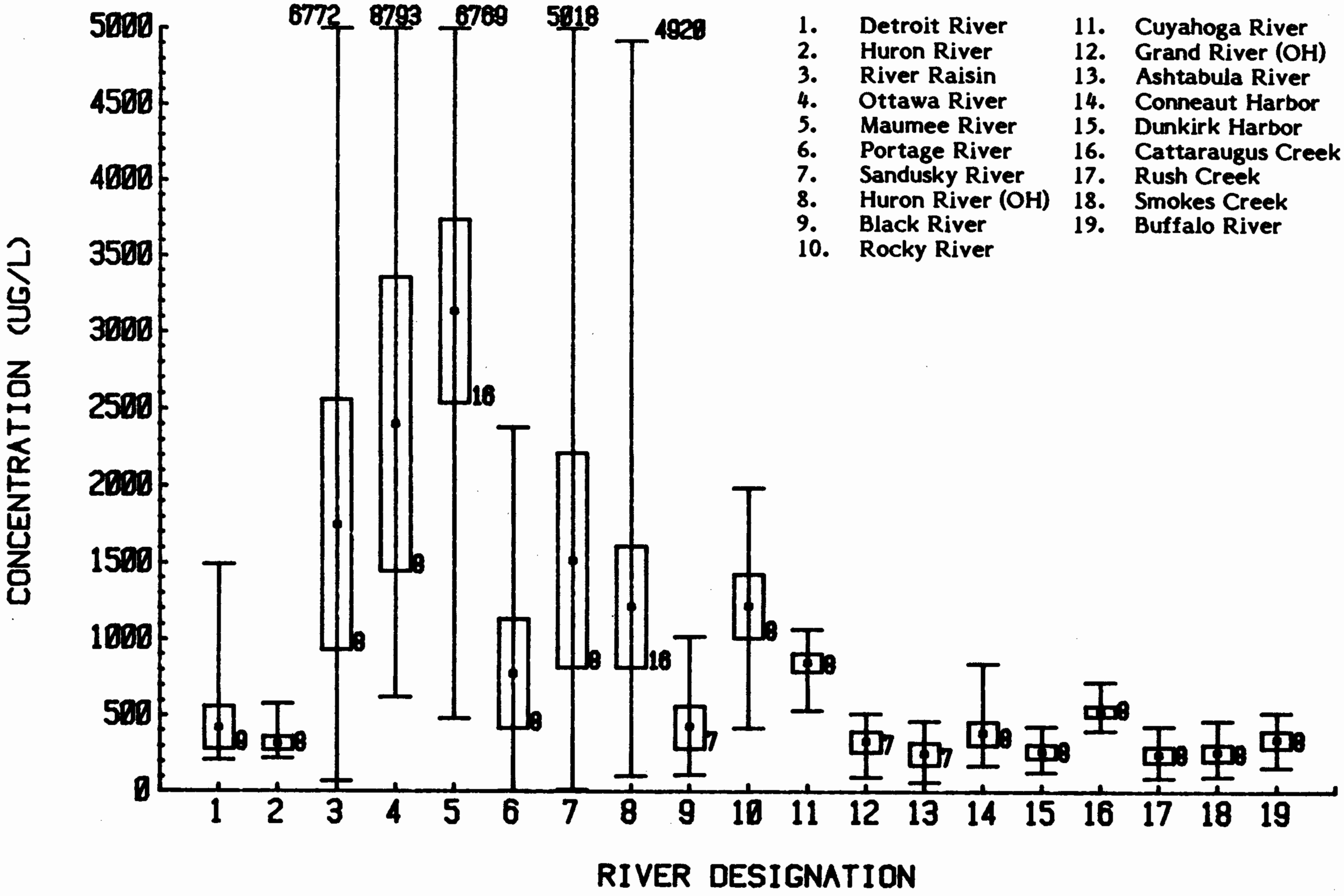


FIGURE 79. SOUTH SHORE RIVER AND HARBOR MEAN NITRATE PLUS NITRITE CONCENTRATIONS SUMMARIZED FOR 1978 AND 1979.

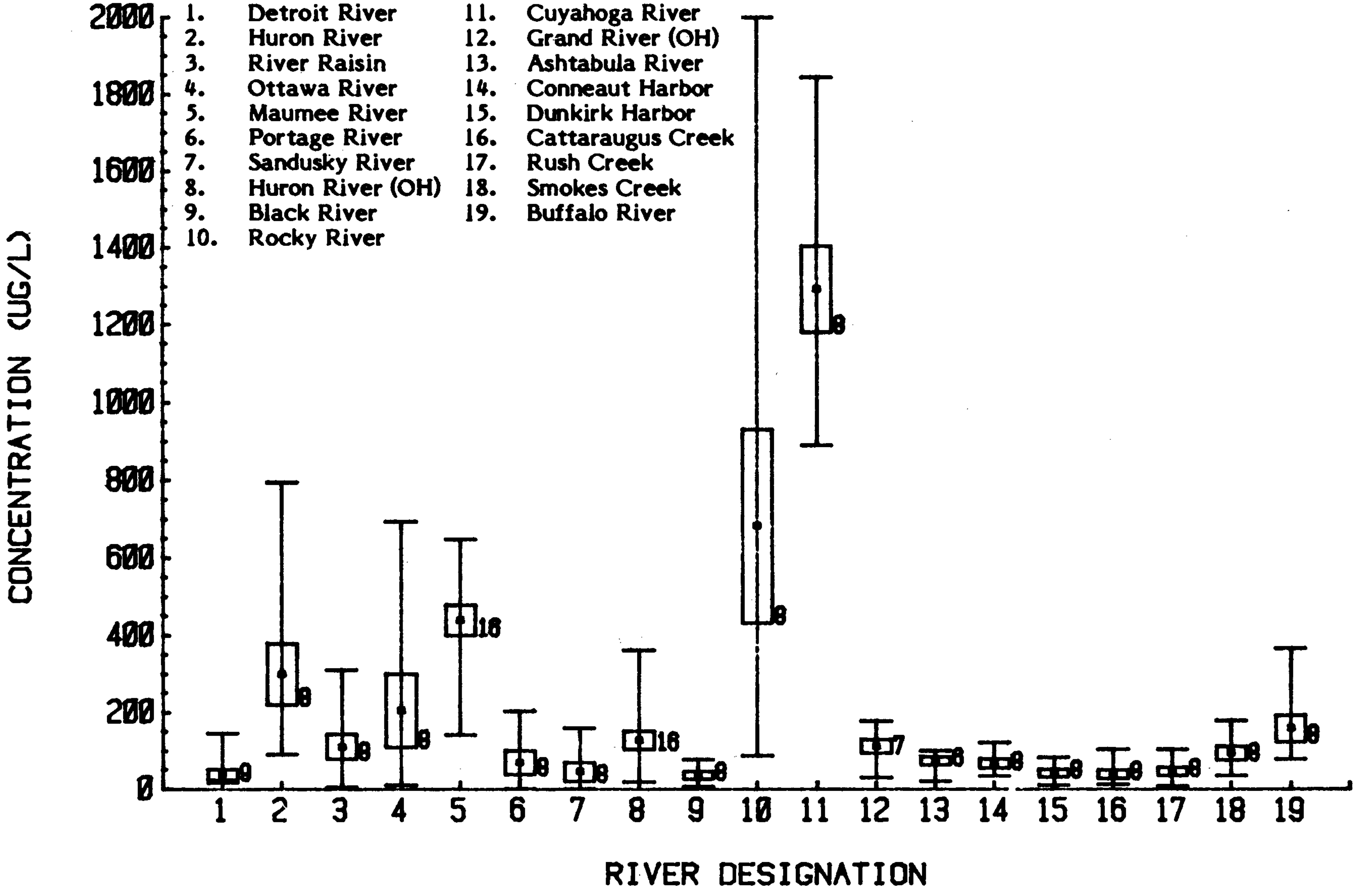


FIGURE 80. SOUTH SHORE RIVER AND HARBOR MEAN AMMONIA CONCENTRATIONS SUMMARIZED FOR 1978 AND 1979.

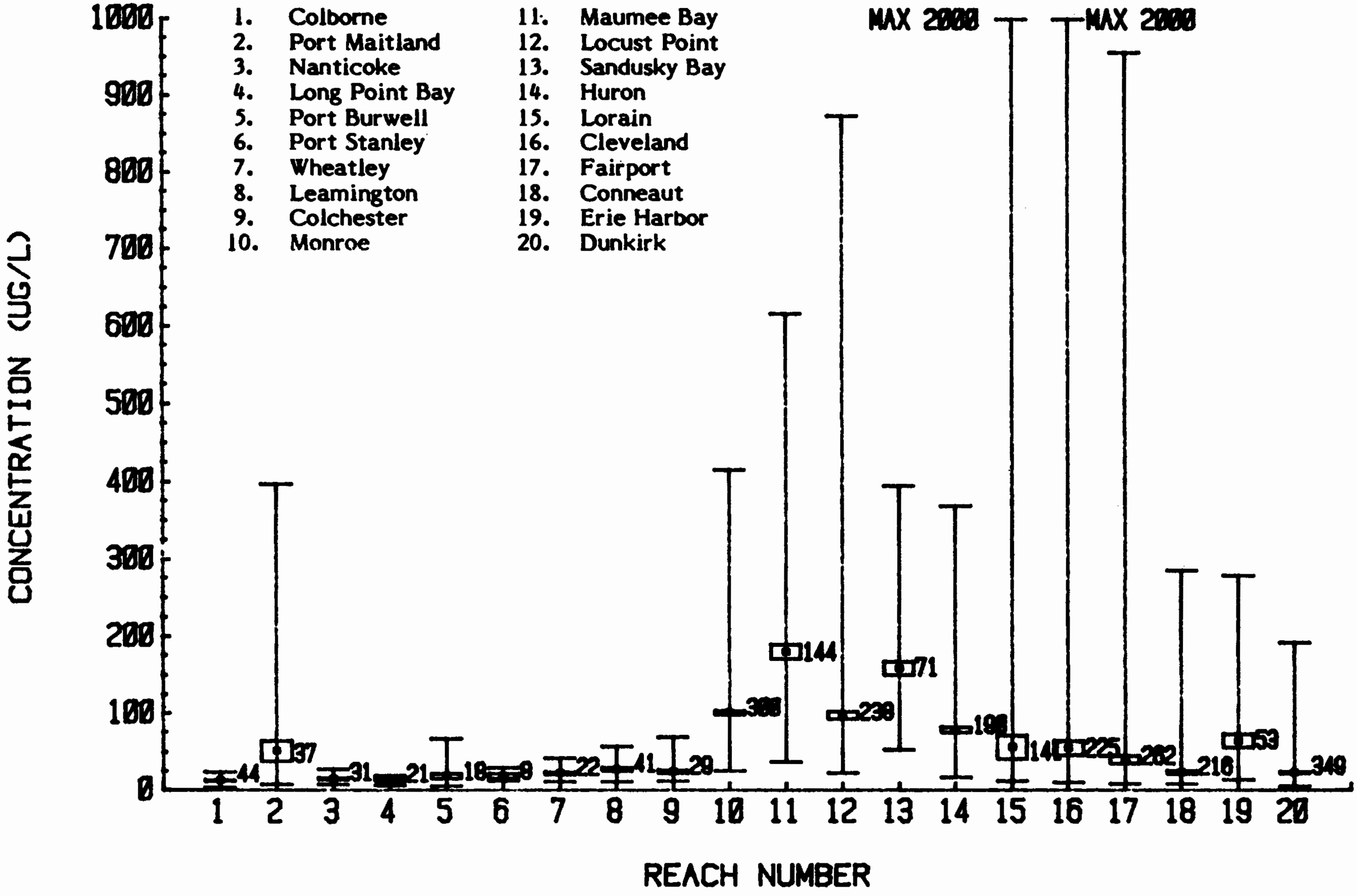


FIGURE 81. MEAN NEARSHORE REACH CONCENTRATIONS OF TOTAL PHOSPHORUS FOR 1978 - 1979.

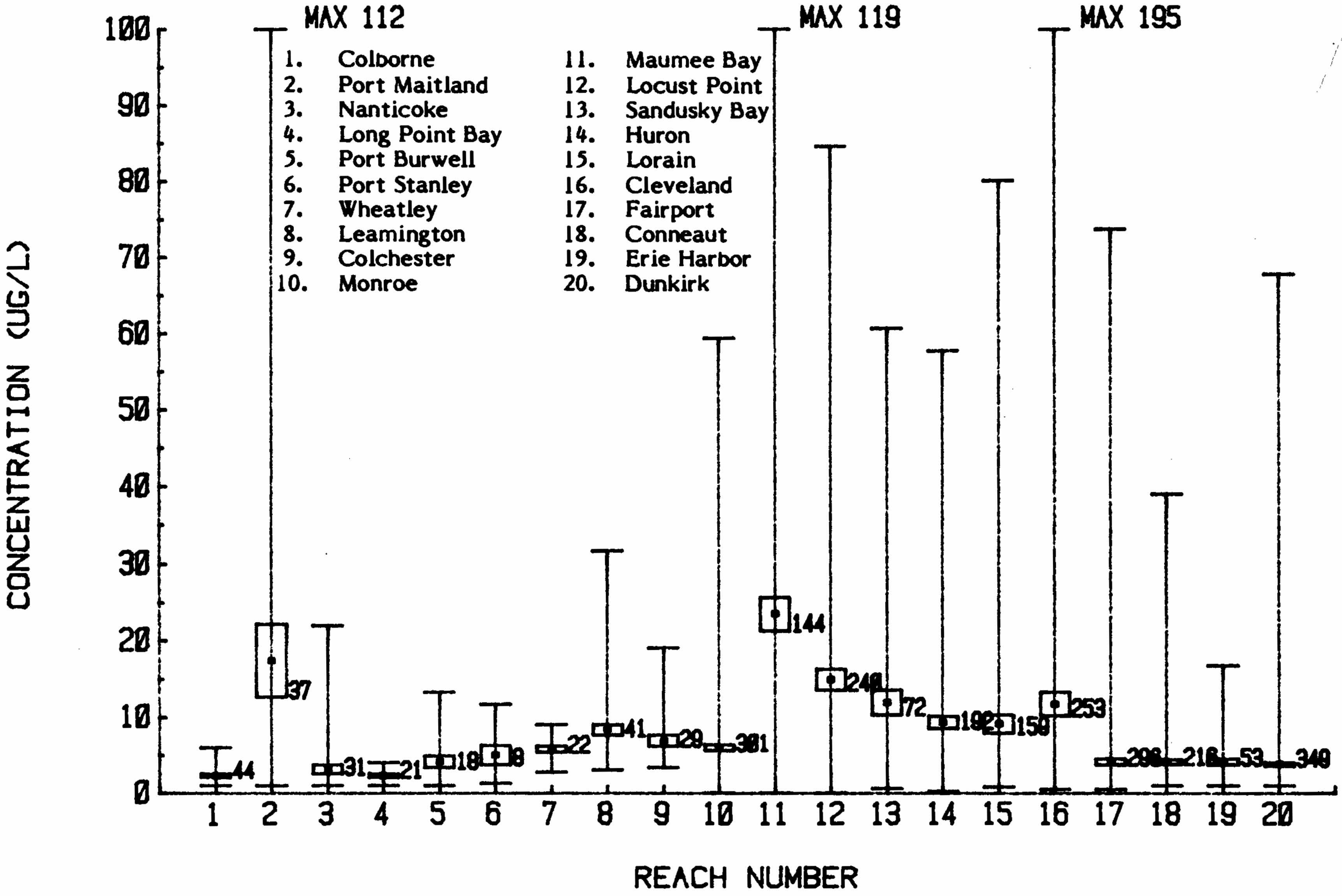


FIGURE 82. MEAN NEARSHORE REACH CONCENTRATIONS OF SOLUBLE REACTIVE PHOSPHORUS FOR 1978 AND 1979.

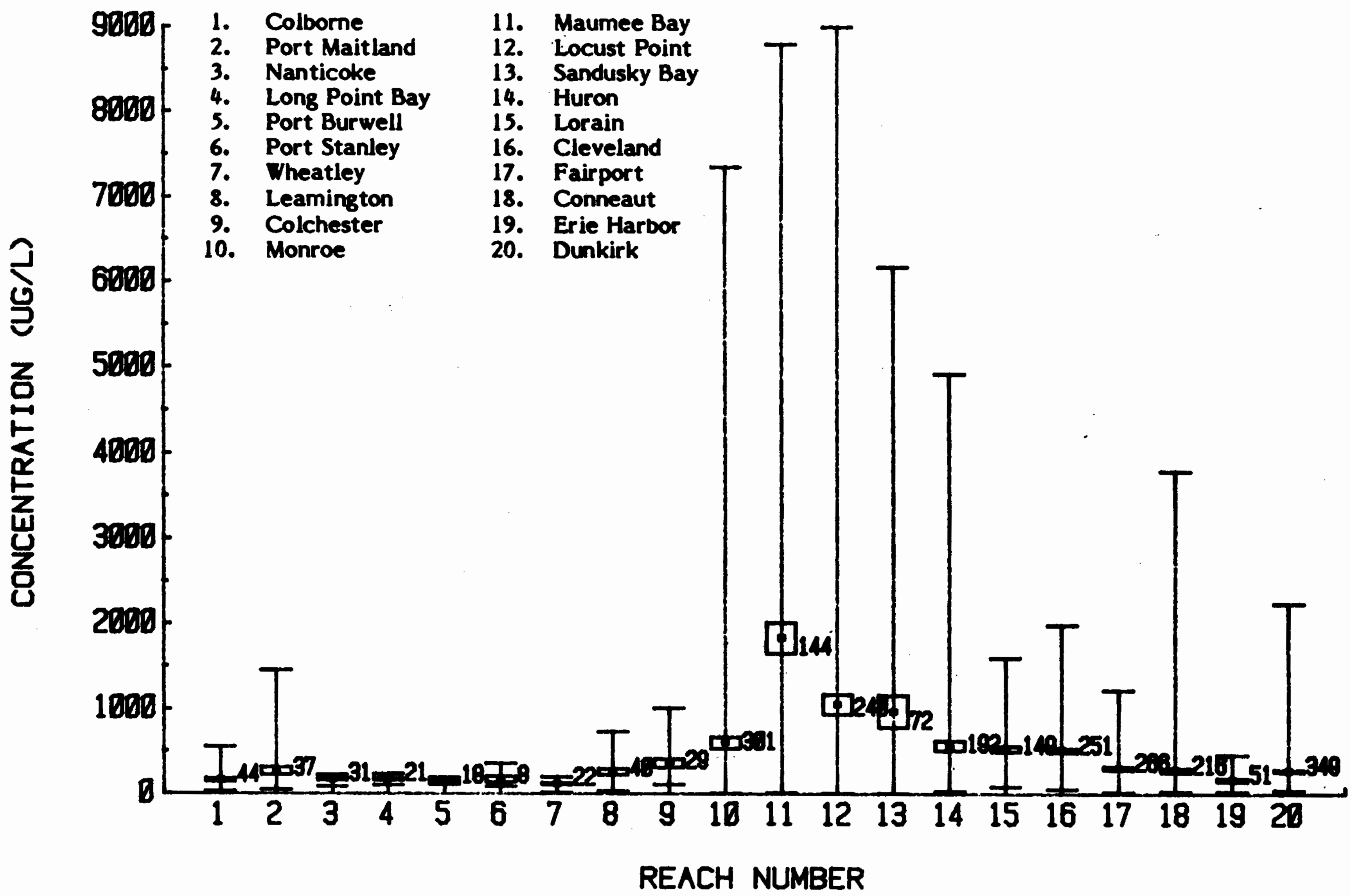


FIGURE 83. MEAN NEARSHORE REACH CONCENTRATIONS OF NITRATE PLUS NITRITE FOR 1978 AND 1979.

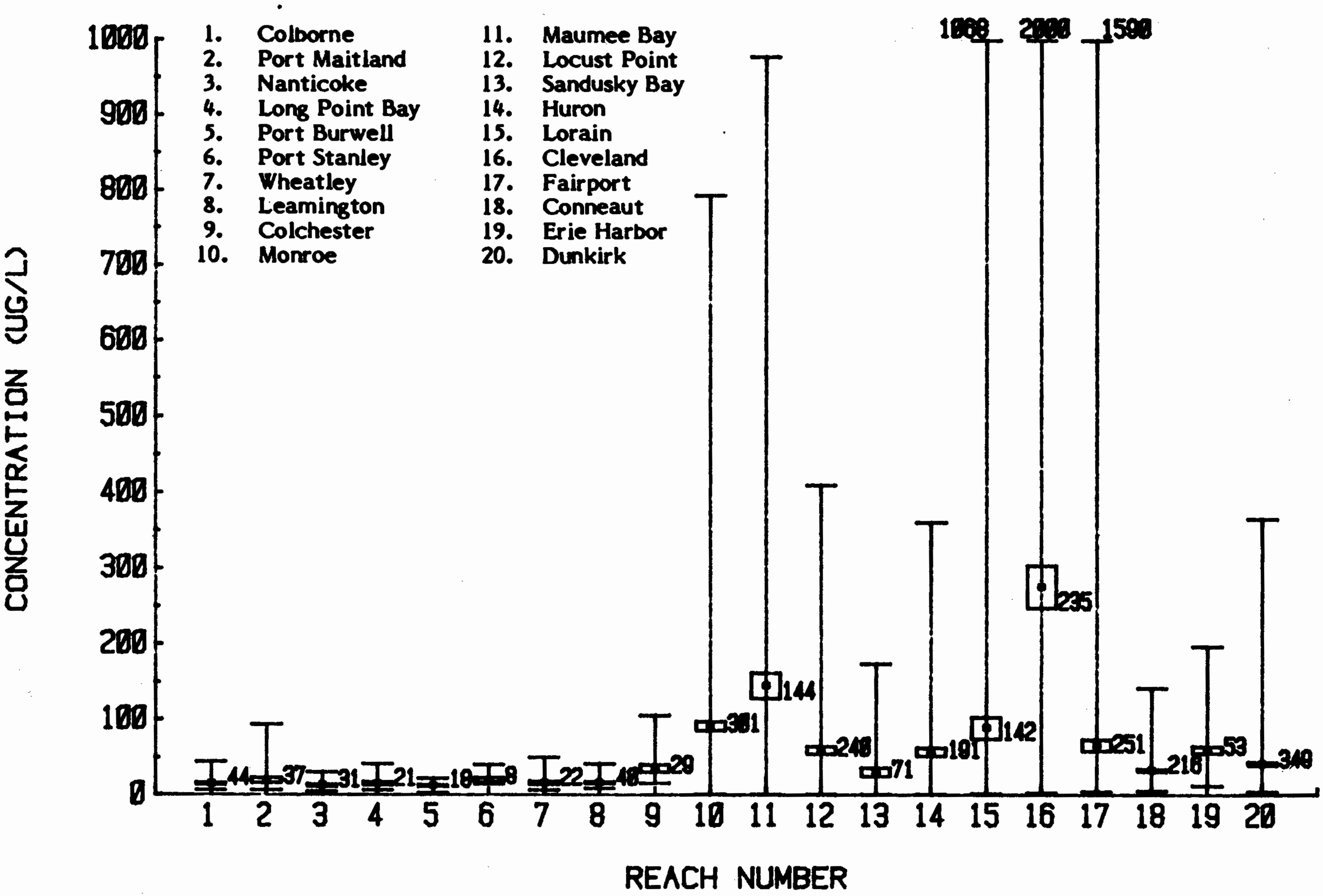


FIGURE 84. MEAN NEARSHORE REACH CONCENTRATIONS OF AMMONIA FOR 1978 AND 1979.

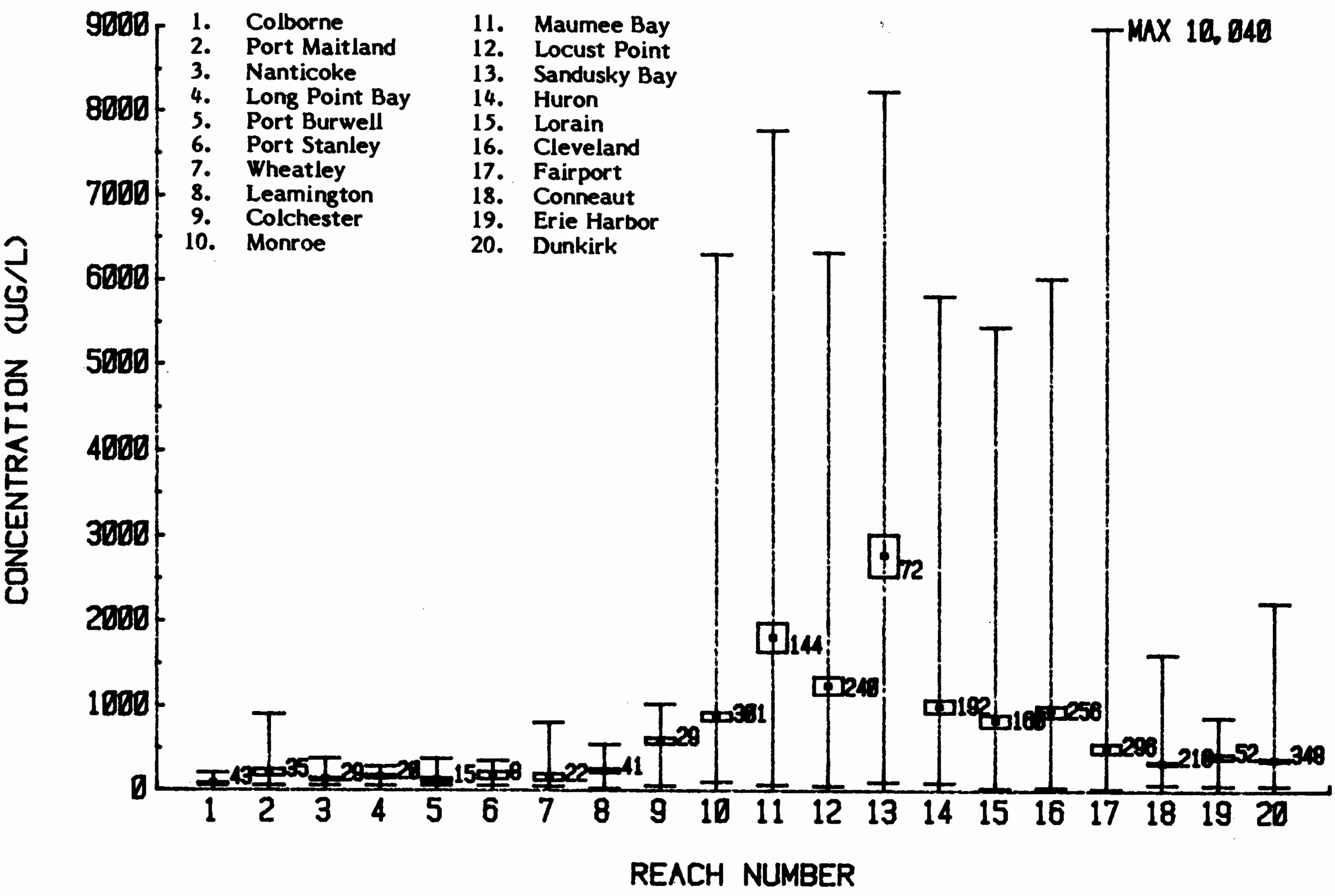


FIGURE 85. MEAN NEARSHORE REACH CONCENTRATIONS OF DISSOLVED SILICA FOR 1978 AND 1979.

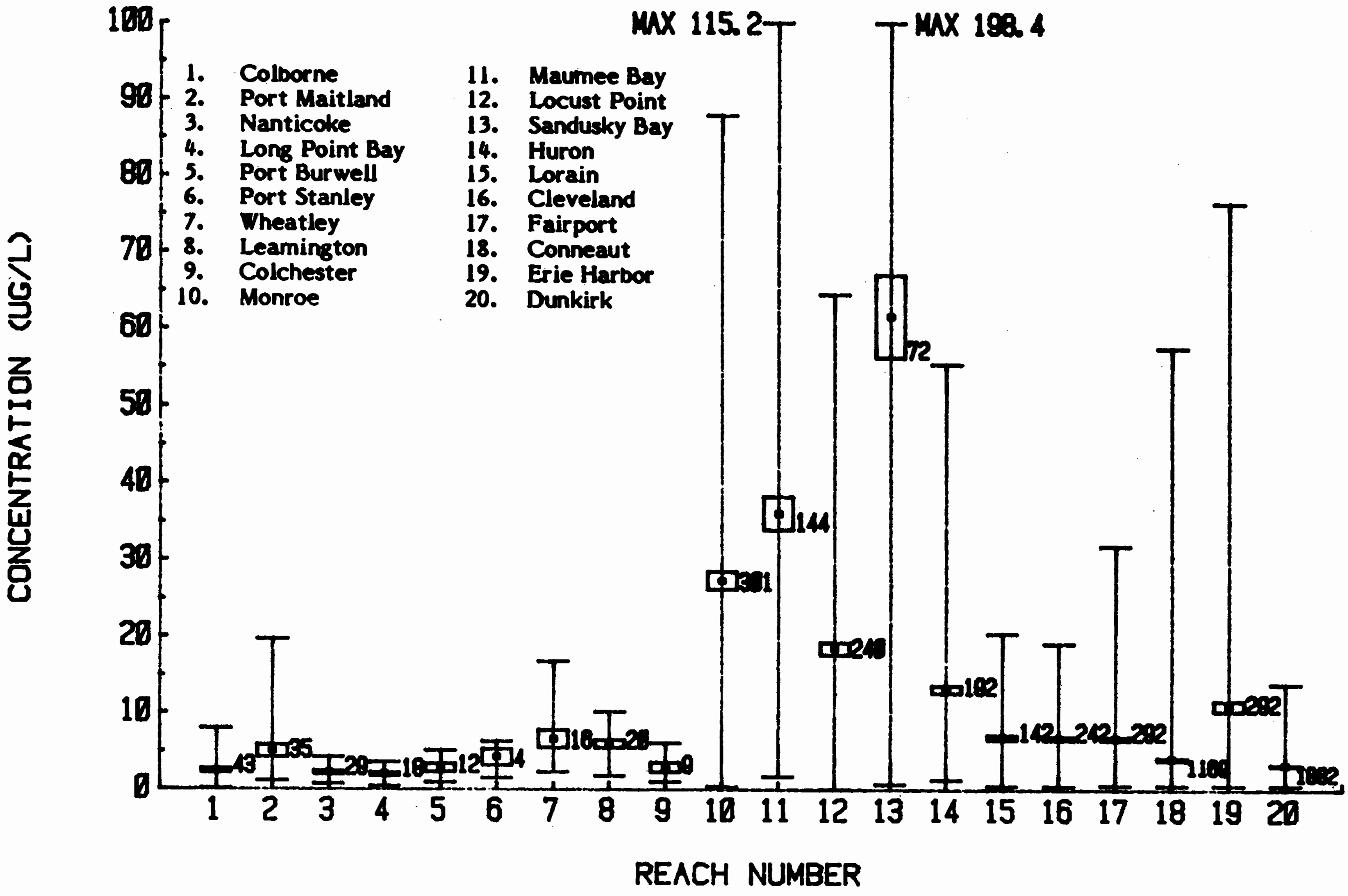


FIGURE 86. MEAN NEARSHORE REACH CONCENTRATIONS OF CORRECTED CHLOROPHYLL A FOR 1978 AND 1979.

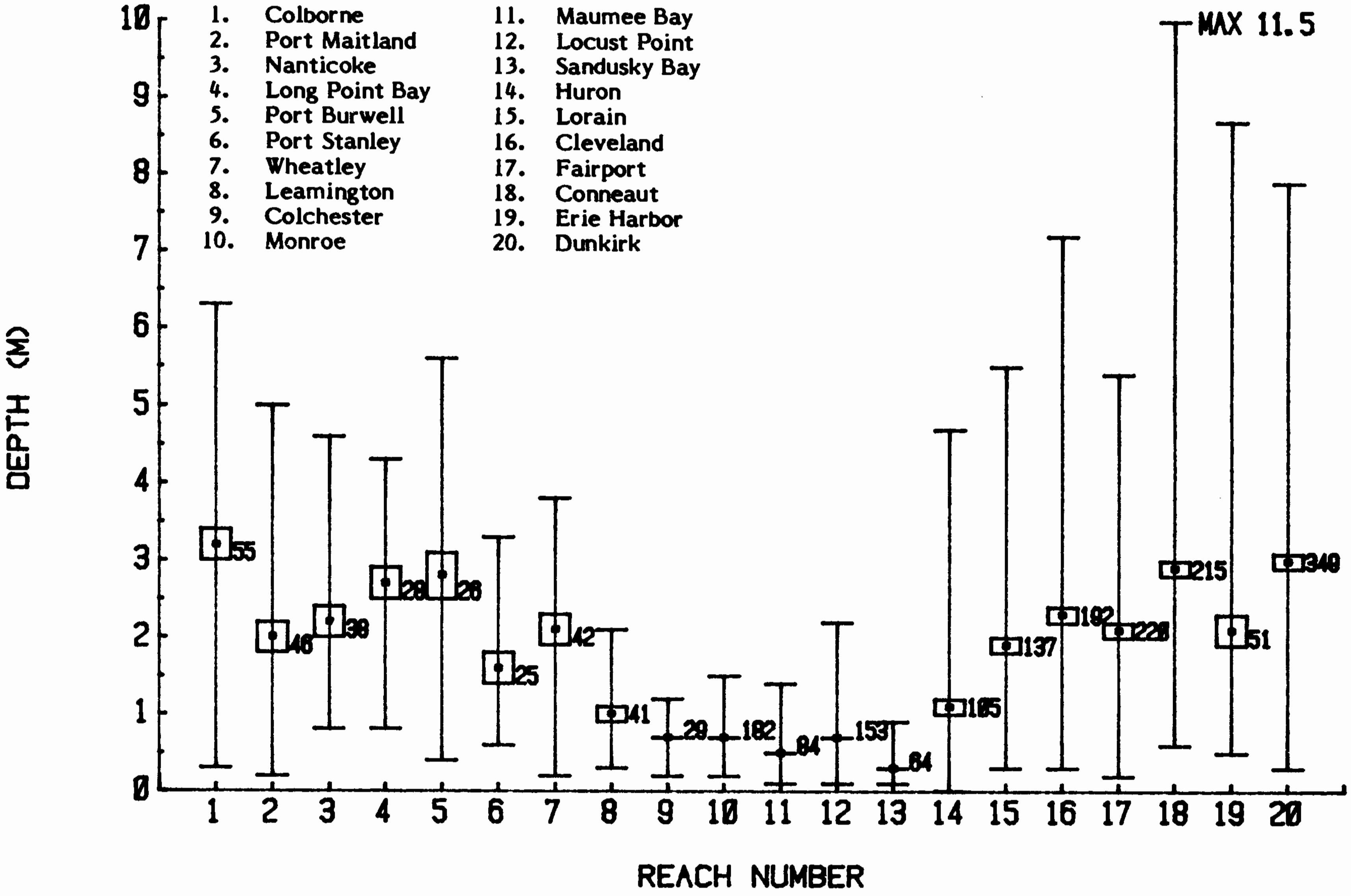


FIGURE 87. MEAN NEARSHORE REACH CONCENTRATIONS OF SECCHI DEPTH FOR 1978 AND 1979.

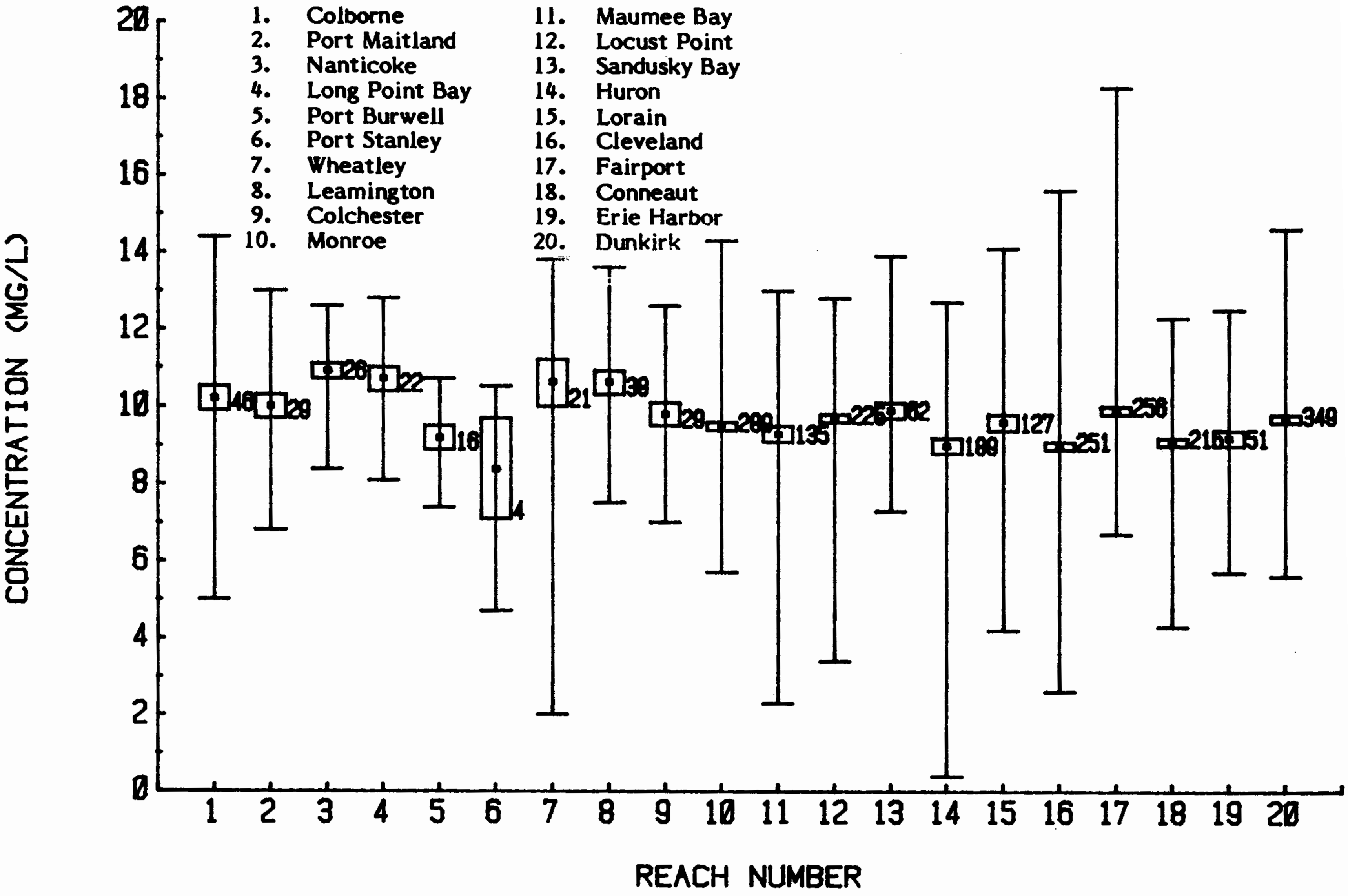


FIGURE 88. MEAN NEARSHORE REACH CONCENTRATIONS OF DISSOLVED OXYGEN FOR 1978 AND 1979.

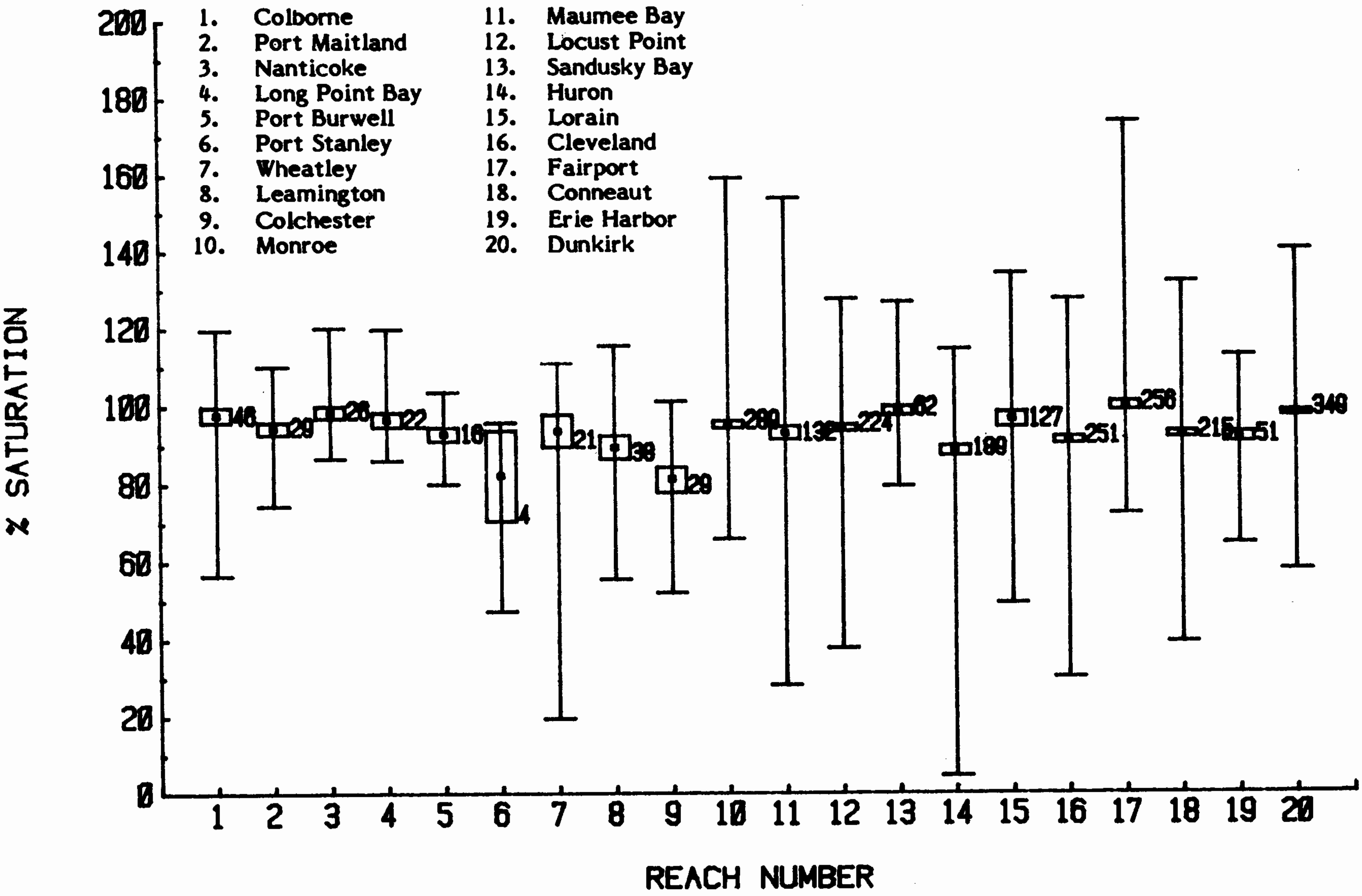


FIGURE 89. MEAN NEARSHORE REACH PERCENT SATURATION OF DISSOLVED OXYGEN FOR 1978 AND 1979.

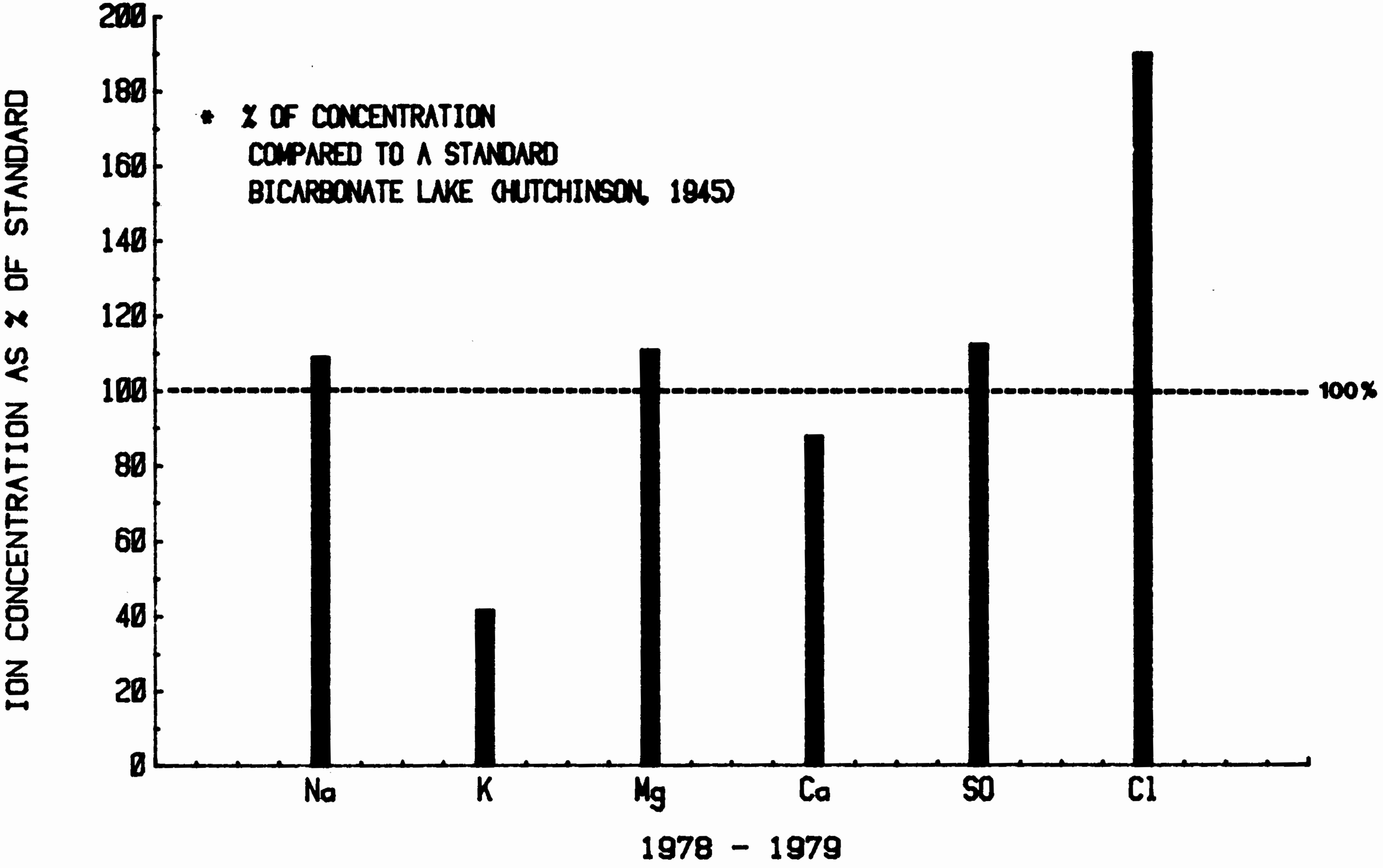


FIGURE 90. A COMPARISON OF LAKE ERIE PRINCIPAL ION COMPOSITION WITH THAT OF A STANDARD BICARBONATE LAKE.

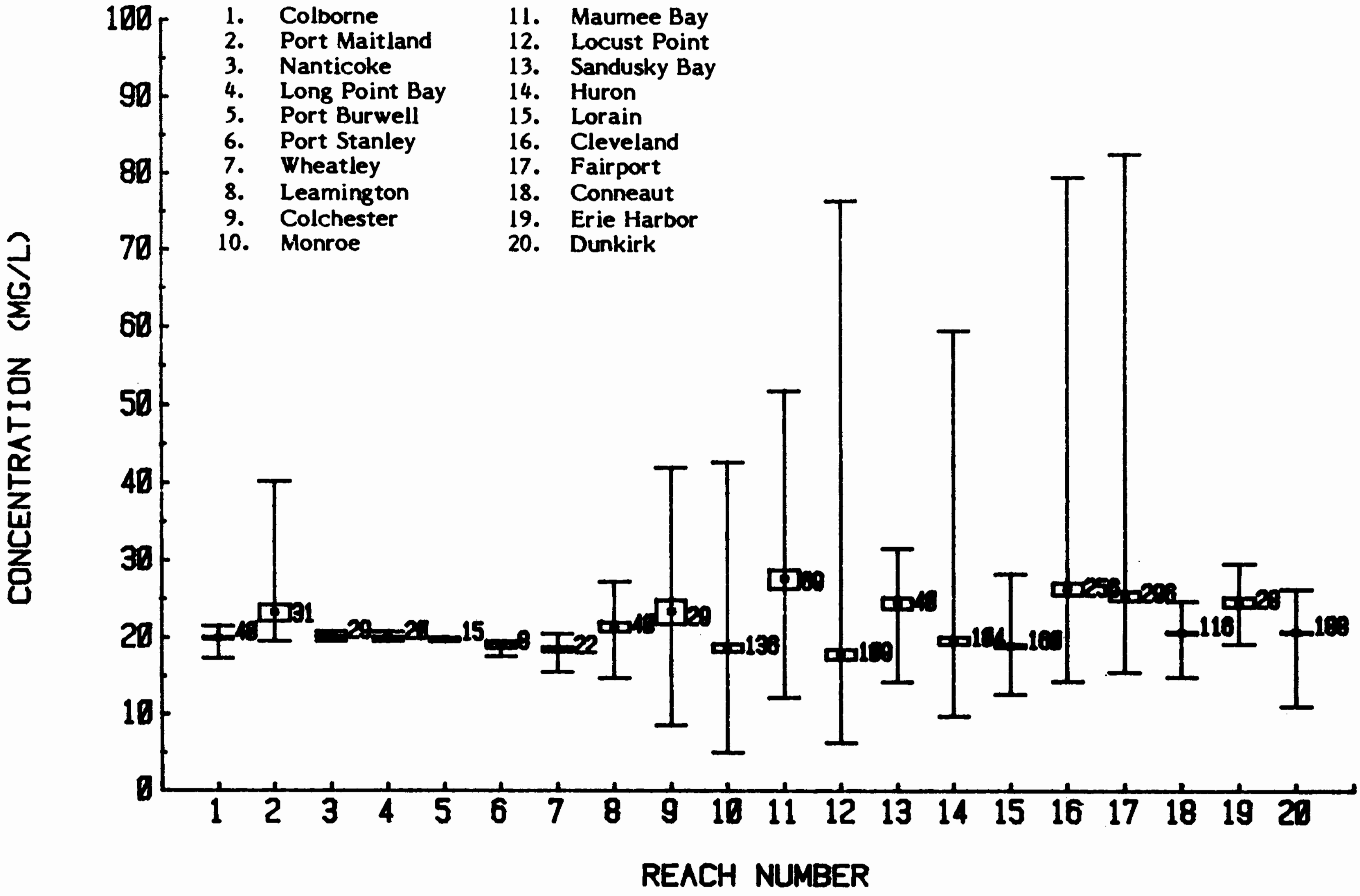


FIGURE 91. MEAN NEARSHORE REACH CONCENTRATIONS OF CHLORIDE FOR 1978 AND 1979.

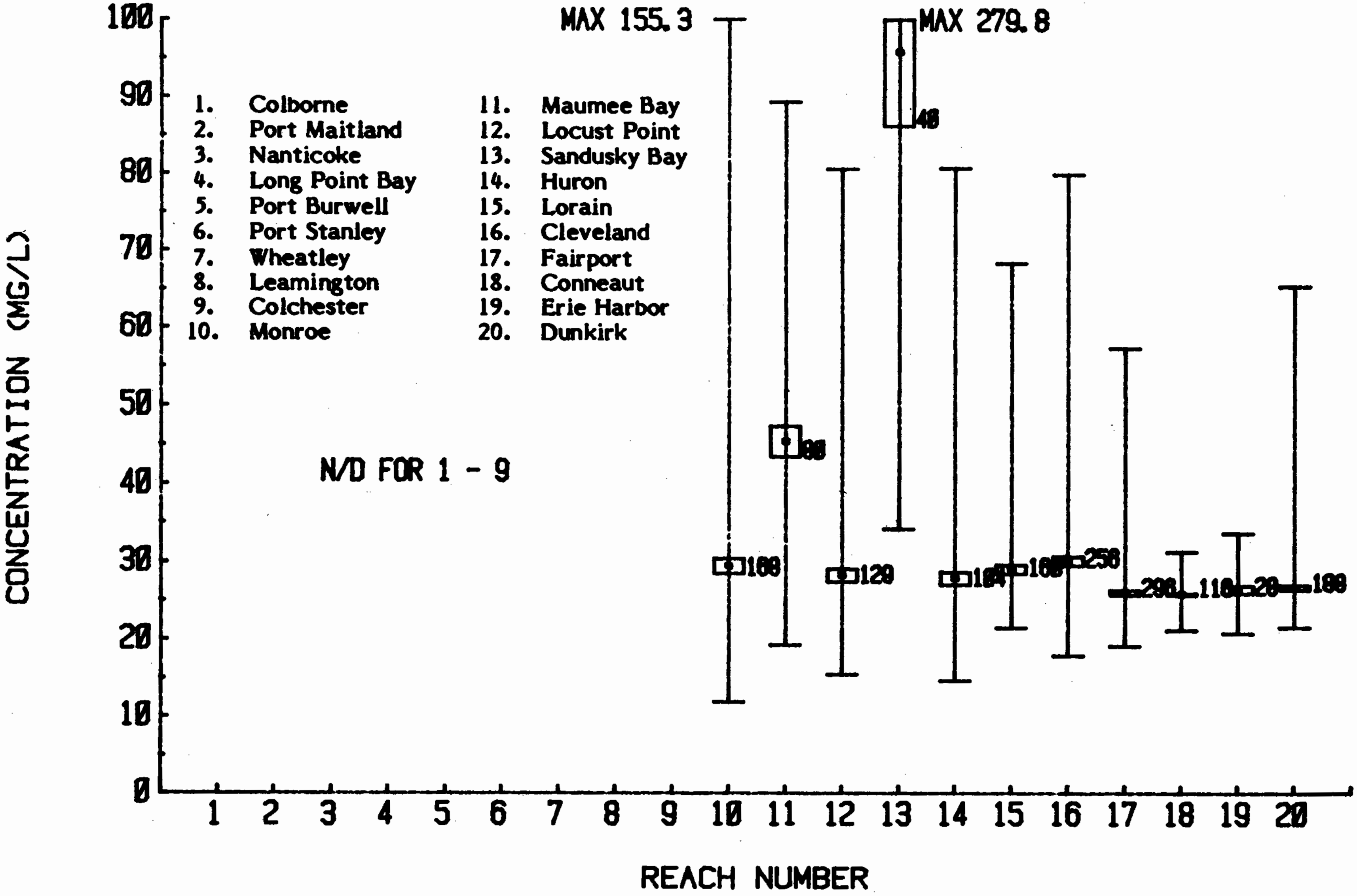


FIGURE 92. MEAN NEARSHORE REACH CONCENTRATIONS OF SULFATE FOR 1978 AND 1979.

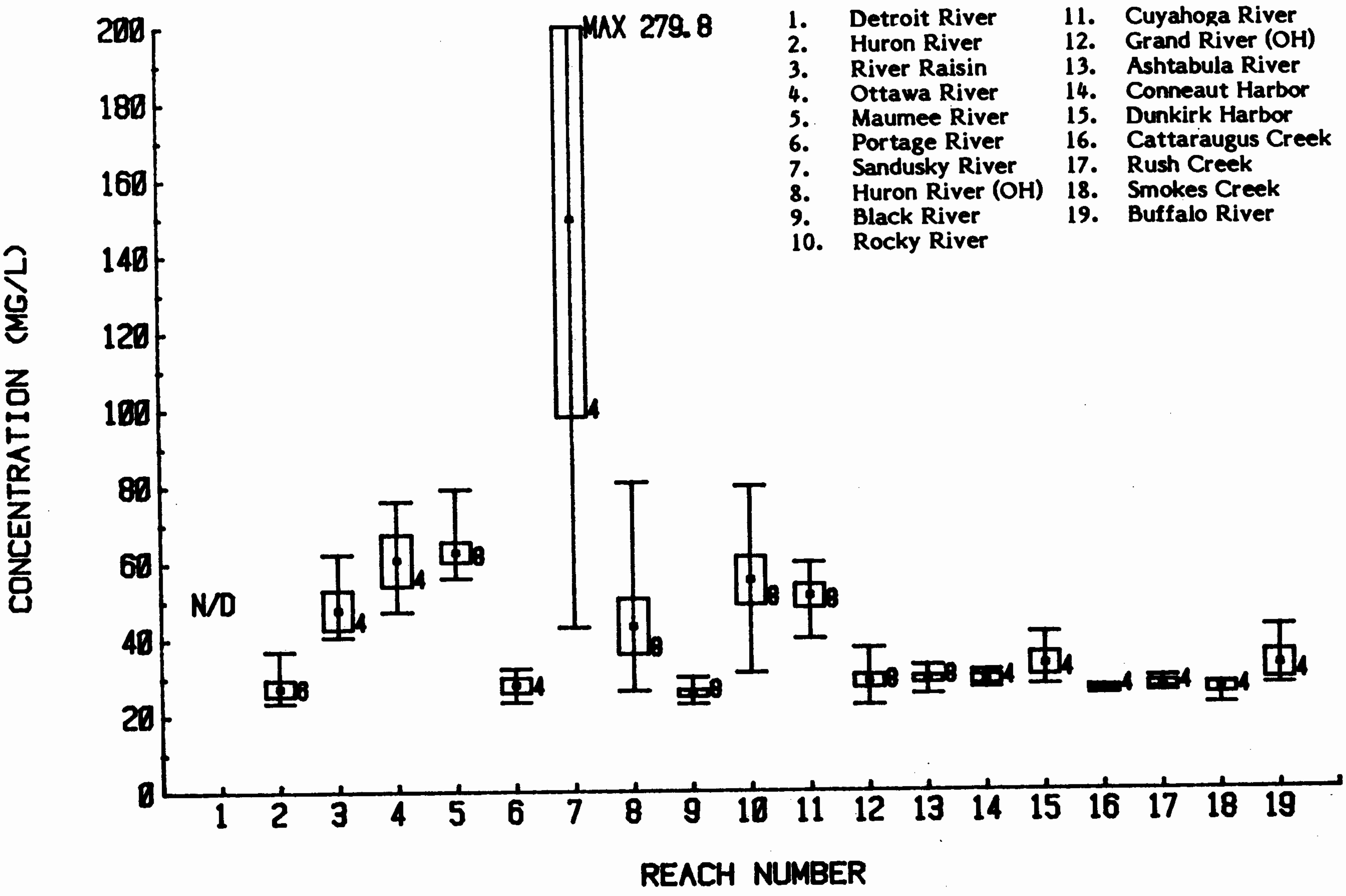
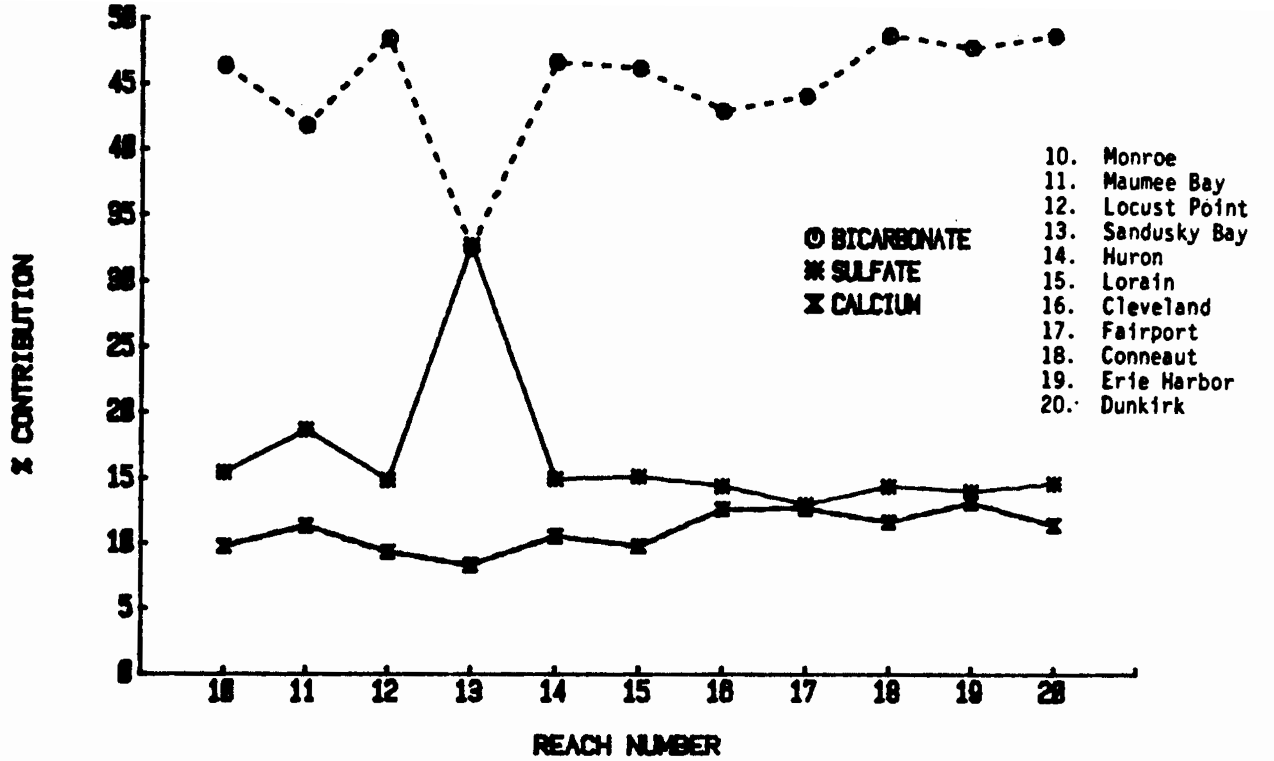


FIGURE 93. SOUTH SHORE RIVER AND HARBOR MEAN SULFATE CONCENTRATIONS SUMMARIZED FOR 1978 AND 1979.



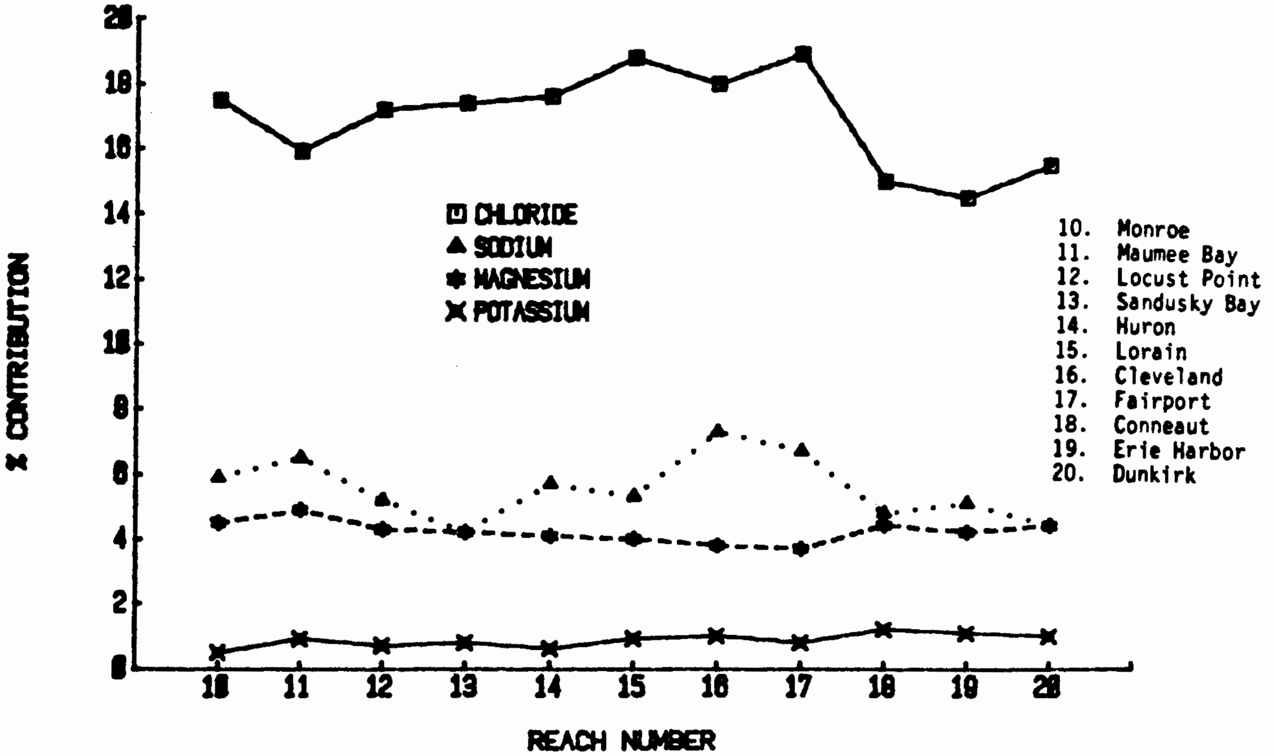


FIGURE 94. THE PERCENT CONTRIBUTION OF THE INDIVIDUAL PRINCIPAL IONS TO THE TOTAL CONDUCTANCE FOR EACH OF THE U.S. REACHES.

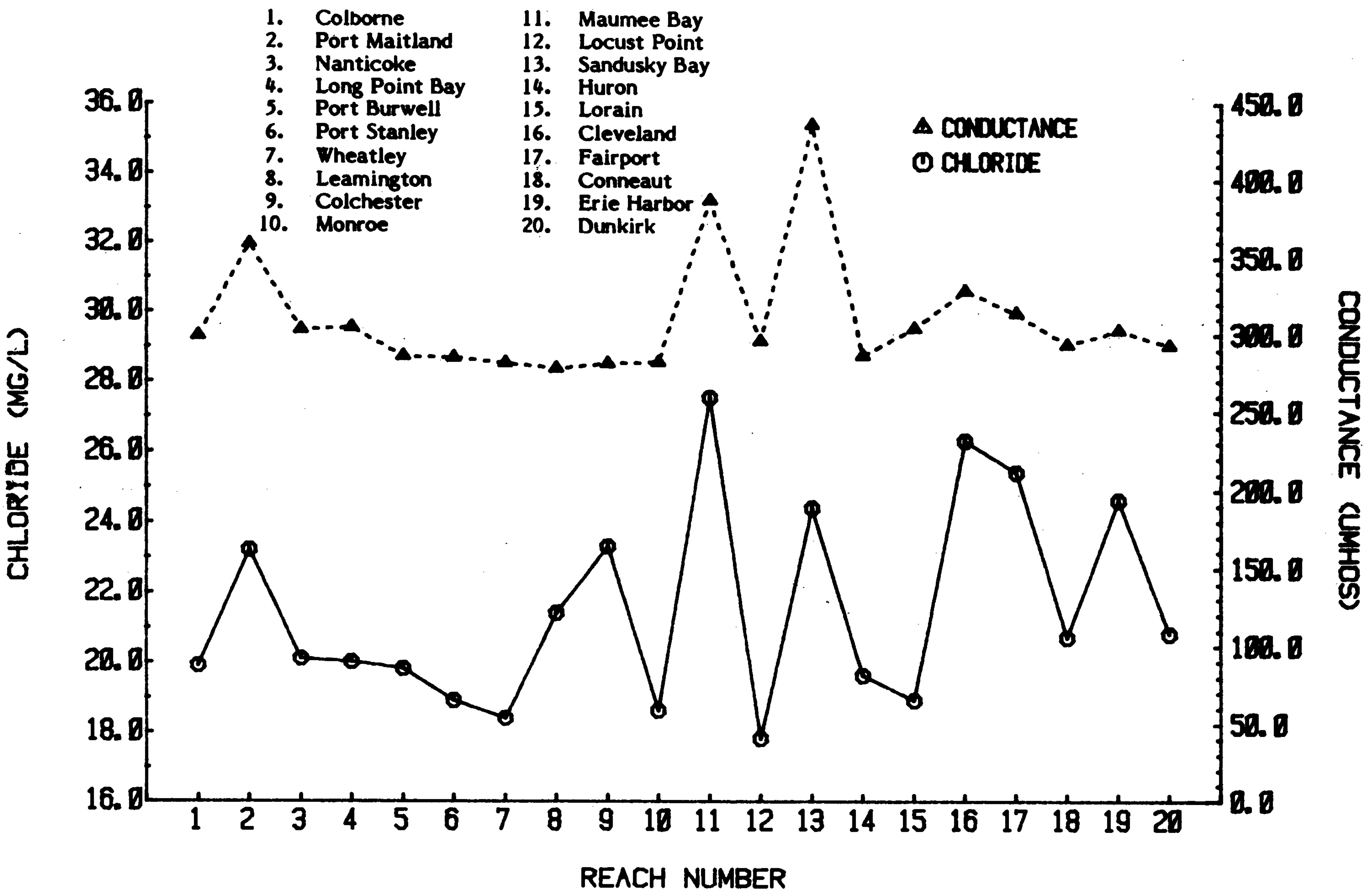


FIGURE 95. MEAN NEARSHORE REACH CHLORIDE CONCENTRATIONS AND CONDUCTIVITY VALUES FOR 1978 AND 1979.

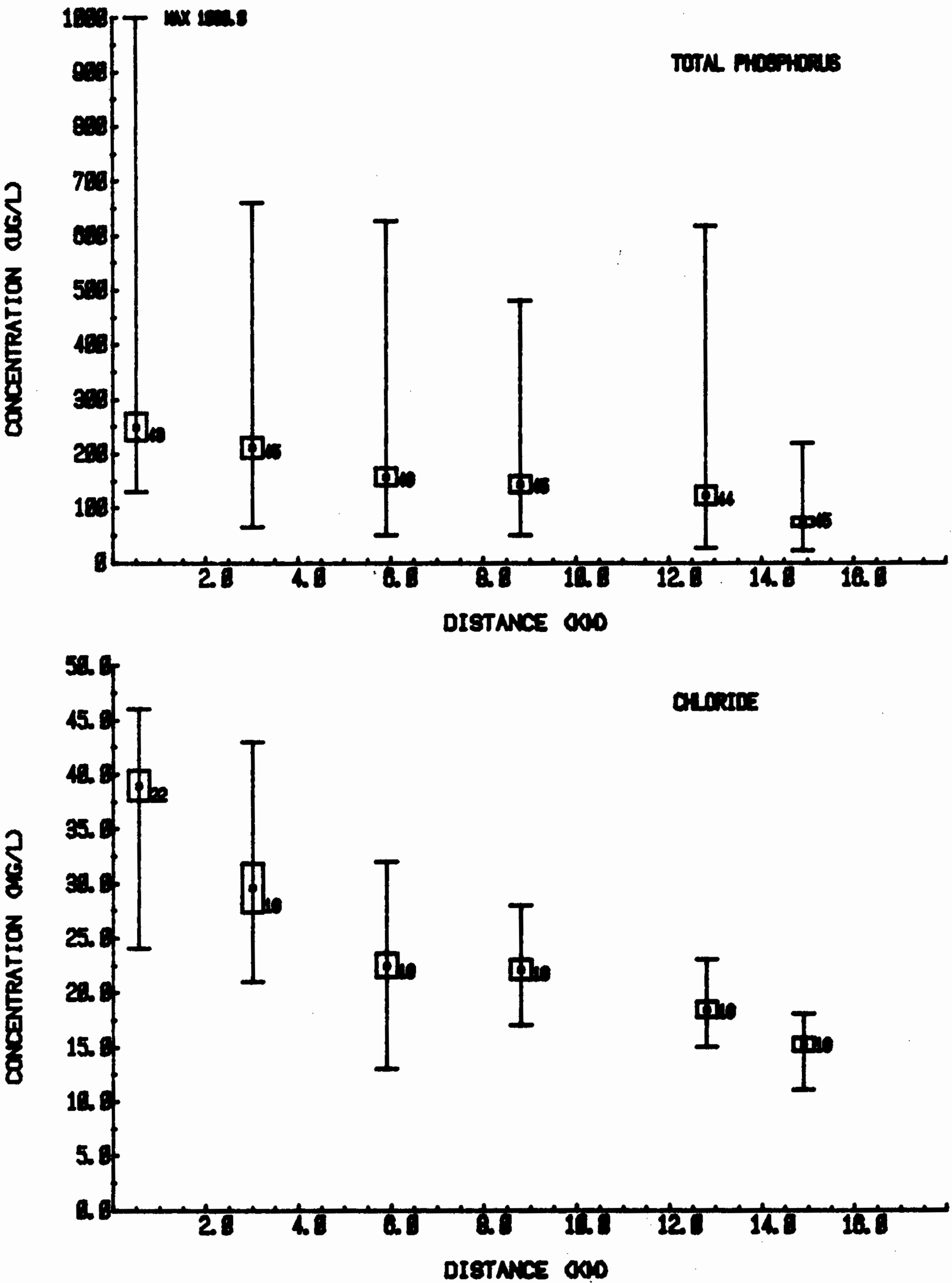


FIGURE 98. MEAN TOTAL PHOSPHORUS AND CHLORIDE CONCENTRATIONS FOR WESTERN BASIN TRANSECT 26 - MAUMEE BAY, 1978 - 1979.

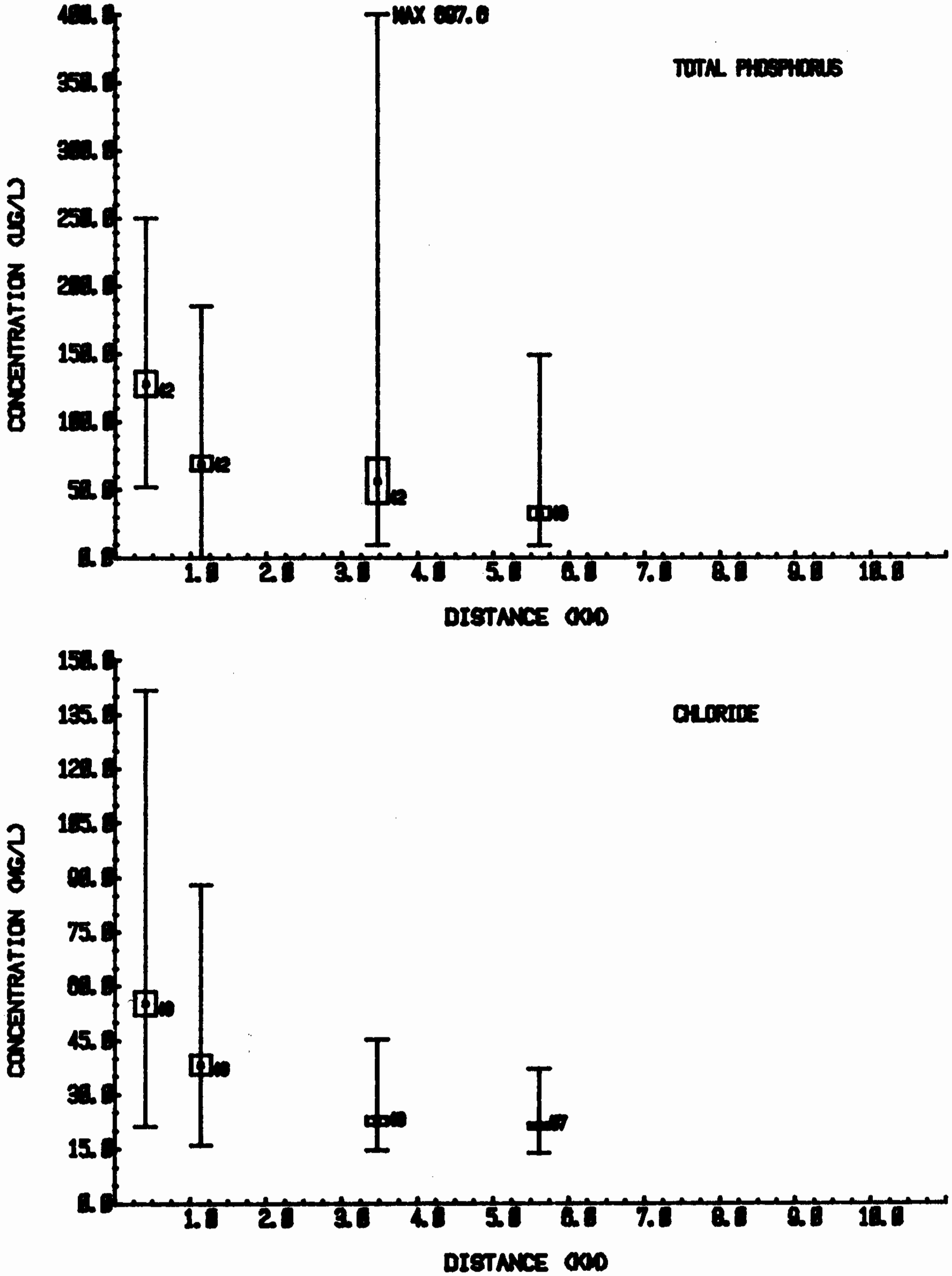


FIGURE 97. MEAN TOTAL PHOSPHORUS AND CHLORIDE CONCENTRATIONS FOR CENTRAL BASIN TRANSECT 34 - CUYAHOGA RIVER, 1978 - 1979.

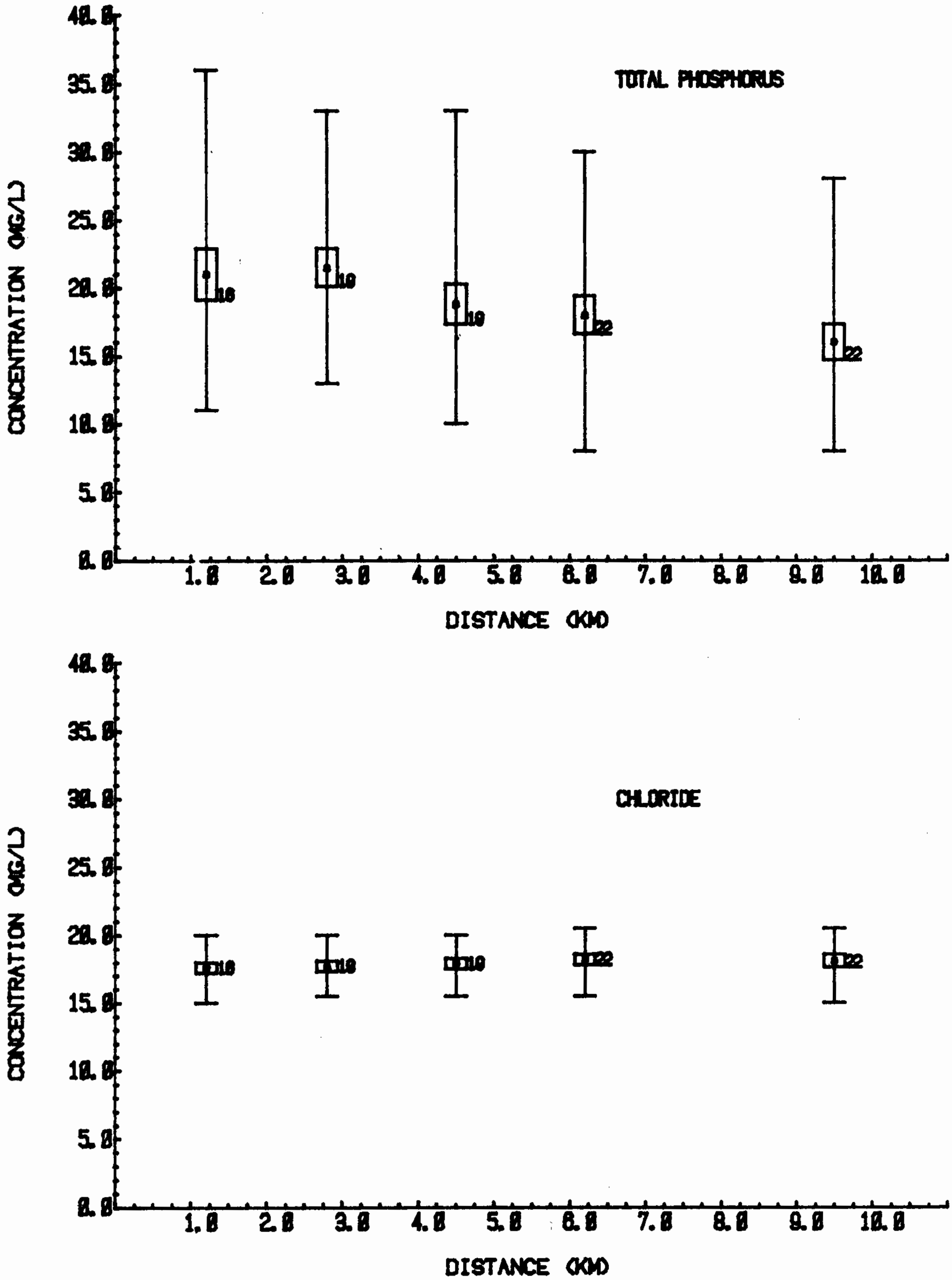


FIGURE 98. MEAN TOTAL PHOSPHORUS AND CHLORIDE CONCENTRATIONS FOR CENTRAL BASIN TRANSECT 16 - WHEATLEY HARBOR, 1978.

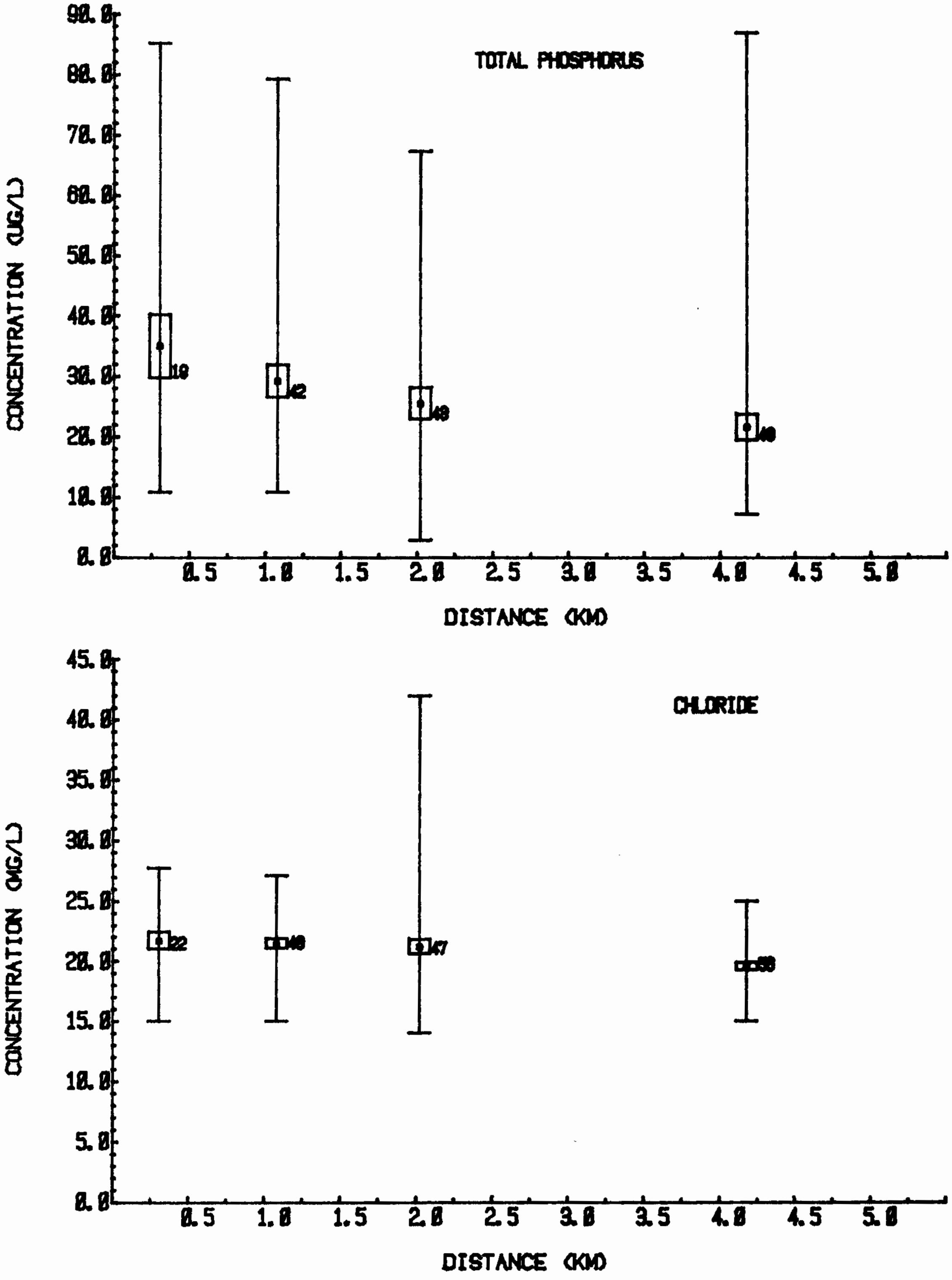


FIGURE 99. MEAN TOTAL PHOSPHORUS AND CHLORIDE CONCENTRATIONS FOR CENTRAL BASIN TRANSECT 39 - ASHTABULA RIVER, 1978 - 1979.

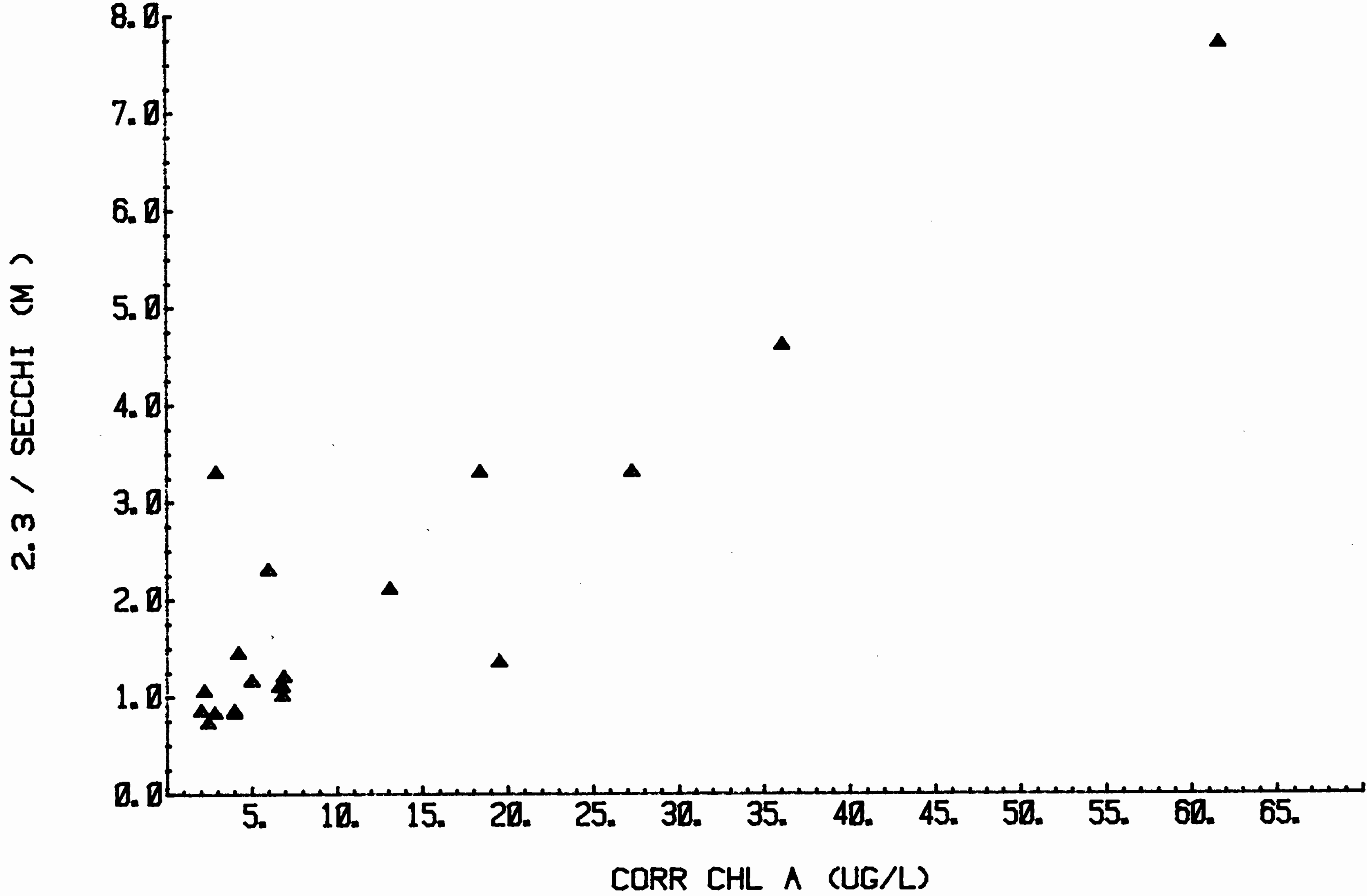


FIGURE 100. SECCHI DEPTH AND CORRECTED CHLOROPHYLL A RELATIONSHIP FOR THE NEARSHORE REACHES 1978 AND 1979.

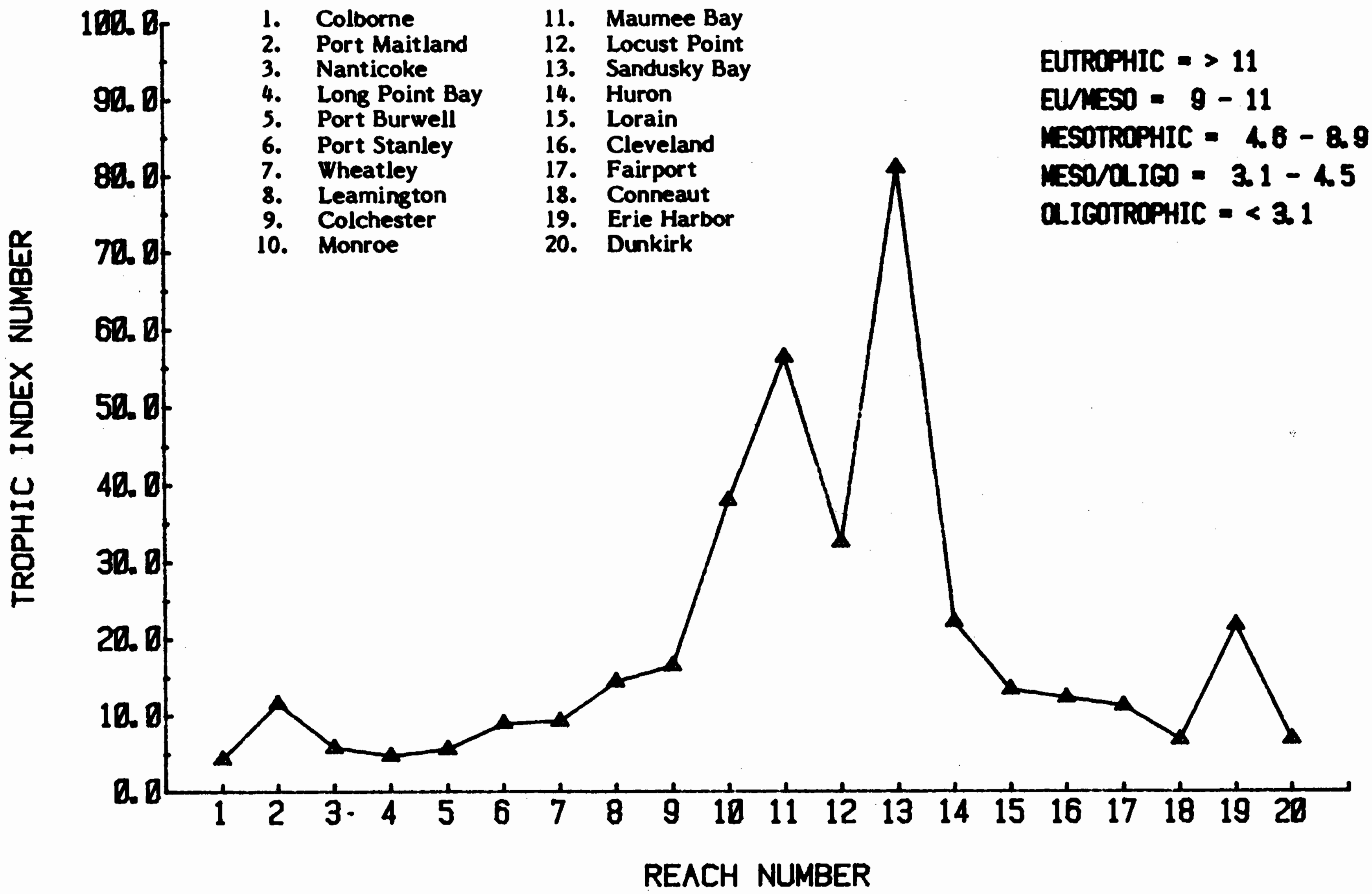
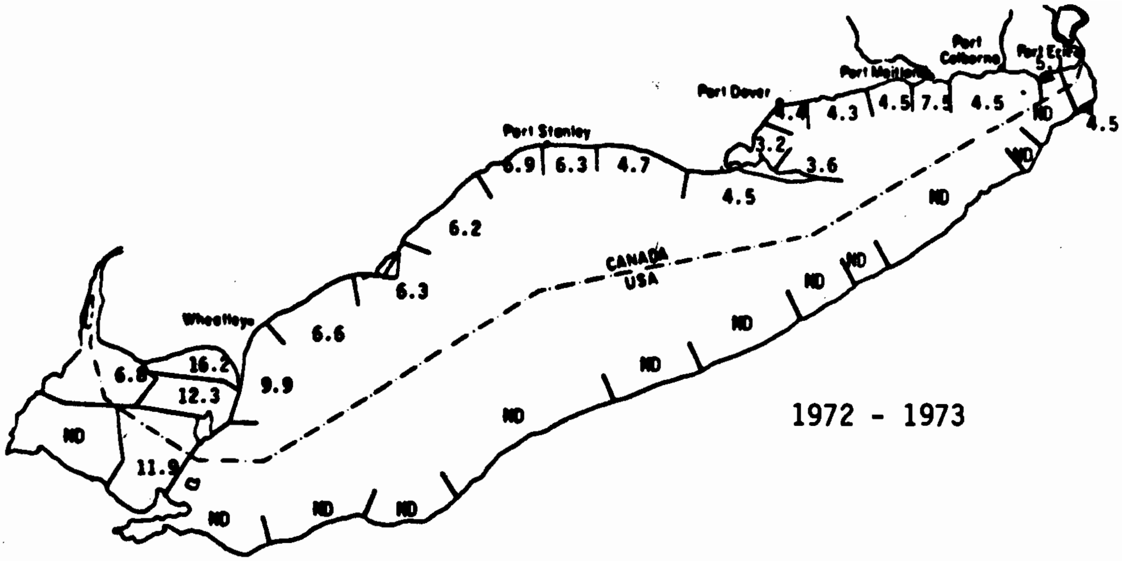


FIGURE 101. ANNUAL MEAN COMPOSITE TROPHIC INDEX FOR THE NEARSHORE REACHES 1978 AND 1979.



eutrophic ≥ 11

eu/mesotrophic 9 - 11

mesotrophic 4.6 - 8.9

meso/oligotrophic 3.1 - 4.5

oligotrophic ≥ 3.1

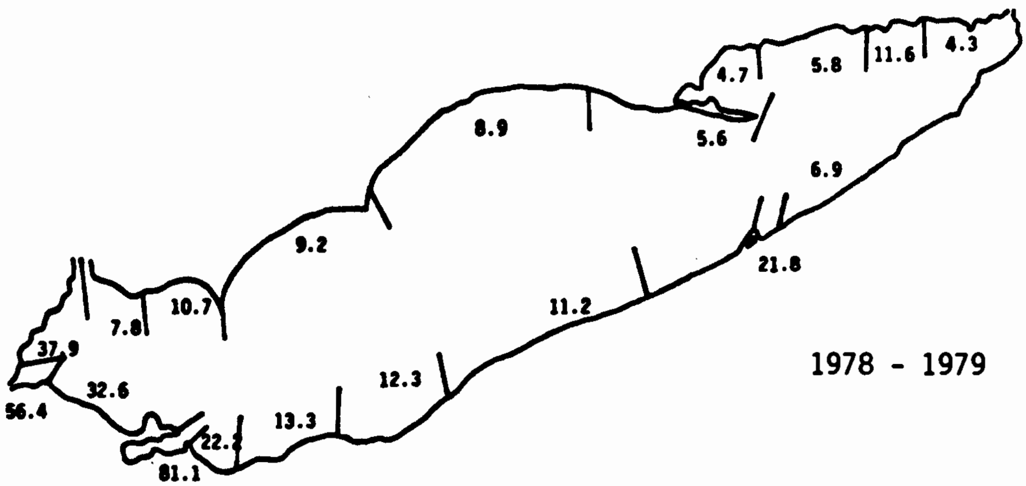
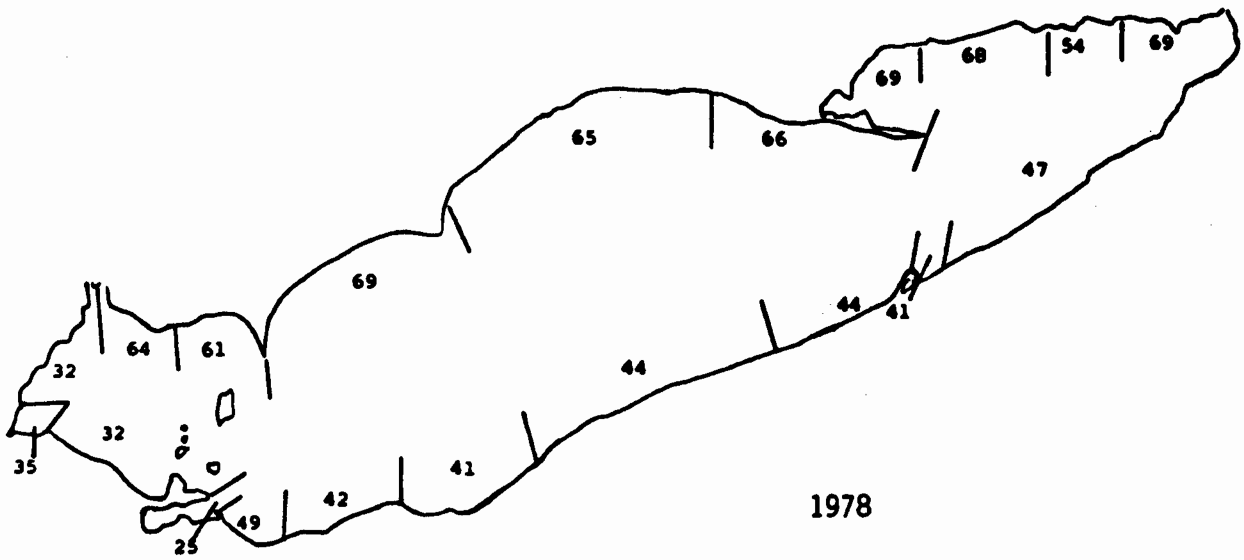


FIGURE 102. COMPOSITE TROPHIC INDEX NUMBERS FOR THE SUMMER MEAN 1972-1973 AND THE ANNUAL MEAN FOR 1978-1979.



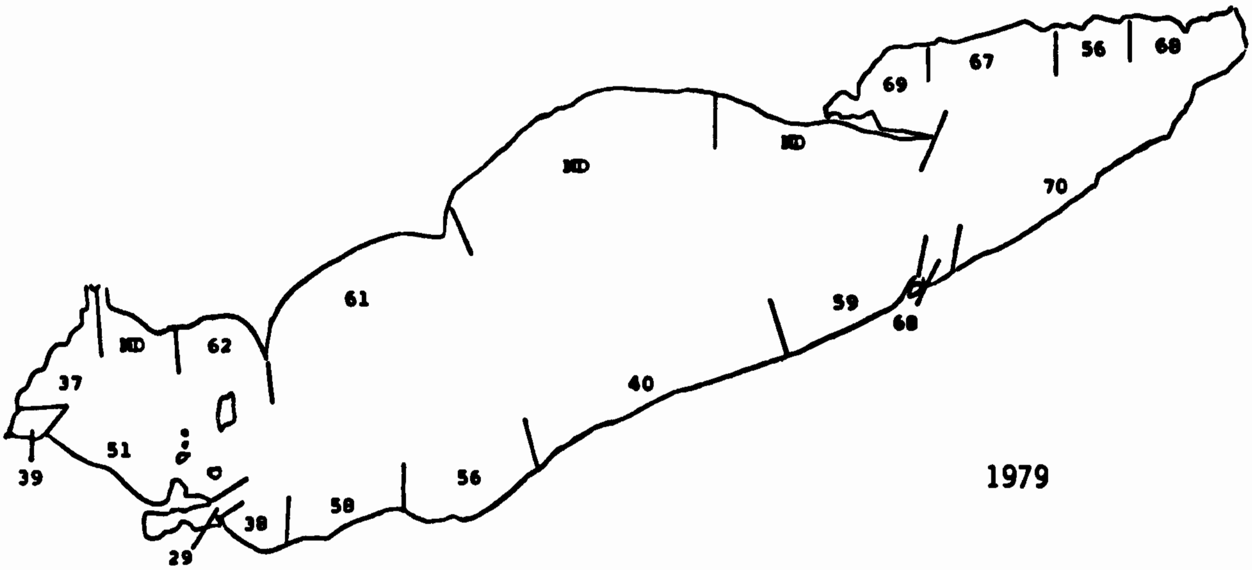


FIGURE 103. STEINHART WATER QUALITY INDEX NUMBERS FOR THE NEARSHORE REACHES 1978 AND 1979.

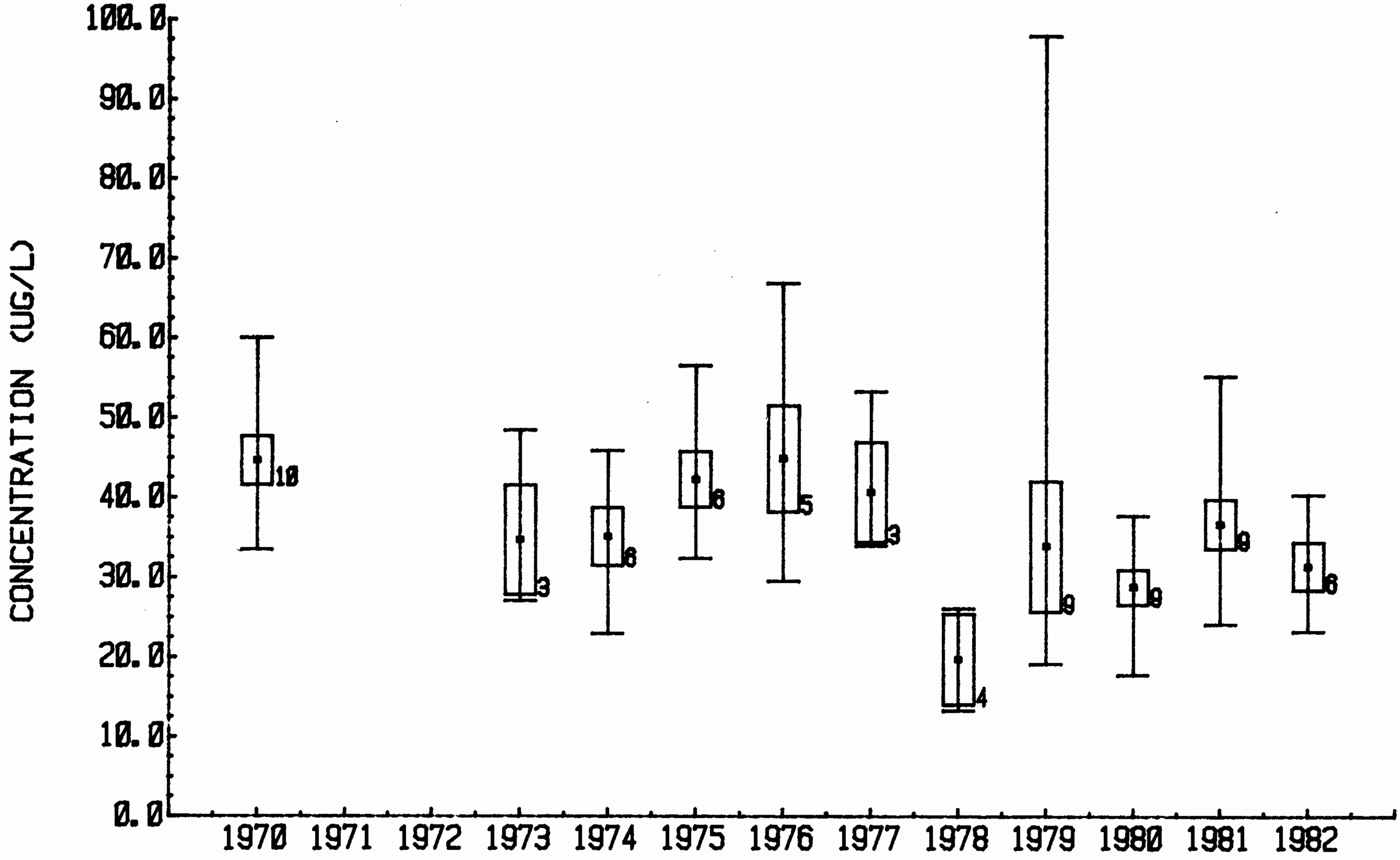
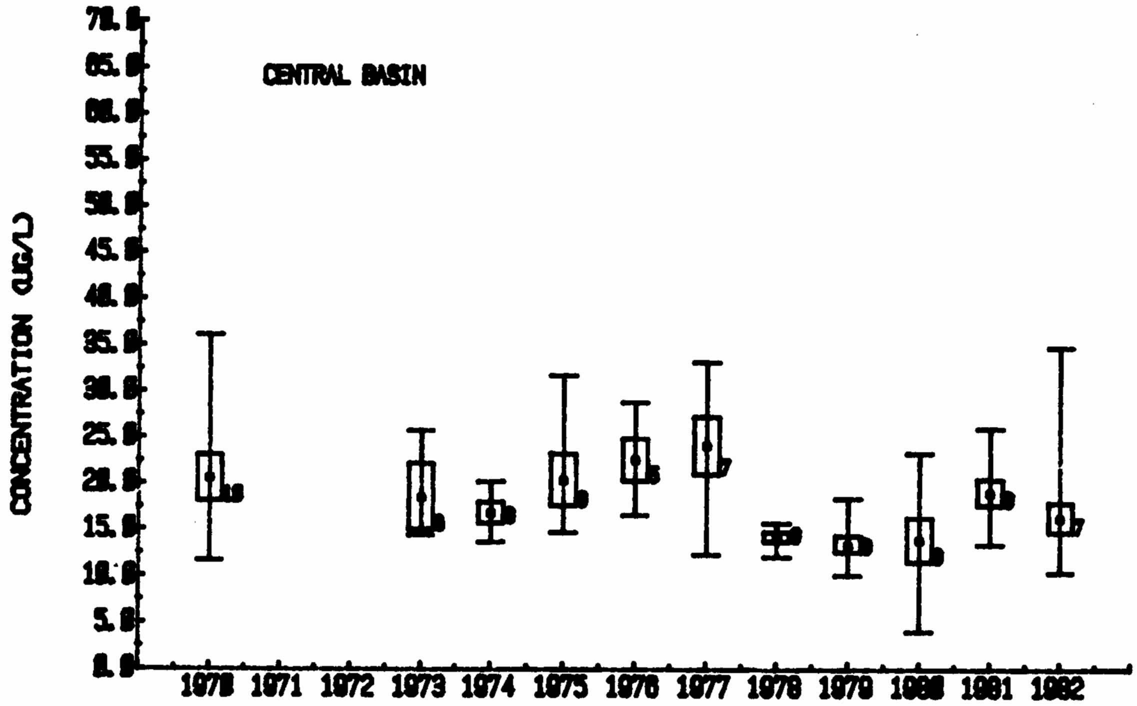


FIGURE 104. WESTERN BASIN ANNUAL CRUISE MEAN CONCENTRATIONS OF TOTAL PHOSPHORUS FOR 1970 - 1982.



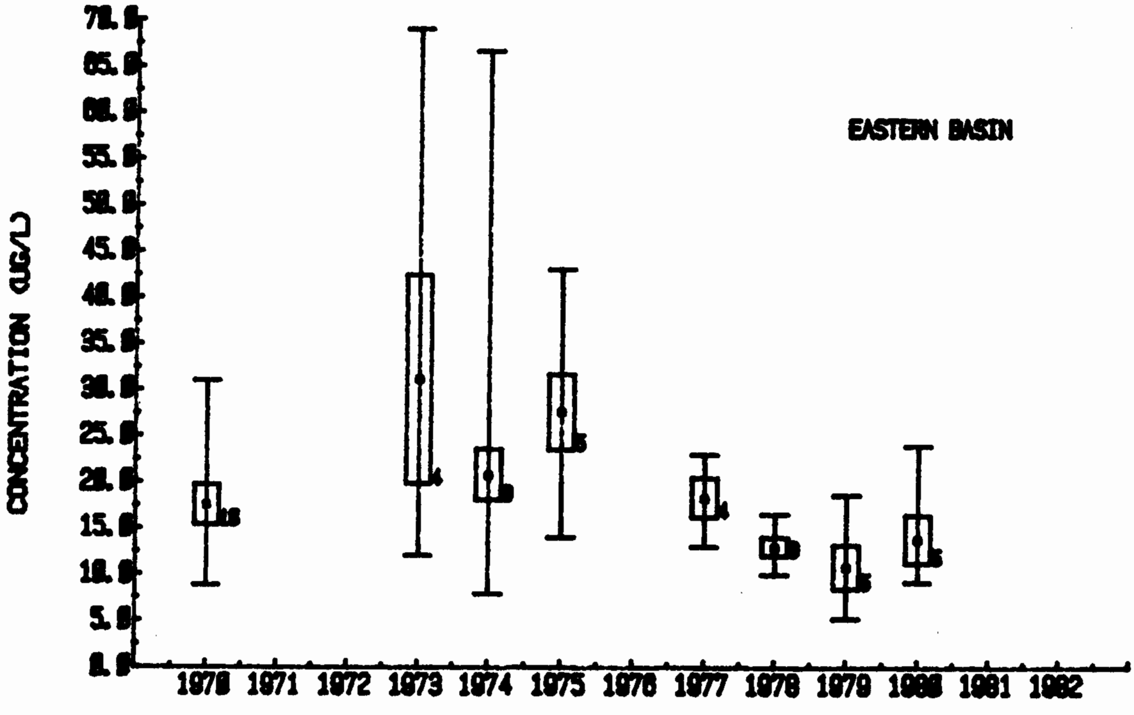


FIGURE 105. CENTRAL AND EASTERN BASIN ANNUAL CRUISE MEAN CONCENTRATION OF TOTAL PHOSPHORUS FOR 1970 - 1982.

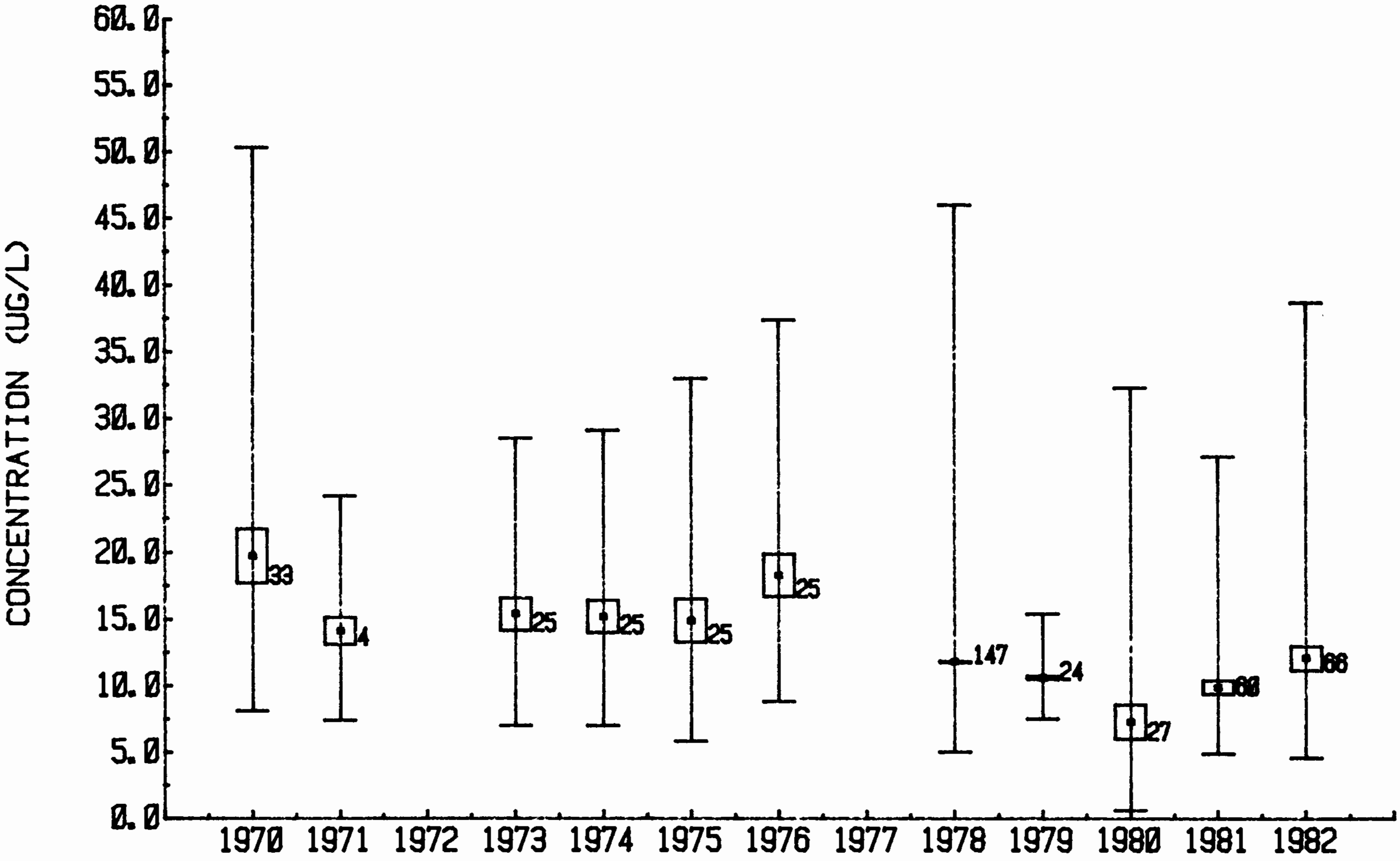


FIGURE 106. EARLY SUMMER MEAN CENTRAL BASIN EPILIMNION TOTAL PHOSPHORUS CONCENTRATIONS FOR 1970 - 1982.

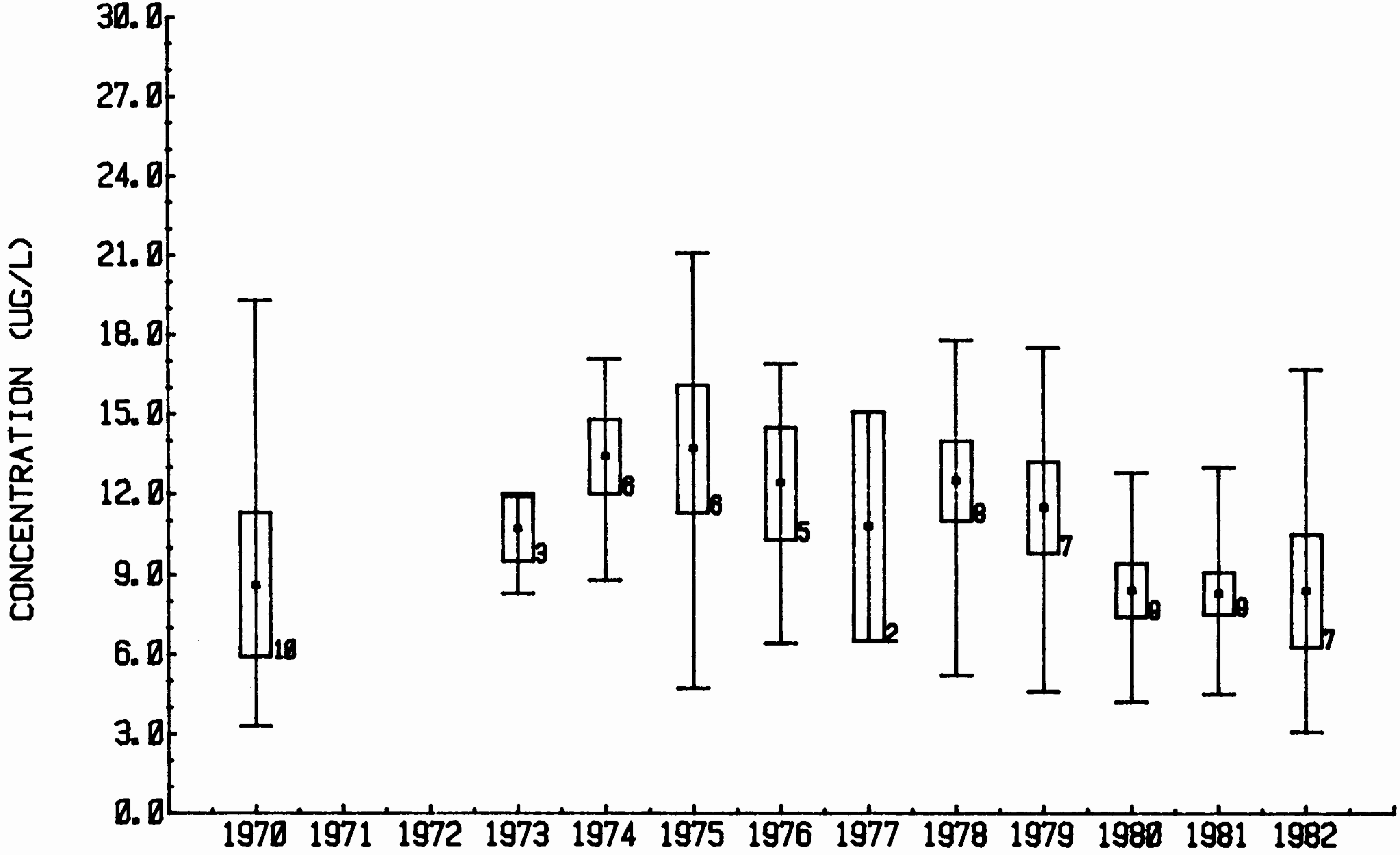
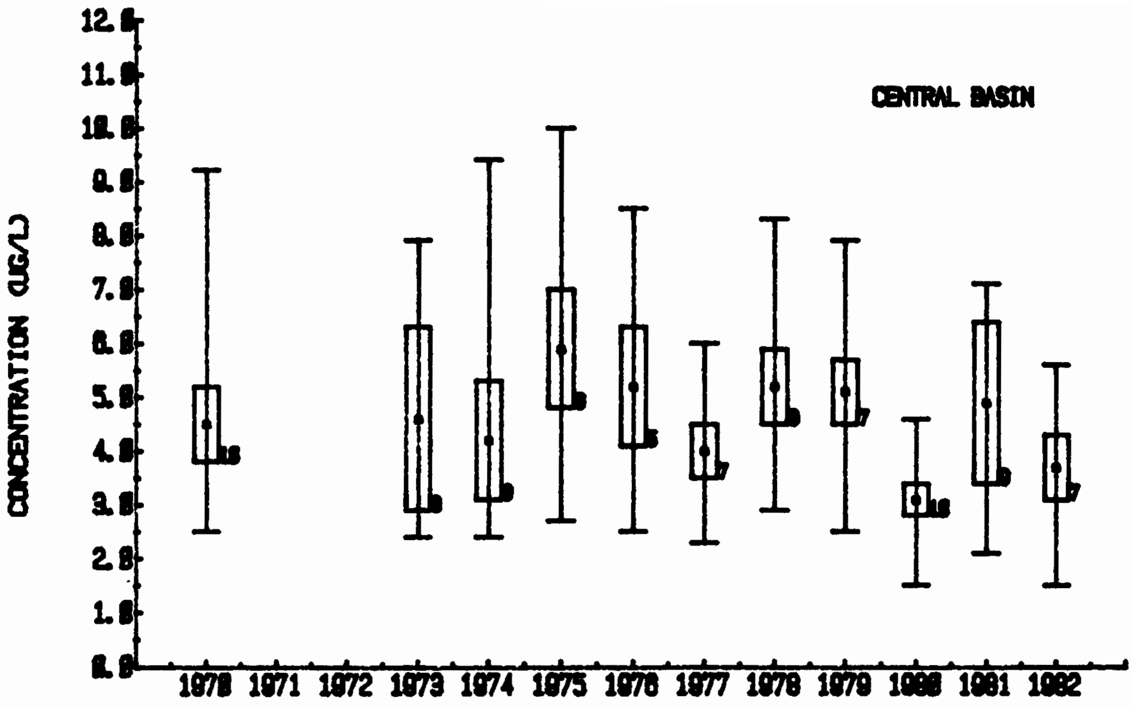


FIGURE 107. WESTERN BASIN ANNUAL CRUISE MEAN CONCENTRATIONS OF CORRECTED CHLOROPHYLL A FOR 1970 - 1982.



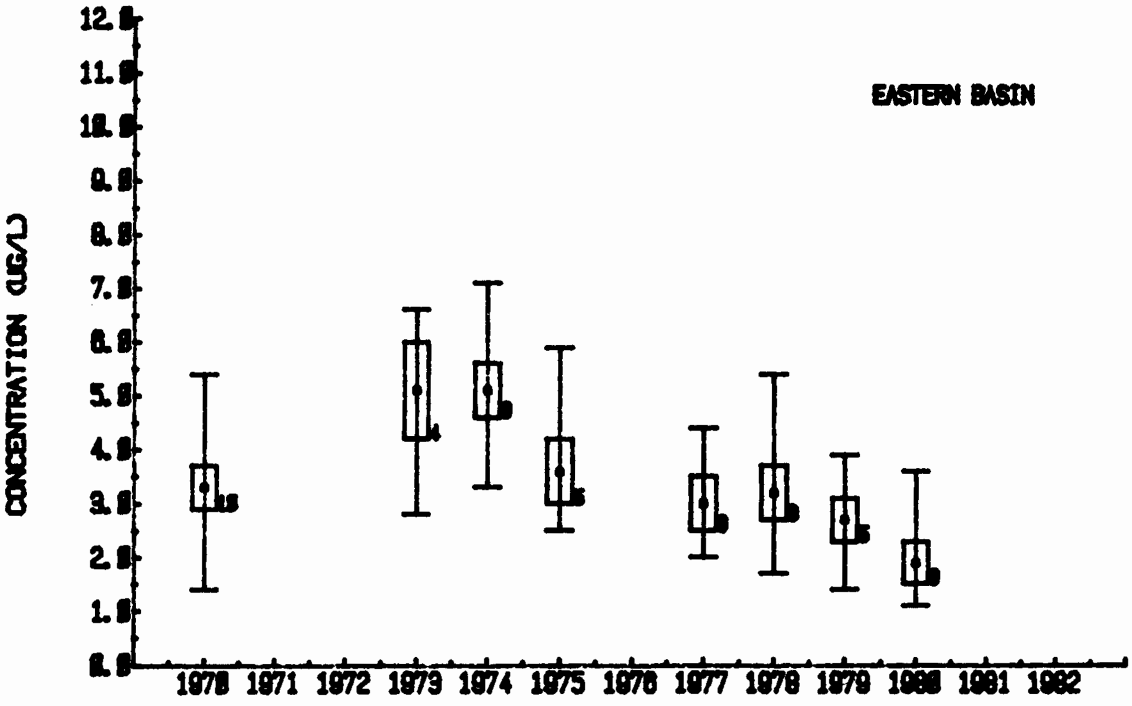


FIGURE 108. CENTRAL AND EASTERN BASIN ANNUAL CRUISE MEAN CONCENTRATIONS OF CORRECTED CHLOROPHYLL A FOR 1970 - 1982.

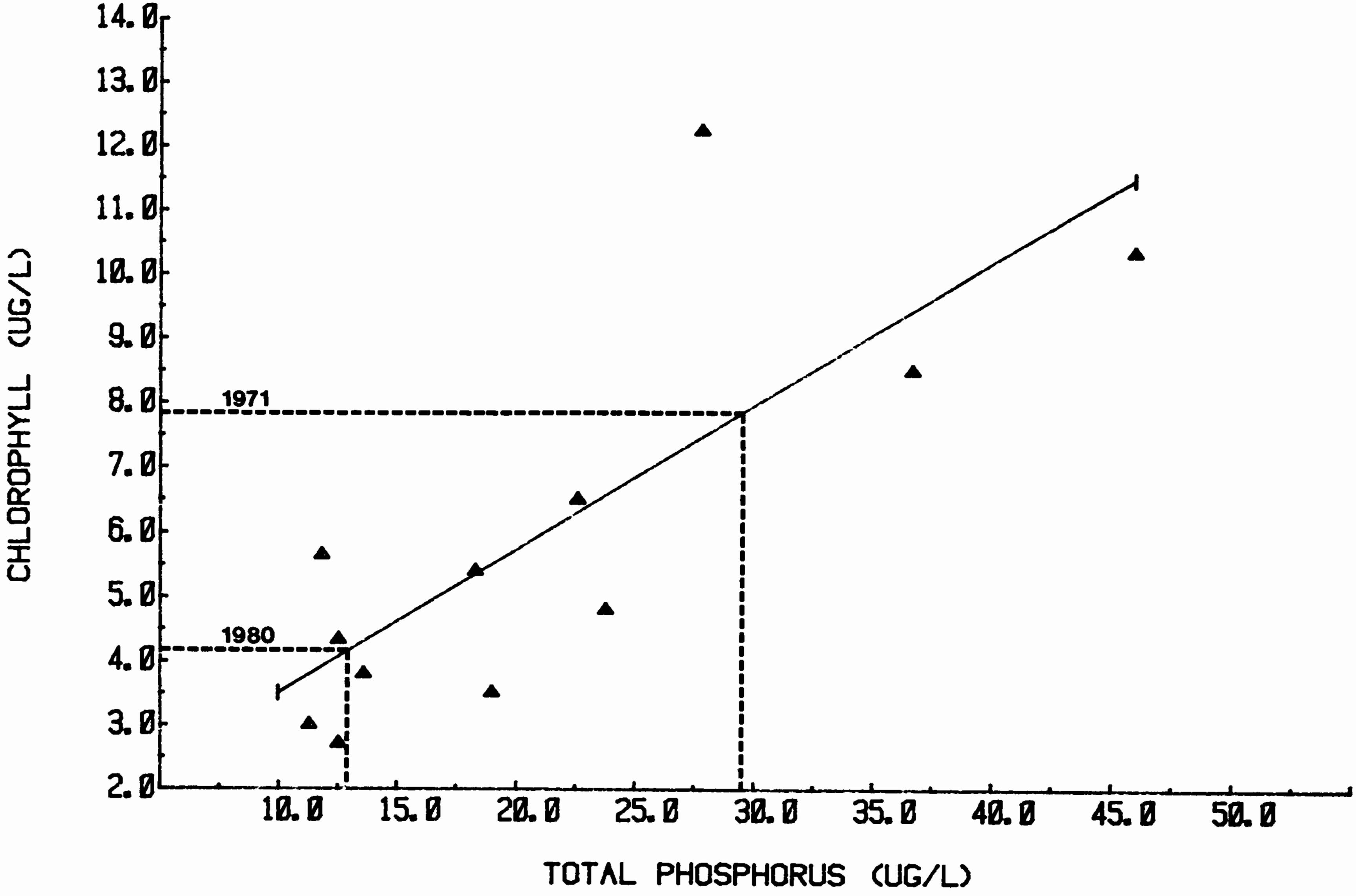


FIGURE 109. RELATIONSHIP BETWEEN YEARLY TOTAL PHOSPHORUS AND CHLOROPHYLL A CONCENTRATIONS CORRECTED FOR SPATIAL AND SEASONAL EFFECTS FROM EL-SHAARAWI (1983).

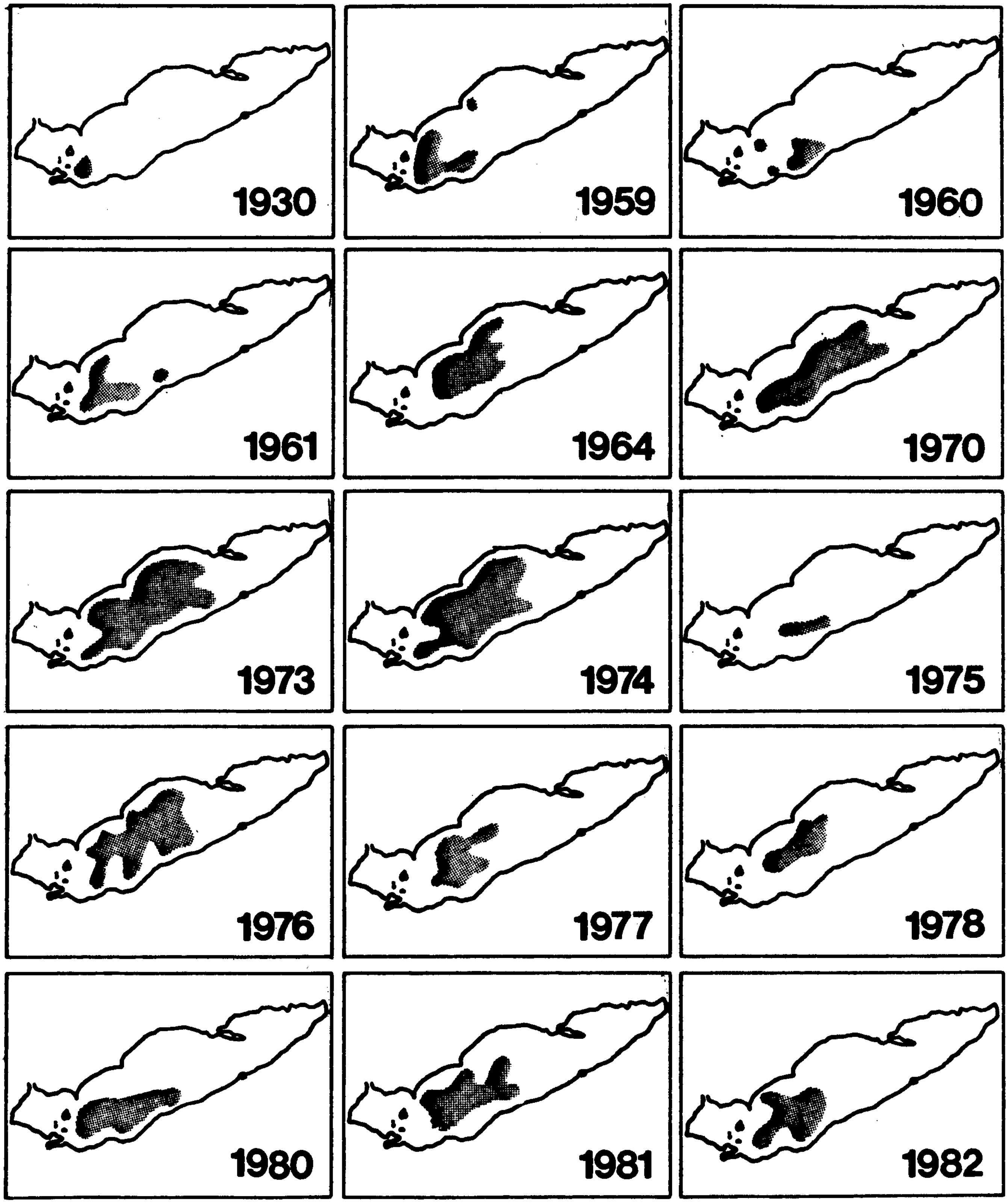


FIGURE 110. COMPOSITE ANOXIC AREA OF THE CENTRAL BASIN FOR THE PERIOD FROM 1930 TO 1982.

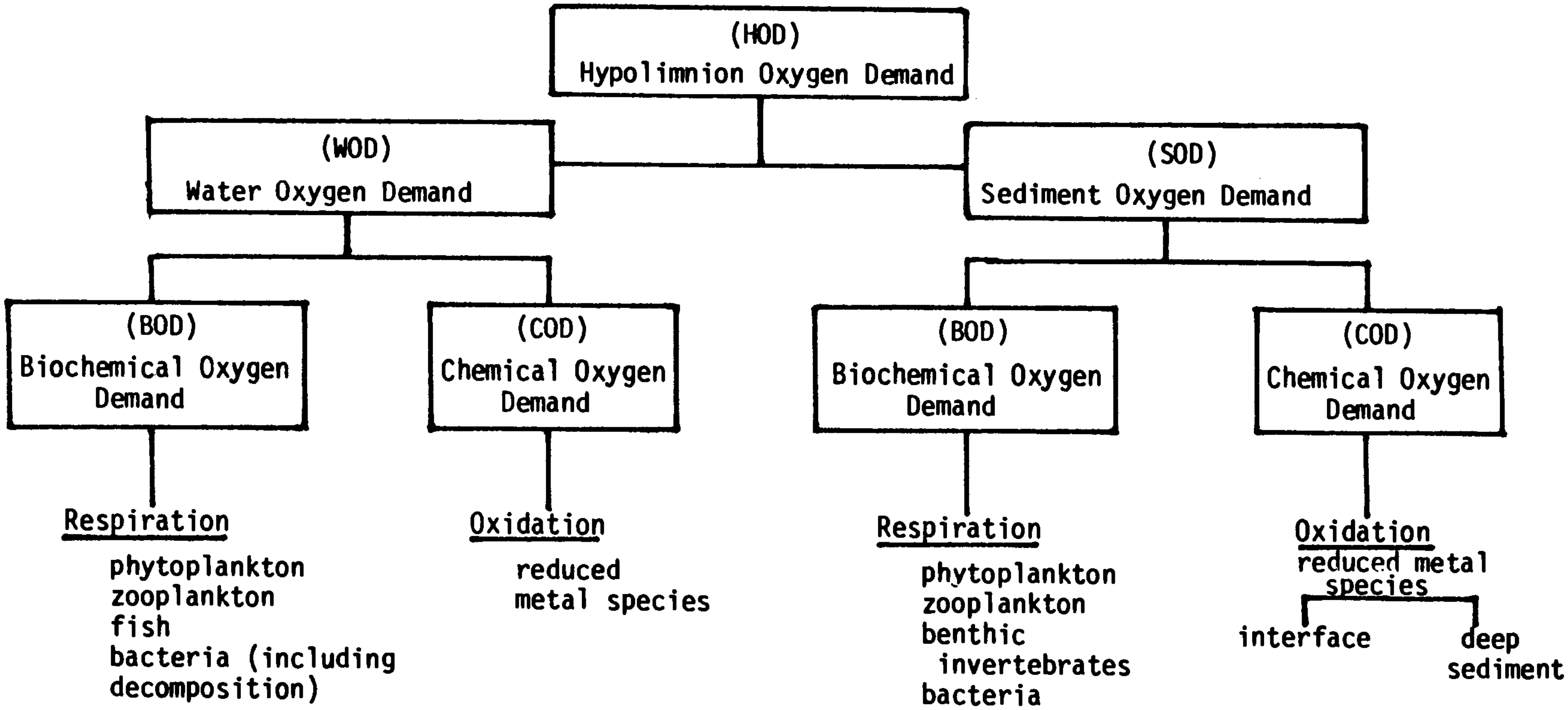


FIGURE 111. SCHEMATIC OF THE COMPONENTS AND PROCESSES OF HYPOLIMNION OXYGEN DEMAND.

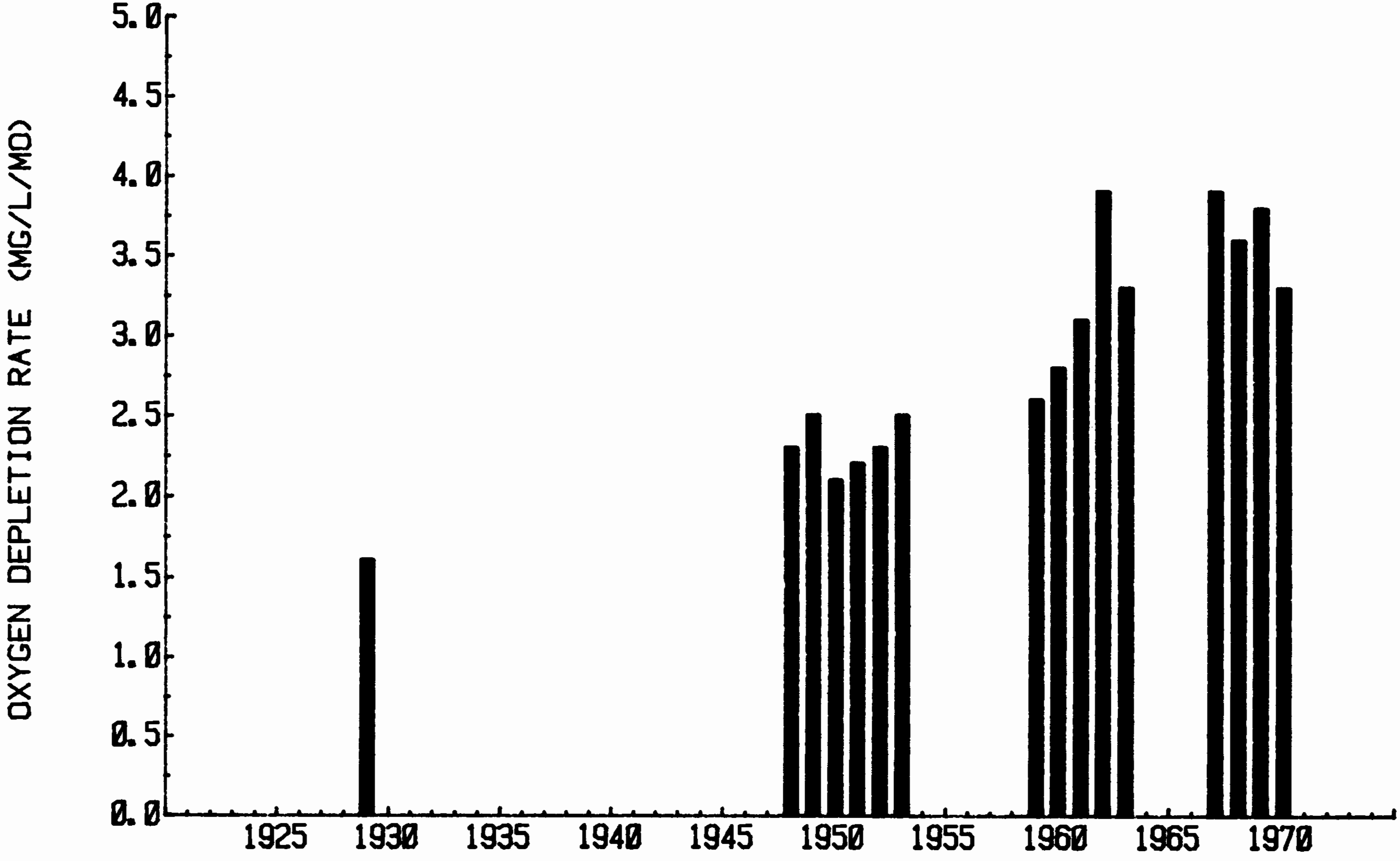


FIGURE 112. CENTRAL BASIN HYPOLIMNION OXYGEN DEPLETION RATES AS REPORTED BY DOBSON AND GILBERTSON, 1971.

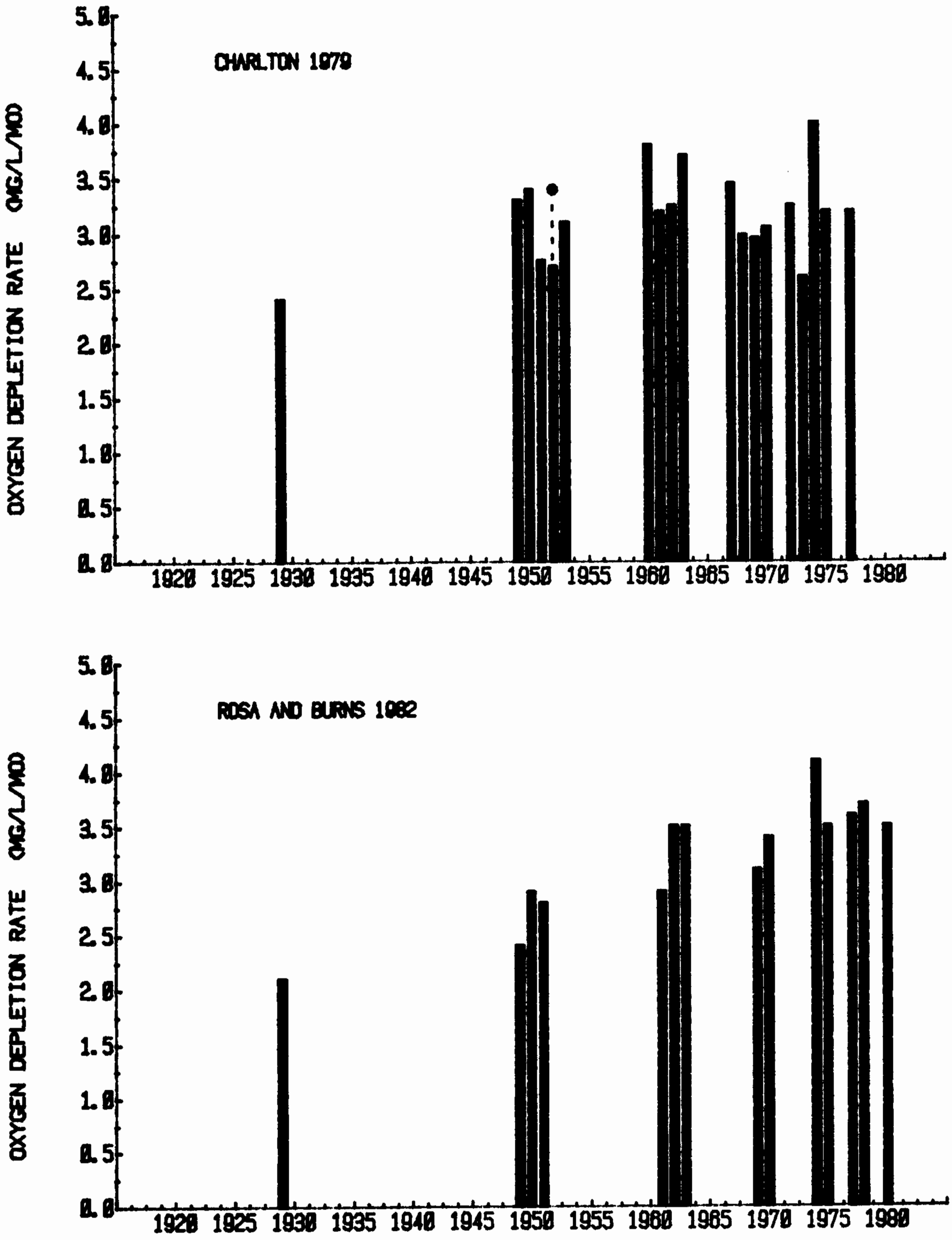


FIGURE 113. CENTRAL BASIN HYPOLIMNION OXYGEN DEPLETION RATES AS REPORTED BY CHARLTON (1979) AND ROSA AND BURNS (1982).

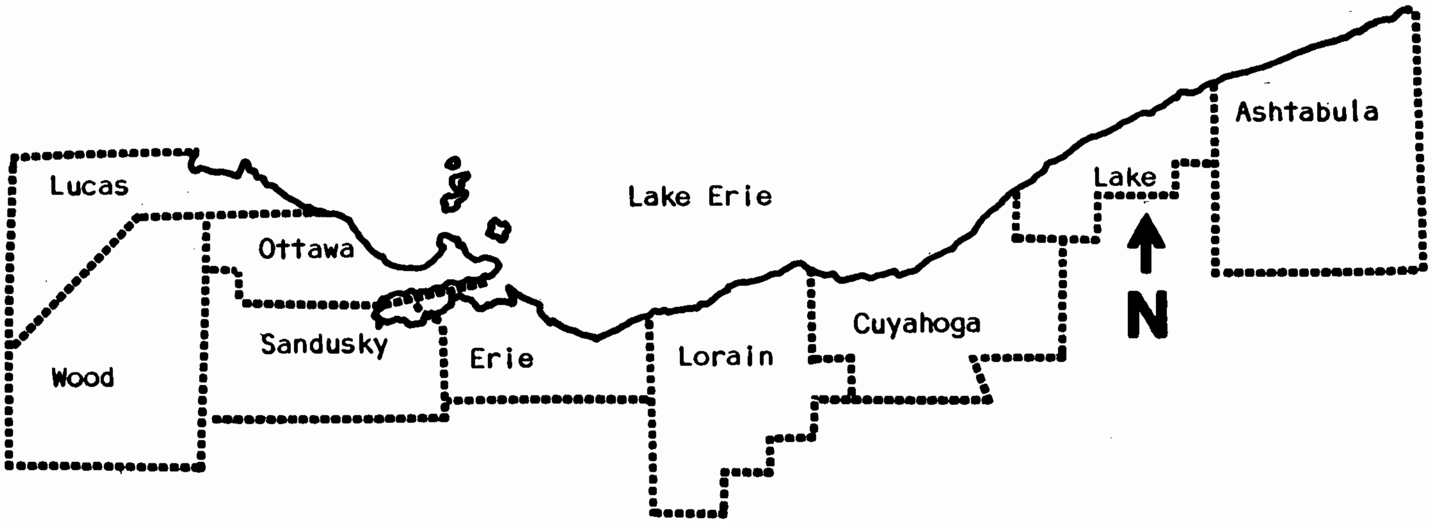
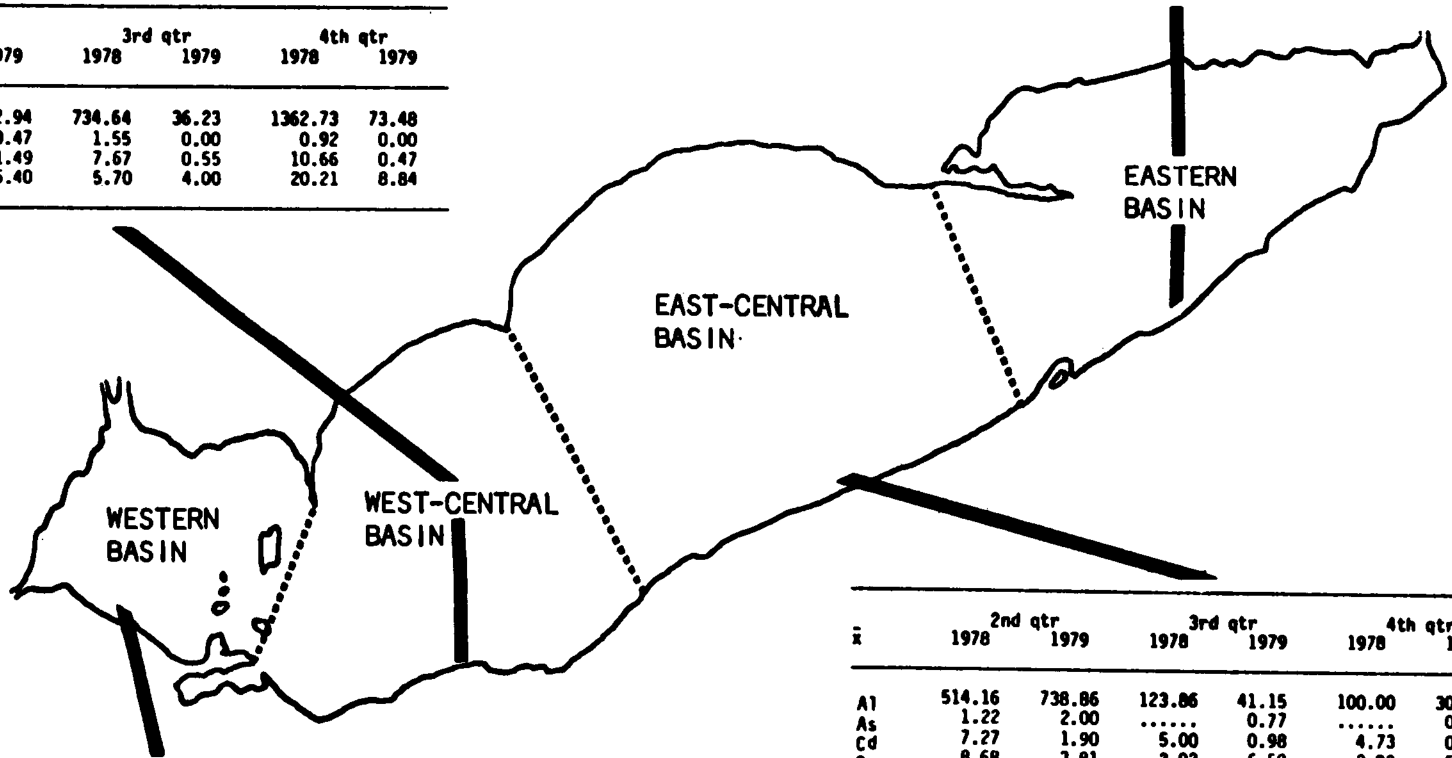


FIGURE 114. SHORELINE COUNTIES OF OHIO UTILIZED IN TABULATING NEARSHORE WATER QUALITY VIOLATIONS.

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Al	251.26	83.06	149.43	39.11	100.00	12.33
As	......	2.00	......	2.00	......	2.00
Cd	4.96	1.38	4.33	1.09	5.00	1.40
Cr	3.52	2.62	2.68	1.58	2.00	3.80

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Al	996.54	302.94	734.64	36.23	1362.73	73.48
As	2.29	0.47	1.55	0.00	0.92	0.00
Cd	5.36	1.49	7.67	0.55	10.66	0.47
Cr	9.30	6.40	5.70	4.00	20.21	8.84



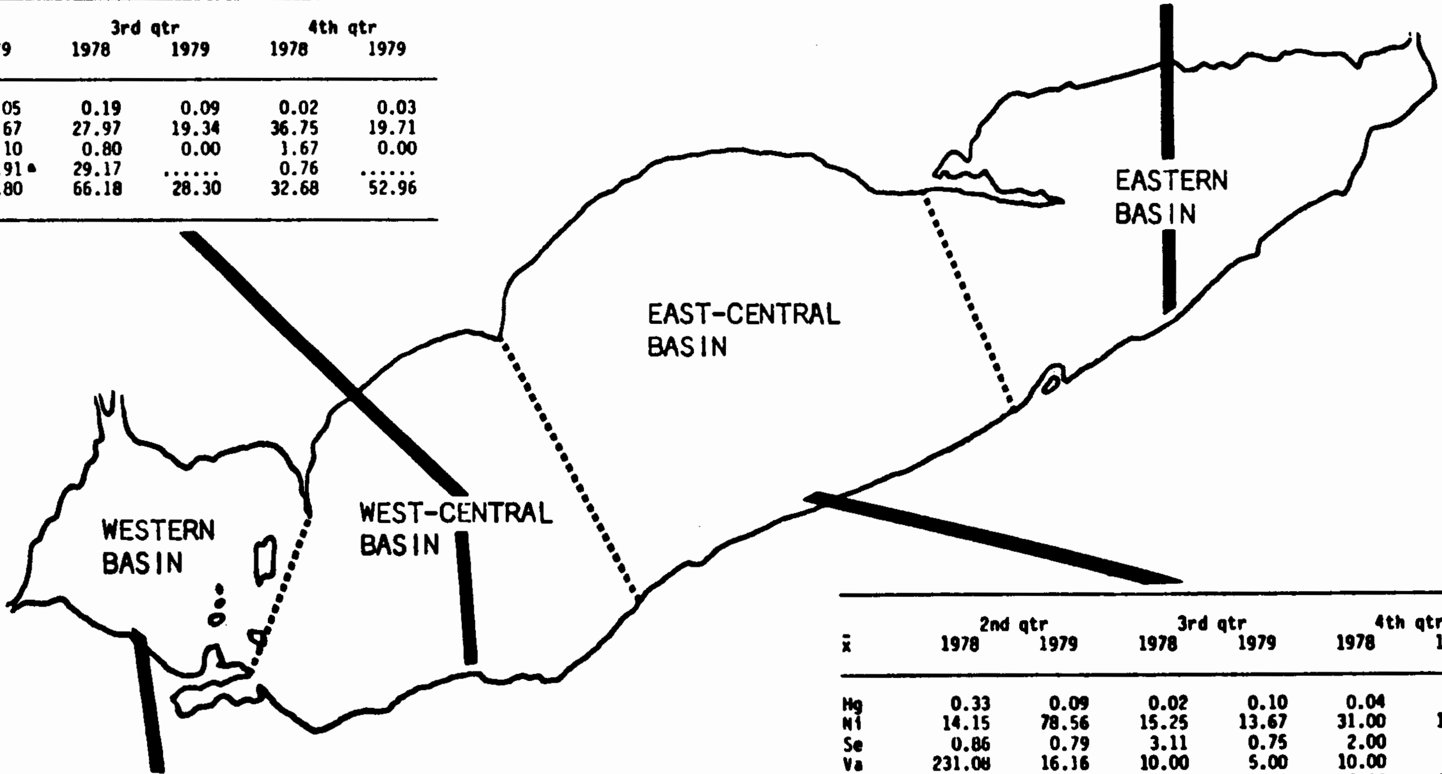
$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Al	514.16	738.86	123.86	41.15	100.00	30.93
As	1.22	2.00	......	0.77	......	0.83
Cd	7.27	1.90	5.00	0.98	4.73	0.83
Cr	8.68	3.81	2.02	6.59	2.82	5.06

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Al	1112.73	......	827.85	......	1394.00	......
As	1.39	......	1.70	......	1.53	......
Cd	.37	......	.59	......	3.61	......
Cr	10.63	......	21.40	......	24.54	......

FIGURE 115. SOUTH SHORE METAL CONCENTRATIONS BY SEASON AND BASIN FOR 1978 AND 1979.

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Hg	......	0.17	0.16	0.08	......	0.09
Ni	28.28	80.77	34.02	10.77	122.50	9.63
Se	2.07	2.00	2.06	2.00	2.00	2.00
Va	10.61	5.93	9.93	5.00	10.00	5.00
Zn	25.58	88.29	9.45	25.85	3.75	55.50

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Hg	0.73	0.05	0.19	0.09	0.02	0.03
Ni	23.83	17.67	27.97	19.34	36.75	19.71
Se	0.72	0.10	0.80	0.00	1.67	0.00
Va	230.85	5.91•	29.17	......	0.76	......
Zn	92.68	37.80	66.18	28.30	32.68	52.96



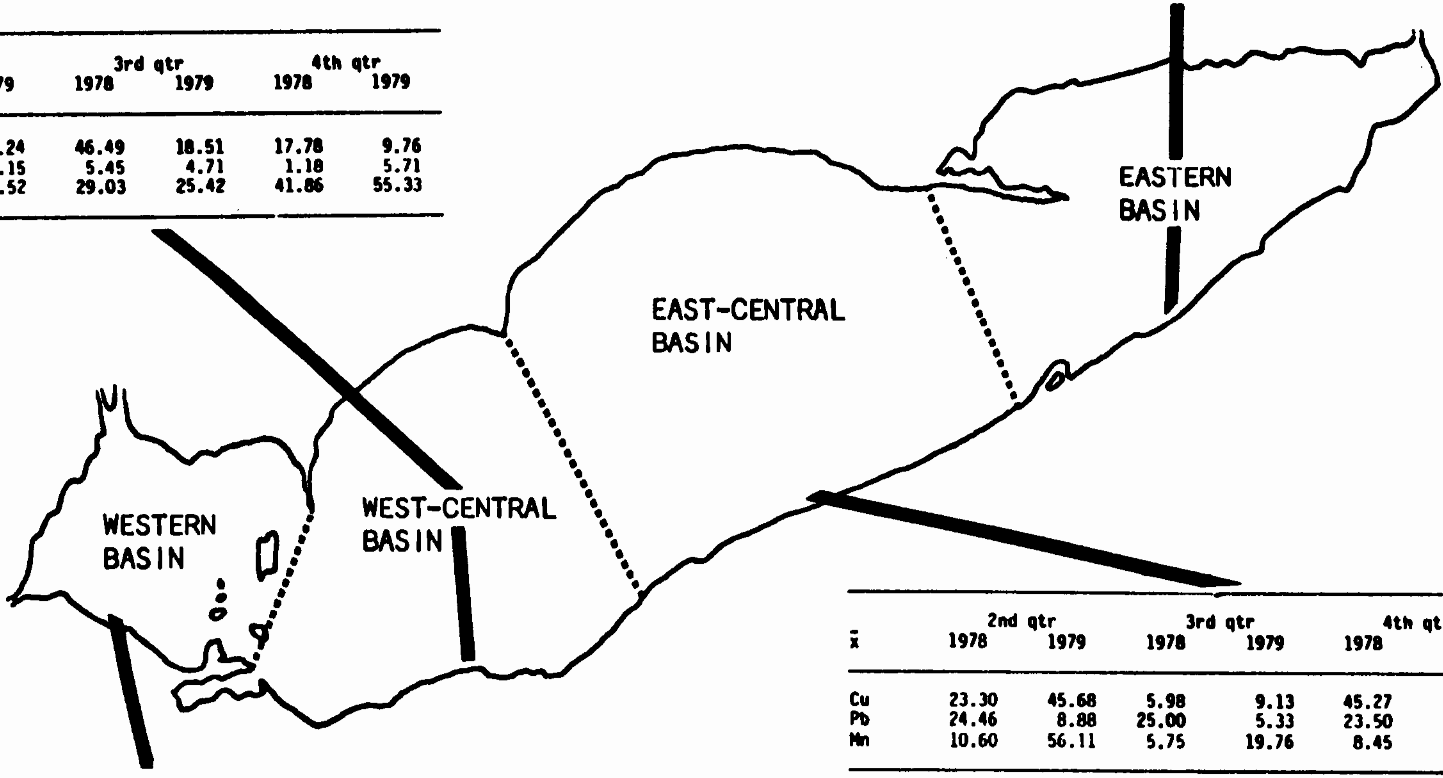
$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Hg	0.33	0.09	0.02	0.10	0.04	0.05
Ni	14.15	78.56	15.25	13.67	31.00	10.78
Se	0.86	0.79	3.11	0.75	2.00	0.81
Va	231.08	16.16	10.00	5.00	10.00	5.00
Zn	53.15	46.84	6.61	34.27	4.24	45.95

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Hg	0.03	......	0.03	......	0.01	......
Ni	28.90	......	22.19	......	19.08	......
Se	1.29	......	1.02	......	1.67	......
Va	2.36	......	0.87	......	1.67	......
Zn	54.58	......	112.31	......	42.65	......

FIGURE 115. CONTINUED

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Cu	7.39	5.57	19.51	3.16	6.00	3.70
Pb	25.28	7.60	26.31	8.30	25.00	8.13
Mn	8.08	6.92	12.64	5.86	5.50	5.20

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Cu	14.74	9.24	46.49	18.51	17.78	9.76
Pb	18.54	5.15	5.45	4.71	1.18	5.71
Mn	19.35	80.52	29.03	25.42	41.86	55.33



$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Cu	23.30	45.68	5.98	9.13	45.27	7.07
Pb	24.46	8.88	25.00	5.33	23.50	6.09
Mn	10.60	56.11	5.75	19.76	8.45	13.33

$\bar{x}$	2nd qtr 1978	2nd qtr 1979	3rd qtr 1978	3rd qtr 1979	4th qtr 1978	4th qtr 1979
Cu	17.50	......	105.17	......	9.70	......
Pb	4.41	......	8.64	......	2.25	......
Mn	46.79	......	30.14	......	45.54	......

FIGURE 115. CONTINUED

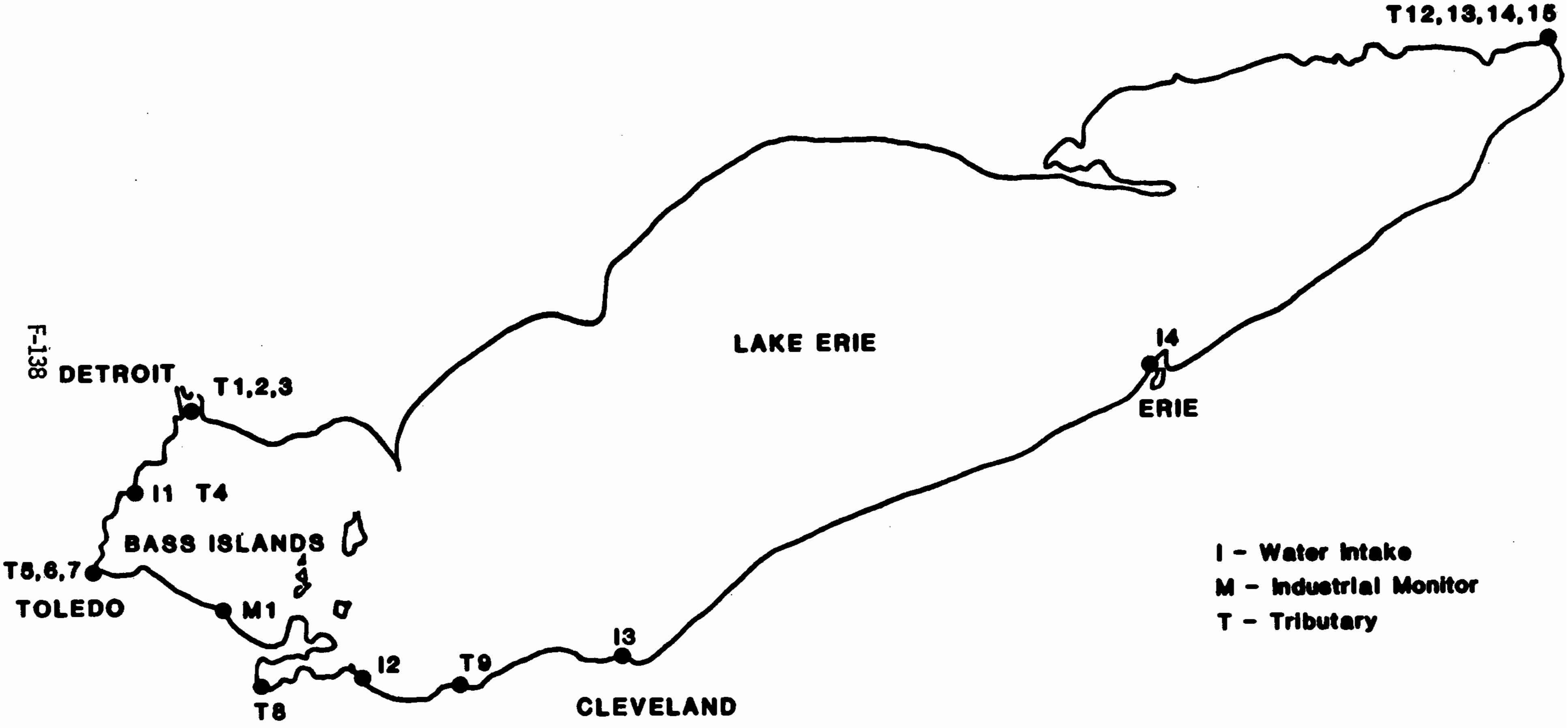


FIGURE 116. SHORELINE LOCATIONS USED TO DETERMINE LONG TERM TREND.

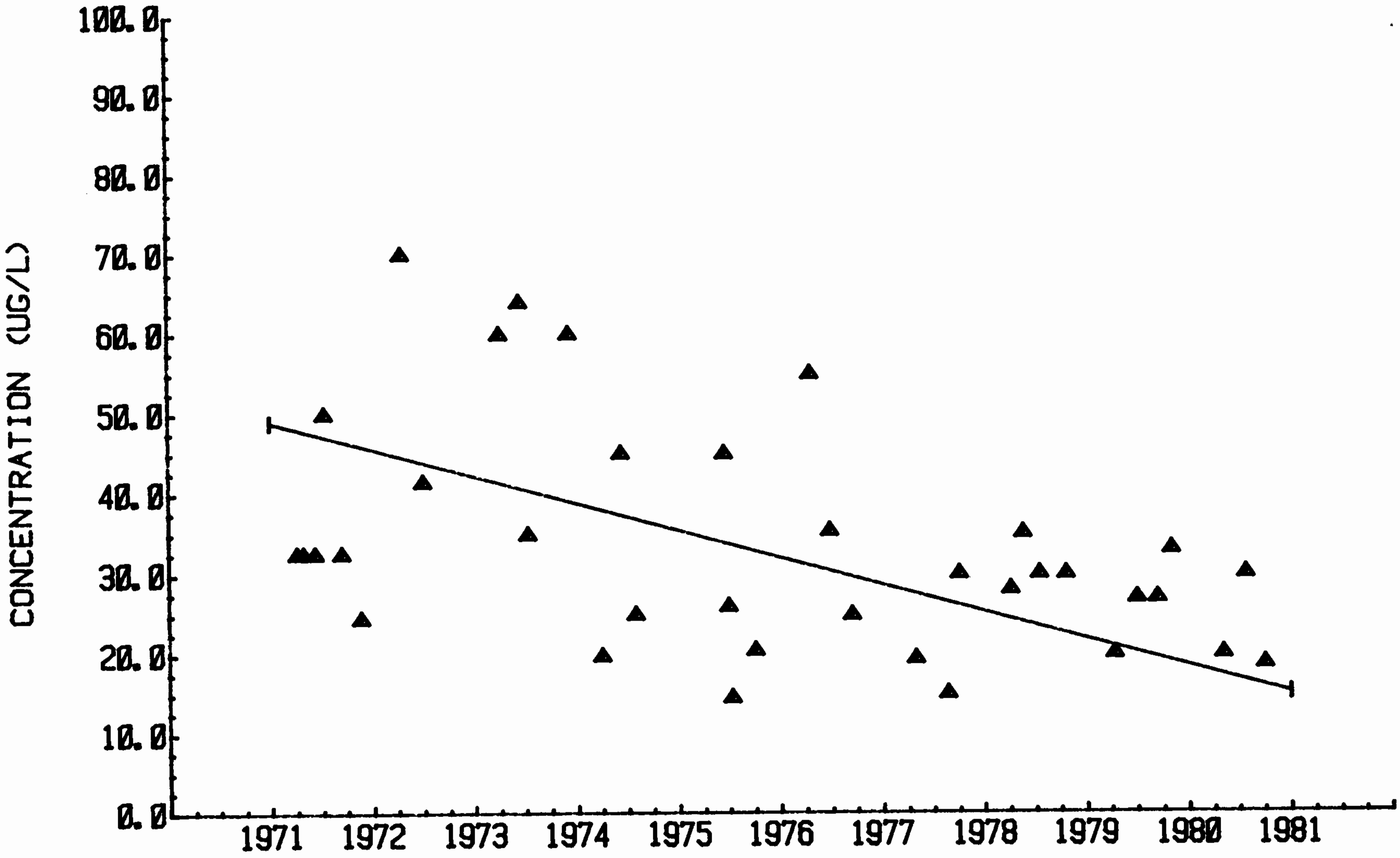


FIGURE 117. TOTAL PHOSPHORUS TREND ANALYSIS FOR THE DETROIT RIVER / LIVINGSTON CHANNEL (STATION 000024).

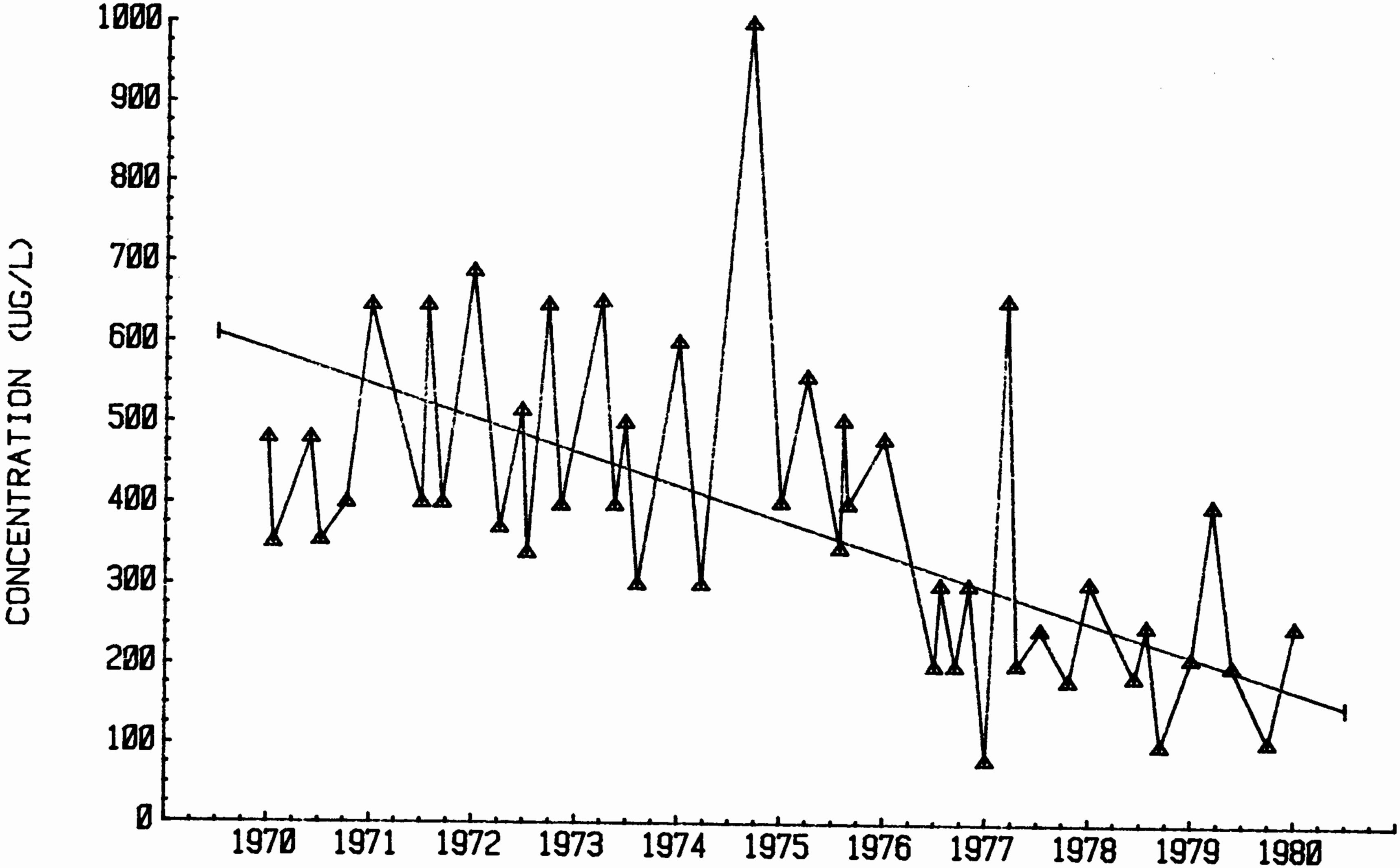


FIGURE 118. TOTAL PHOSPHORUS TREND ANALYSIS FOR THE MAUMEE RIVER / C AND O DOCK.

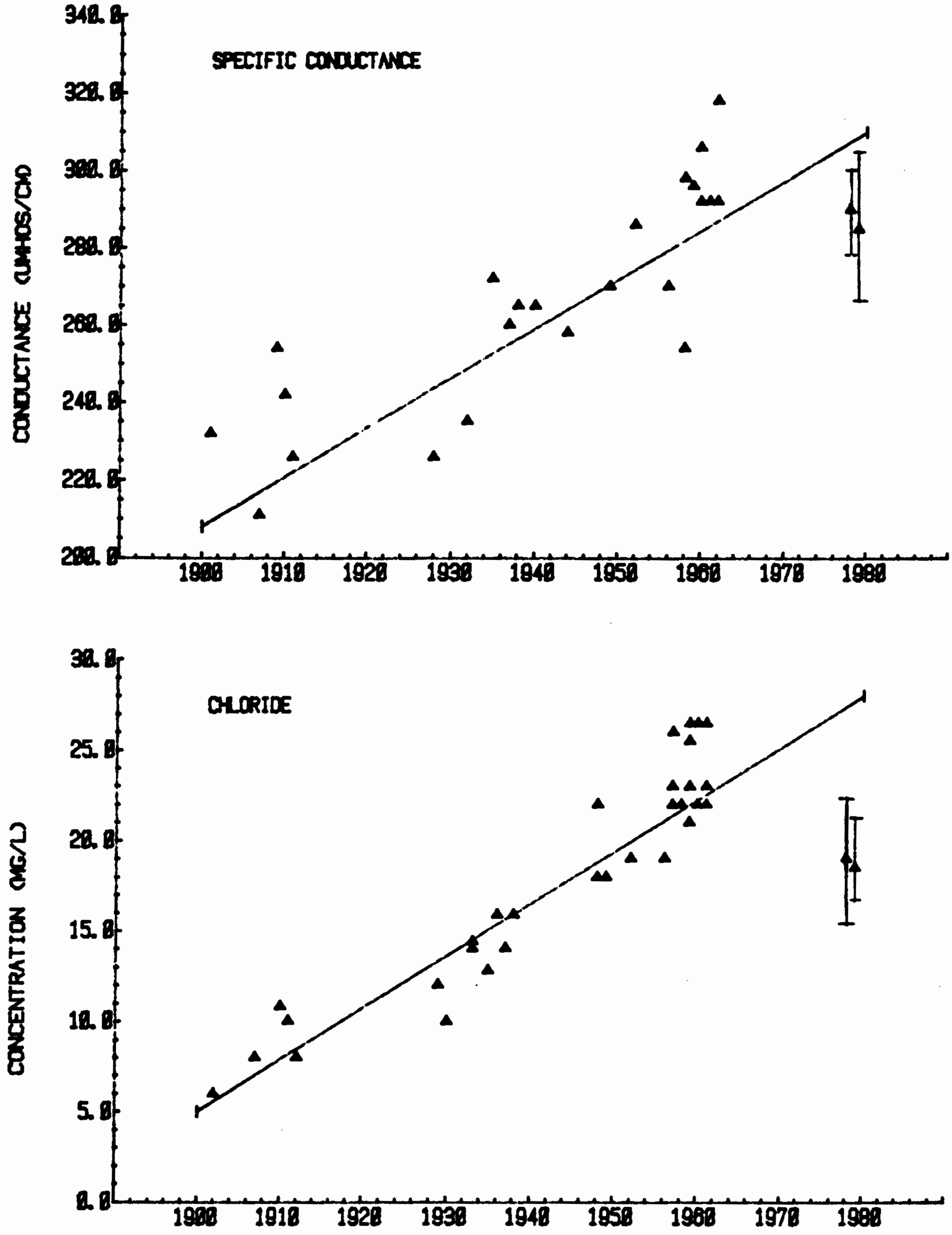
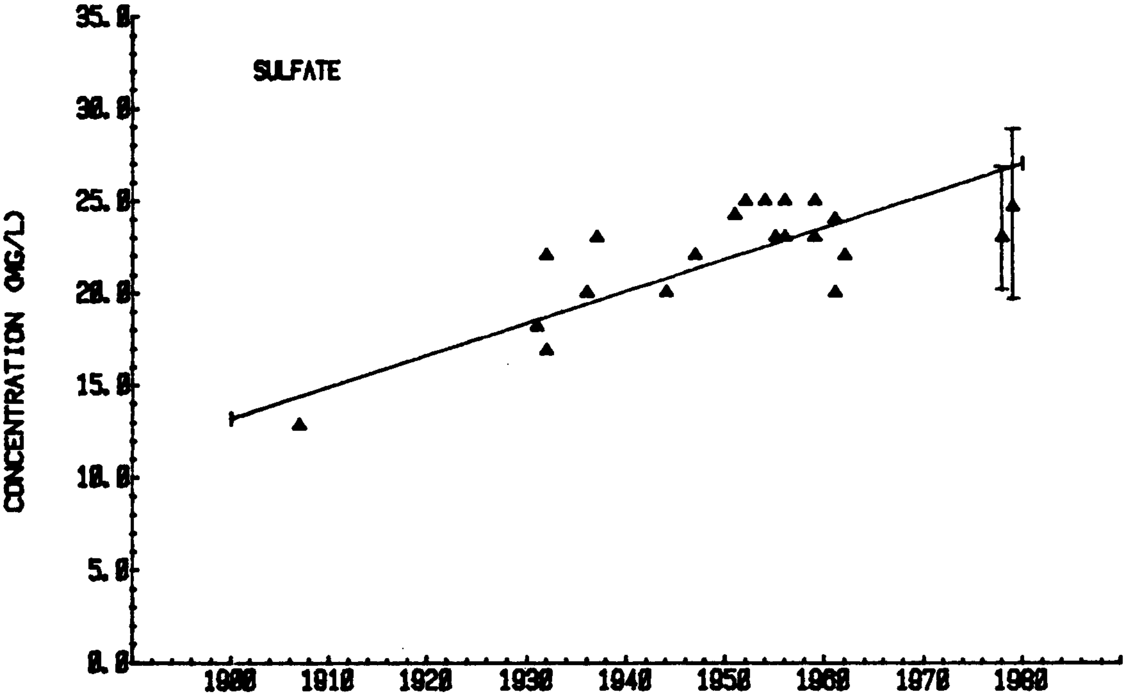


FIGURE 119. SPECIFIC CONDUCTANCE AND CHLORIDE TREND ANALYSIS FOR THE CLEVELAND AREA AS REPORTED BY BEETON (1961) AND RICHARDS (1981).



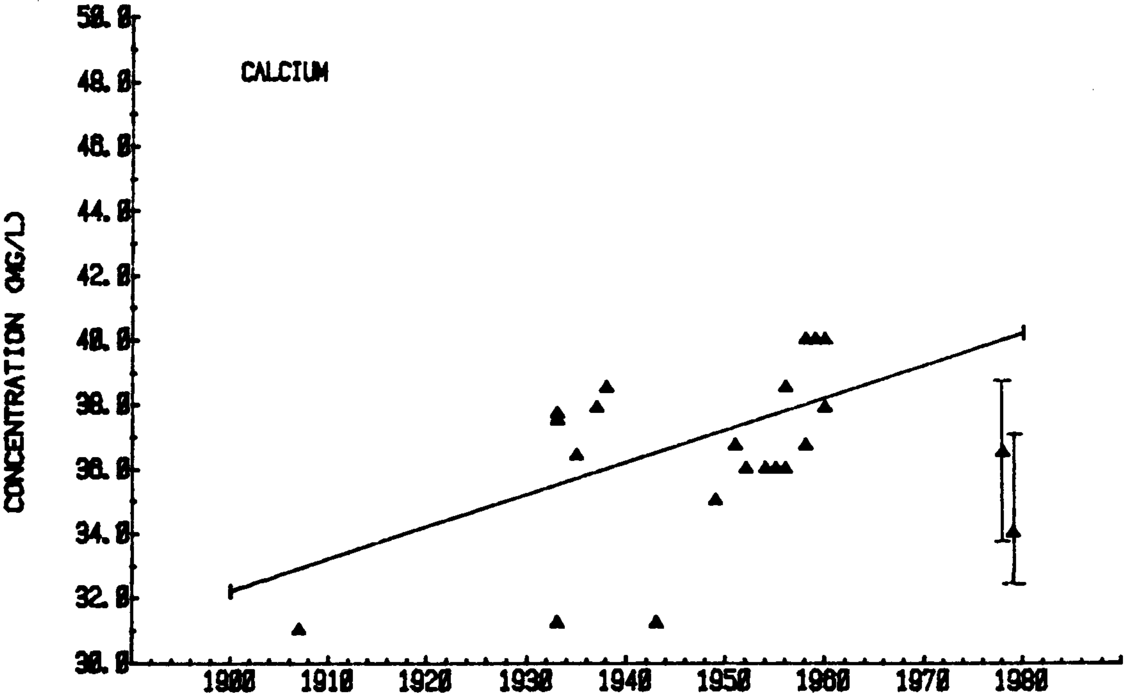


FIGURE 120. SULFATE AND CALCIUM TREND ANALYSIS FOR THE CLEVELAND AREA AS REPORTED BY BEETON (1961) AND RICHARDS (1981).

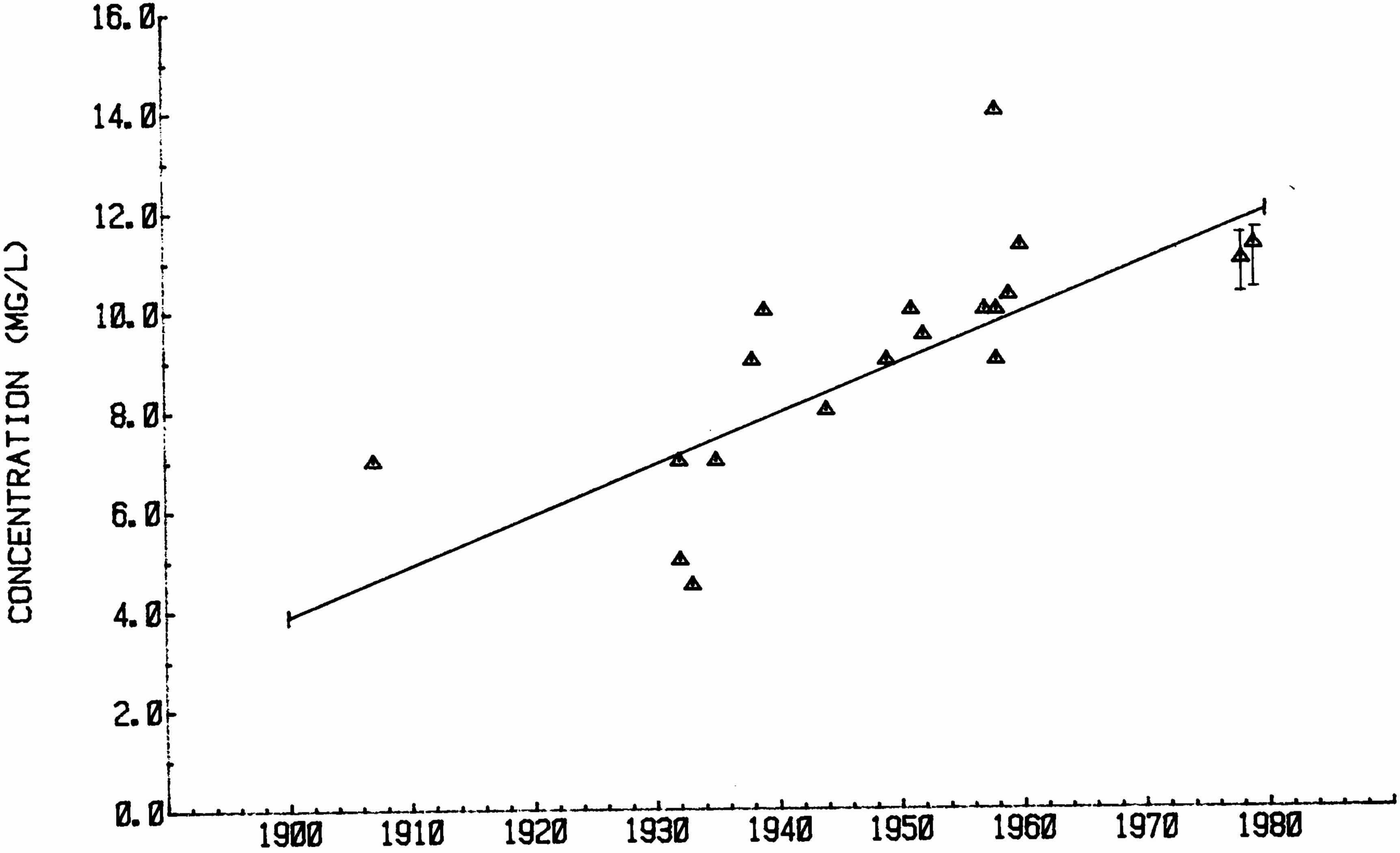


FIGURE 121. SODIUM PLUS POTASSIUM TREND ANALYSIS FOR THE CLEVELAND AREA AS REPORTED BY BEETON (1961) AND RICHARDS (1981).

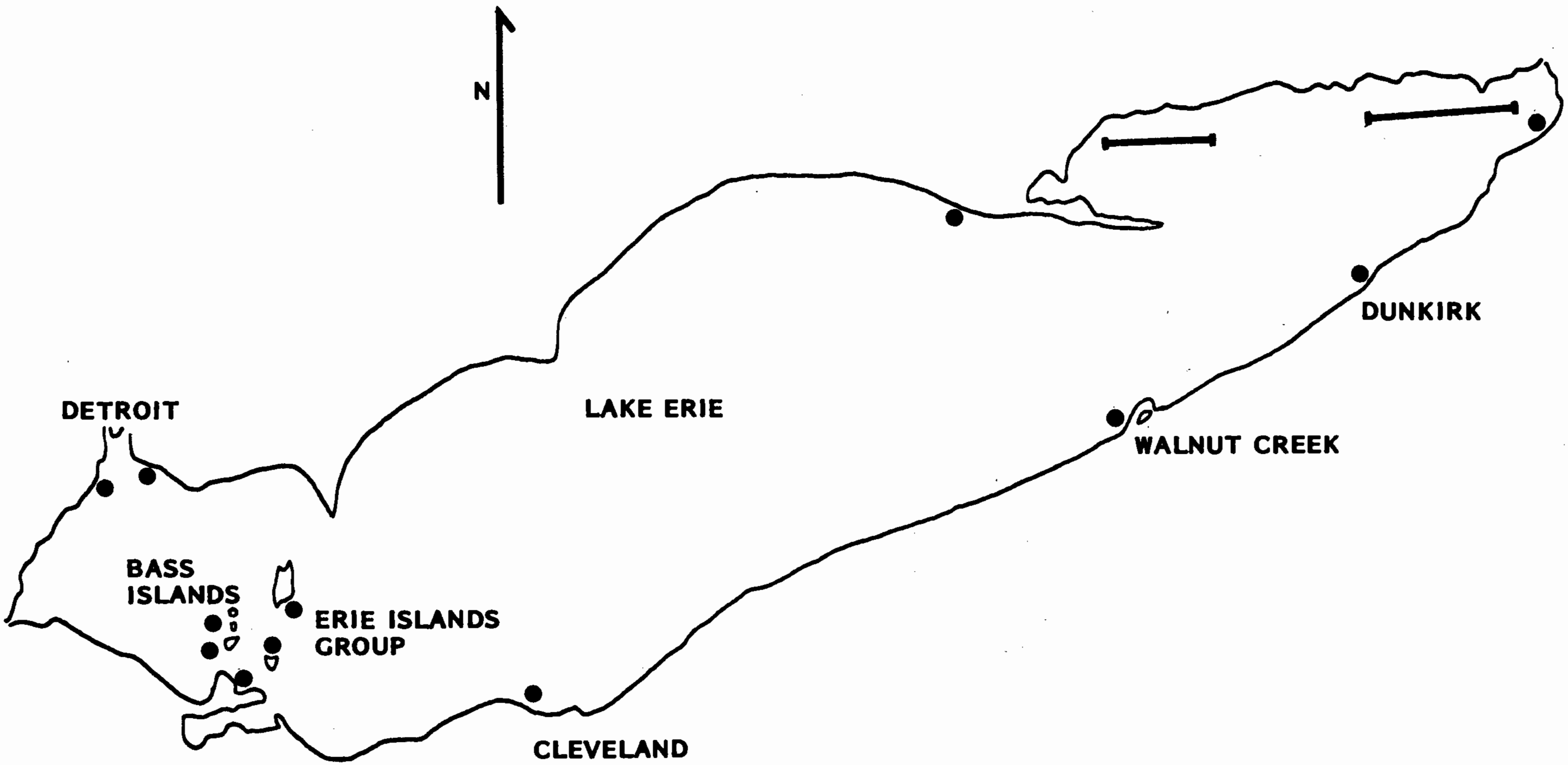


FIGURE 122. AREAS OF WIDESPREAD CLADOPHORA COLONIZATION AS REPORTED BY AUER AND CANALE, 1981.

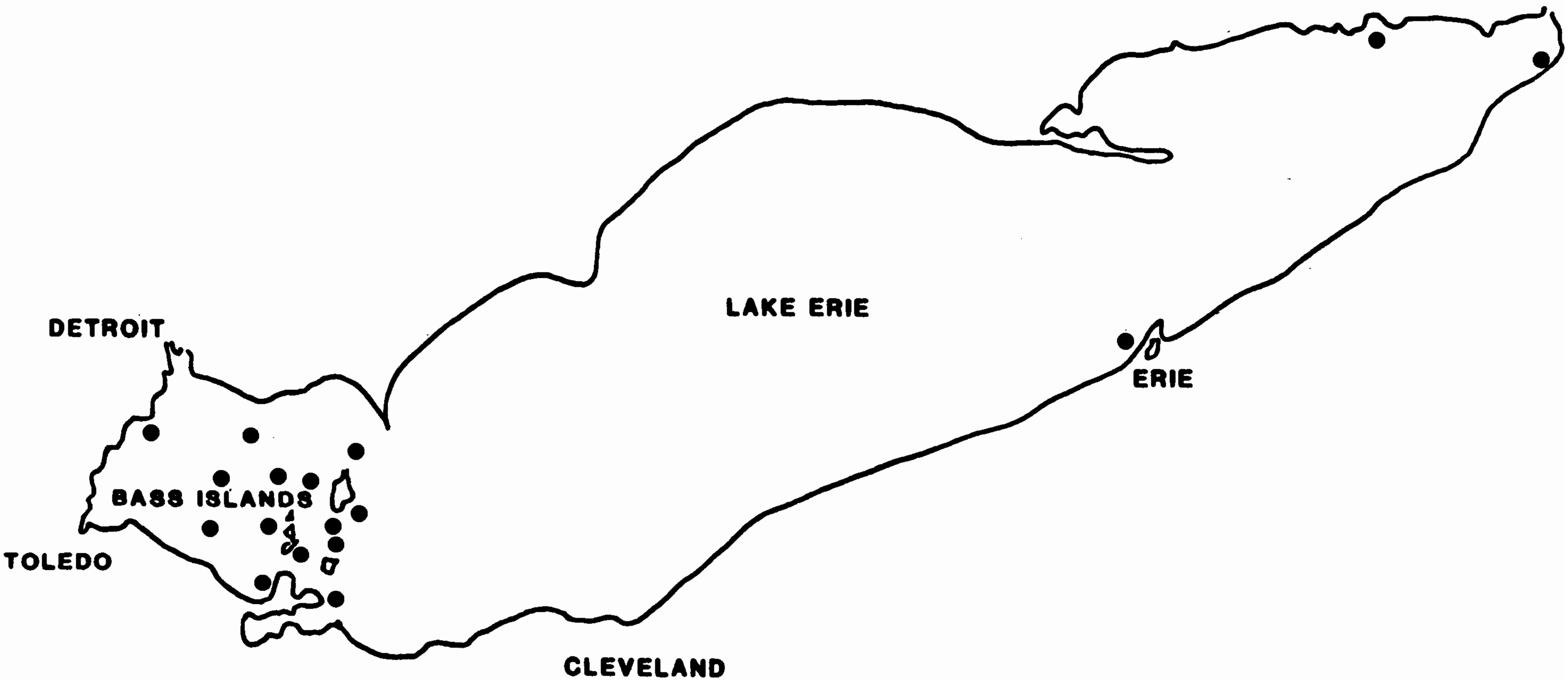
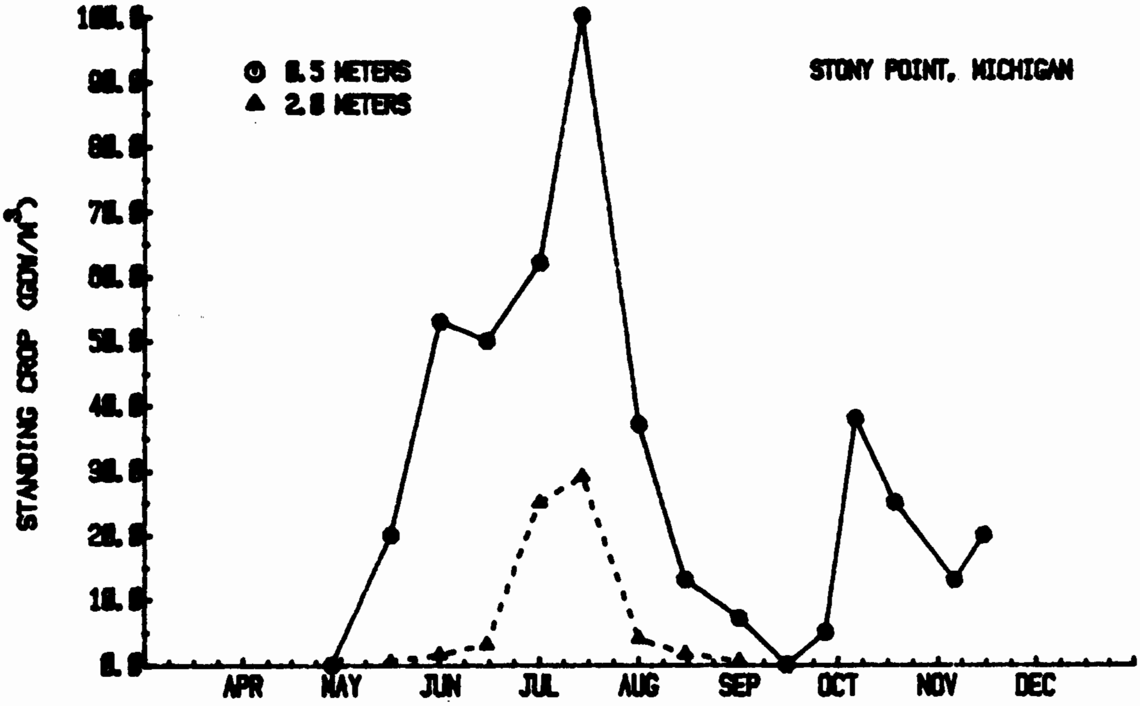


FIGURE 123. STATION LOCATIONS USED IN THE CLADOPHORA SURVEY.



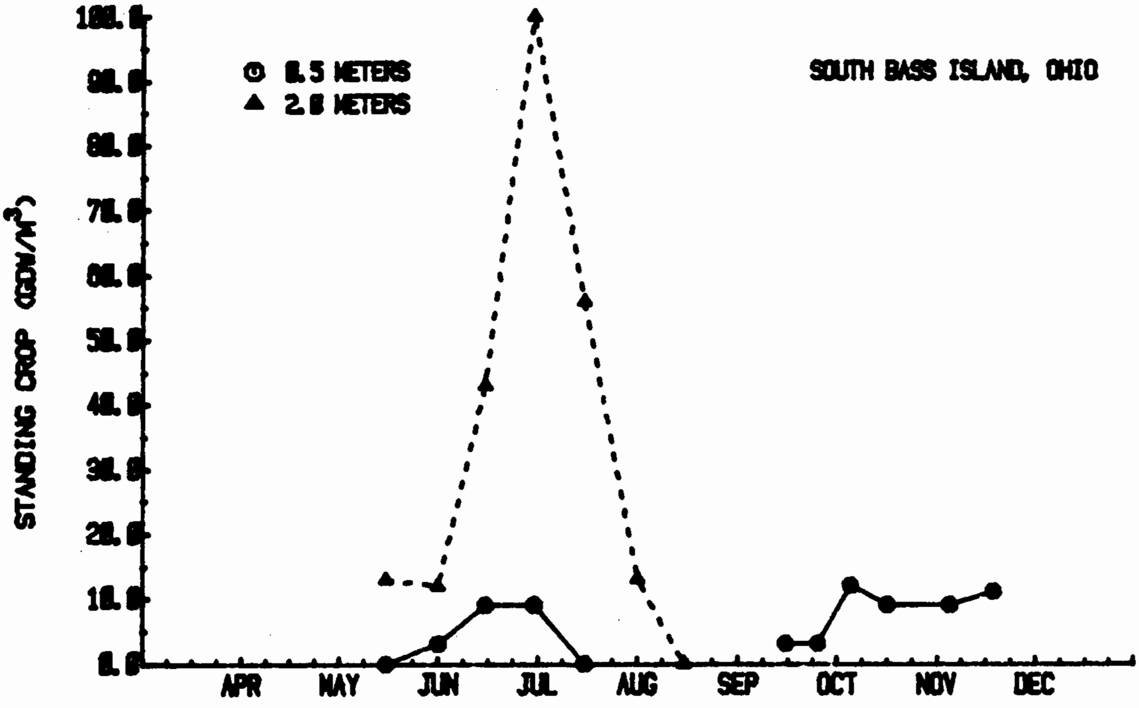


FIGURE 124. WESTERN BASIN CLADOPHORA STANDING CROP ESTIMATES FOR STONY POINT, MICHIGAN AND SOUTH BASS ISLAND, OHIO 1979 (CLEAR).

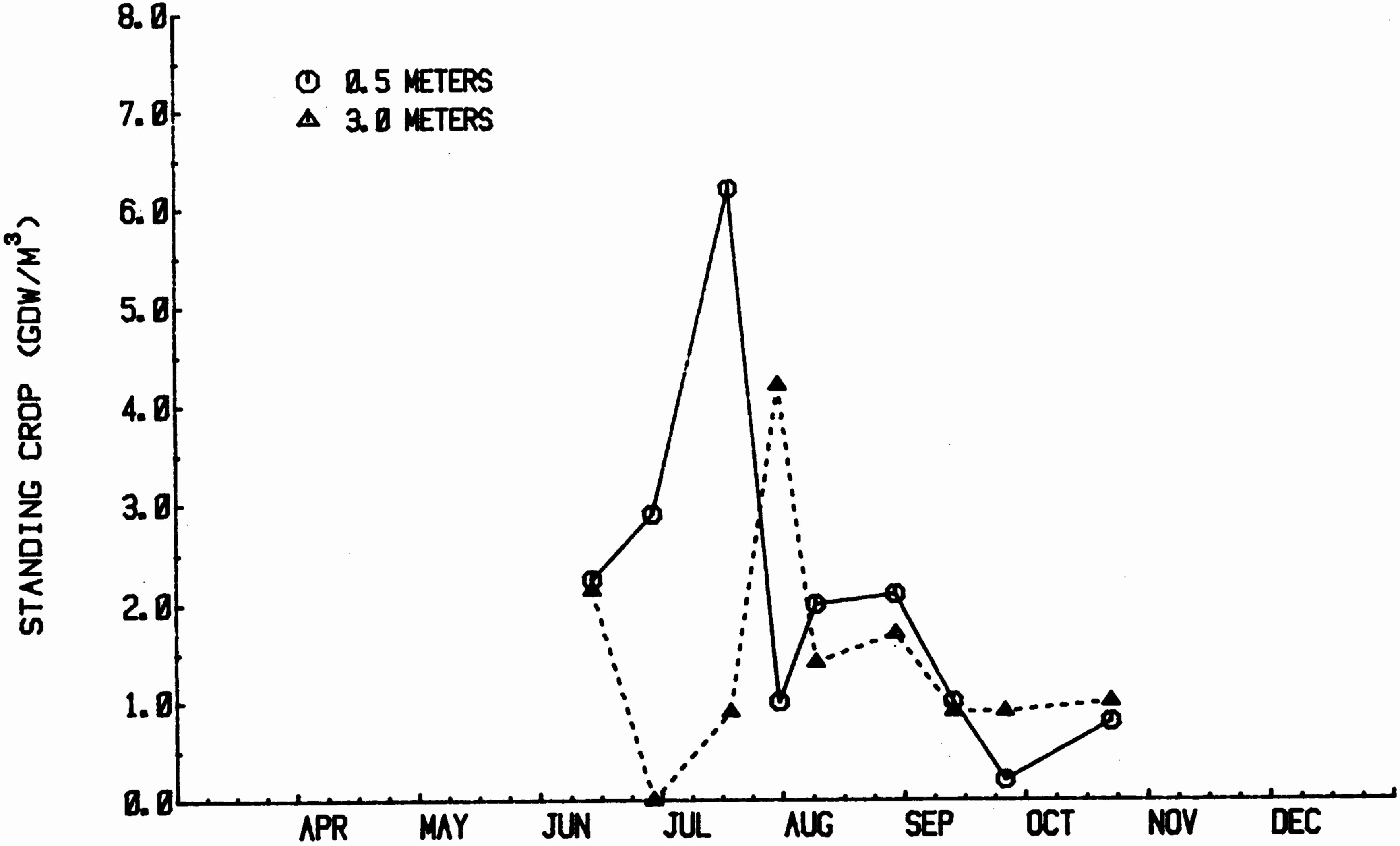


FIGURE 125. CENTRAL - EASTERN BASIN CLADOPHORA STANDING CROP ESTIMATES FOR WALNUT CREEK, PA. 1979 (SUNY).

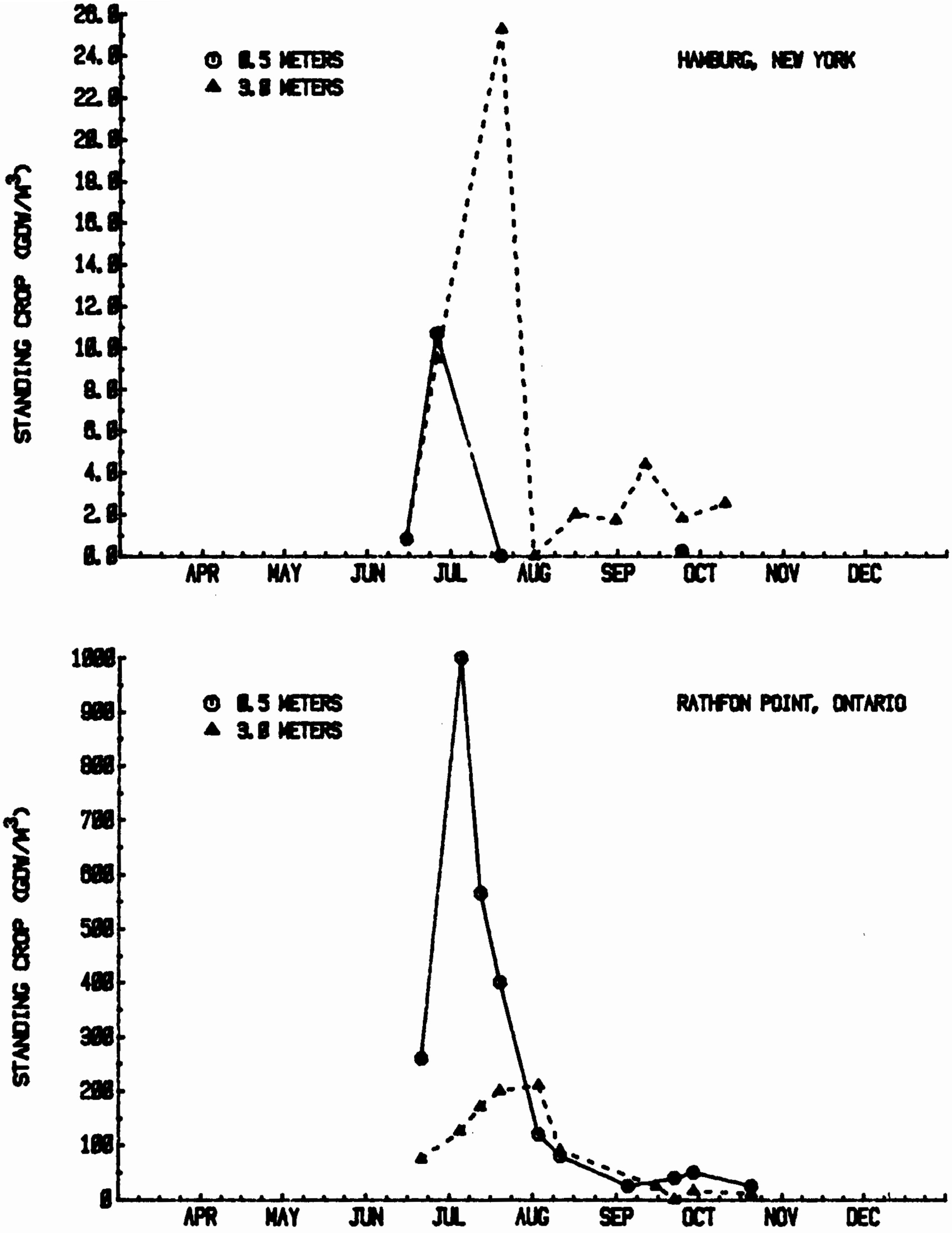


FIGURE 126. EASTERN BASIN CLADOPHORA STANDING CROP ESTIMATES FOR HAMBURG, N.Y. (SUNY) AND RATHFON POINT, ONT. (MOE) 1979.

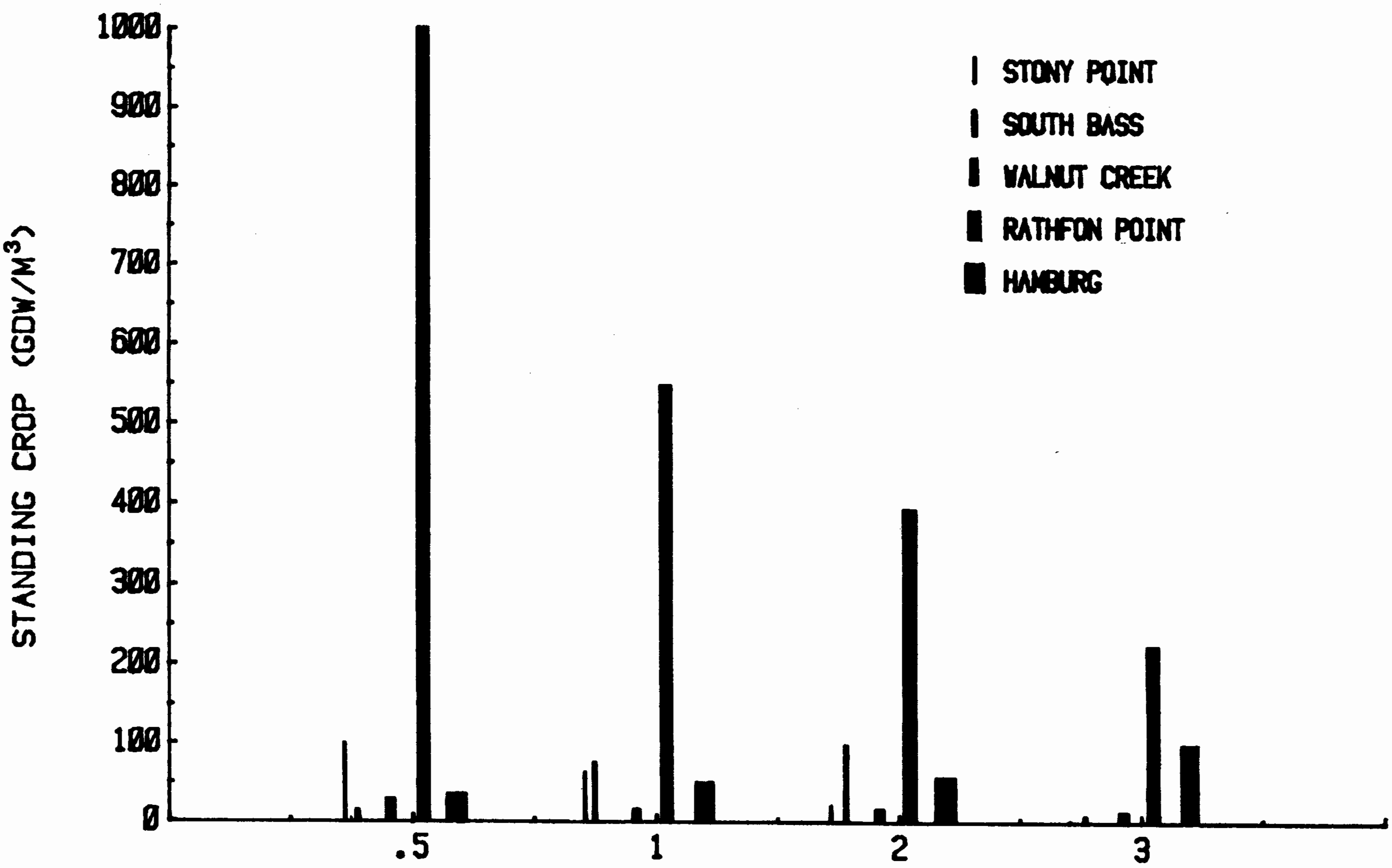


FIGURE 127 A COMPARISON OF THE MAXIMUM CLADOPHORA STANDING CROPS FOR THE FIVE SURVEY LOCATIONS, 1979.

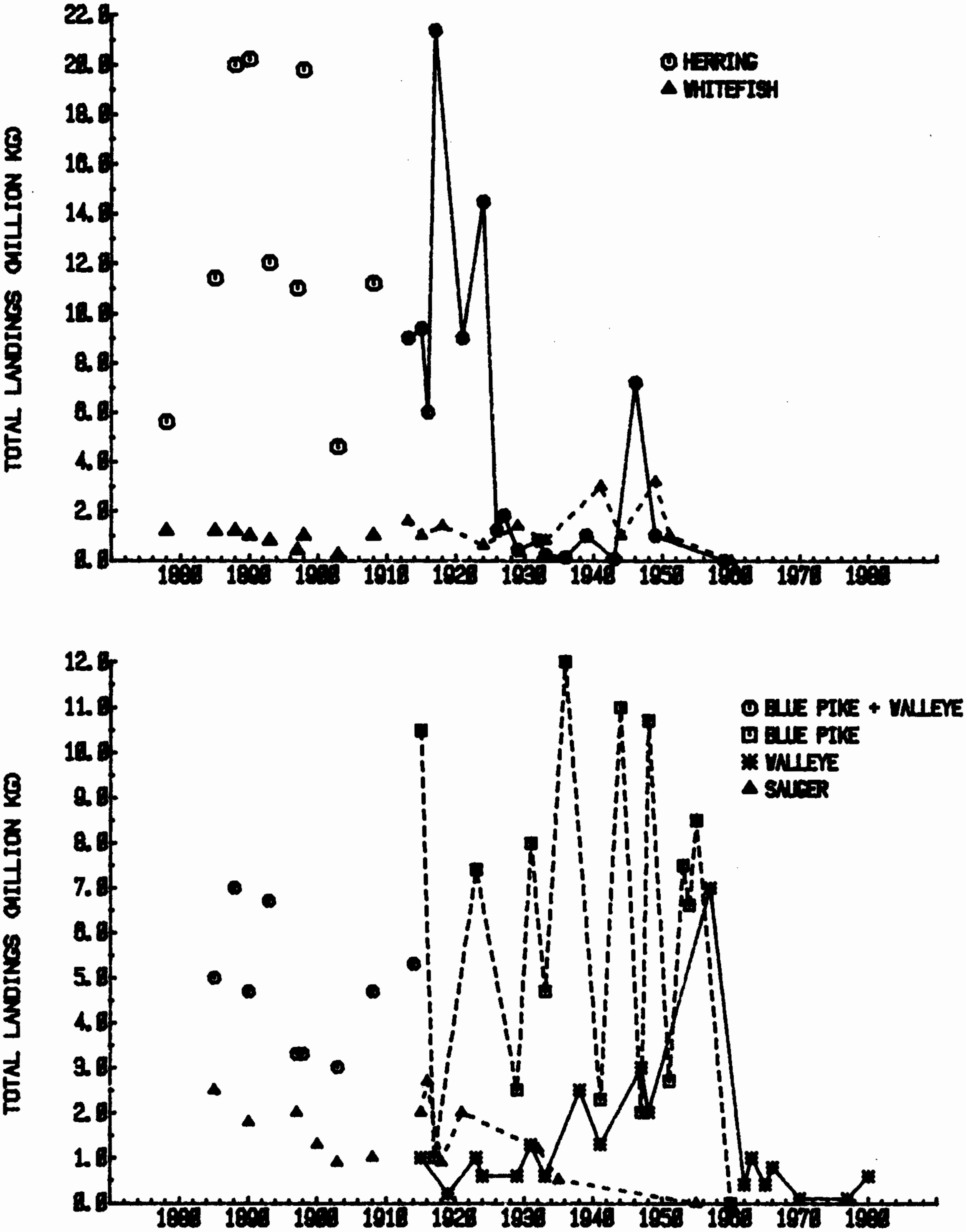


FIGURE 120. TOTAL COMMERCIAL LANDINGS OF HERRING, WHITEFISH, SAUGER, BLUE PIKE AND WALLEYE FROM 1880 TO 1980.

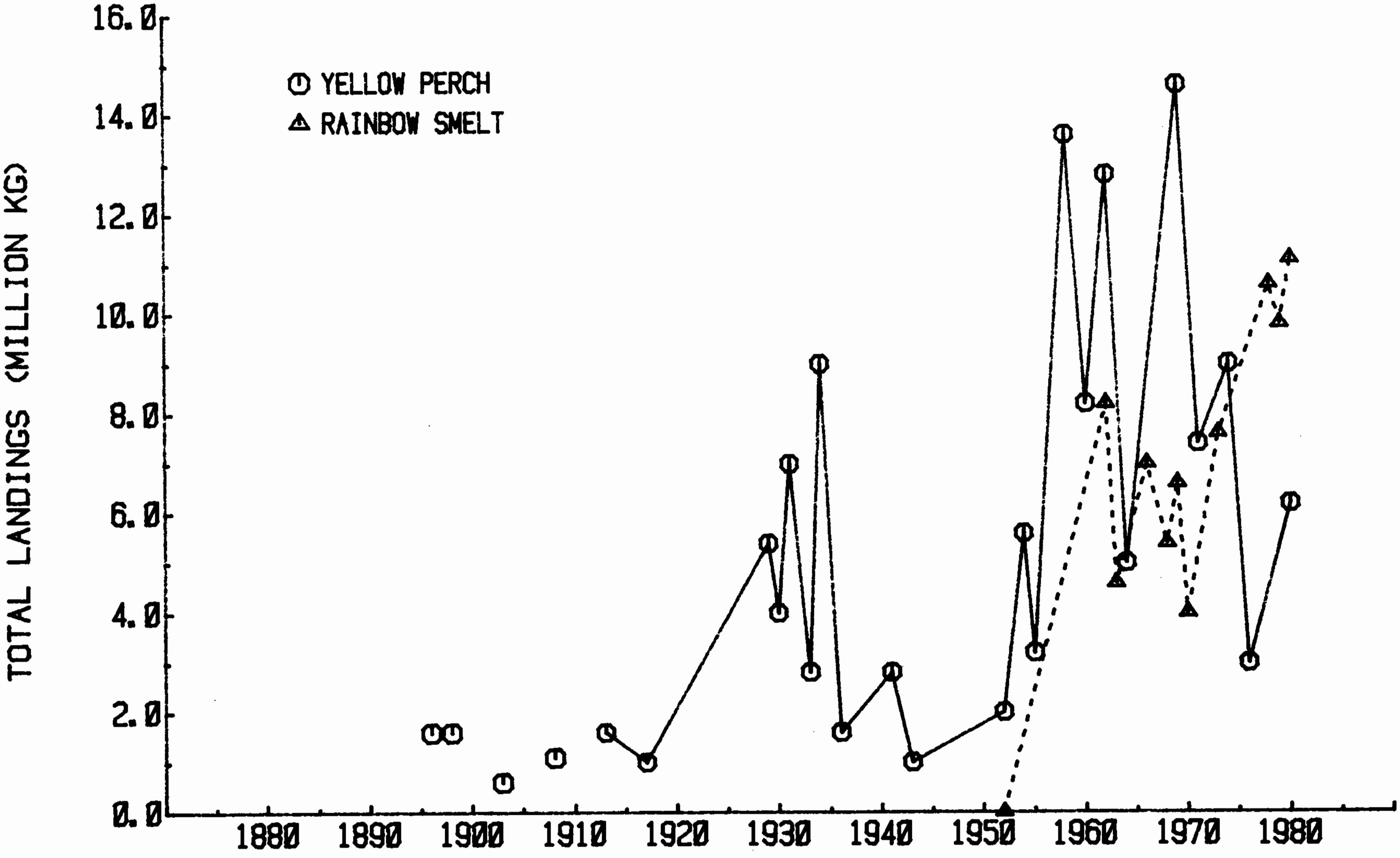


FIGURE 129. TOTAL COMMERCIAL LANDINGS OF YELLOW PERCH AND RAINBOW SMELT FROM 1890 TO 1980.

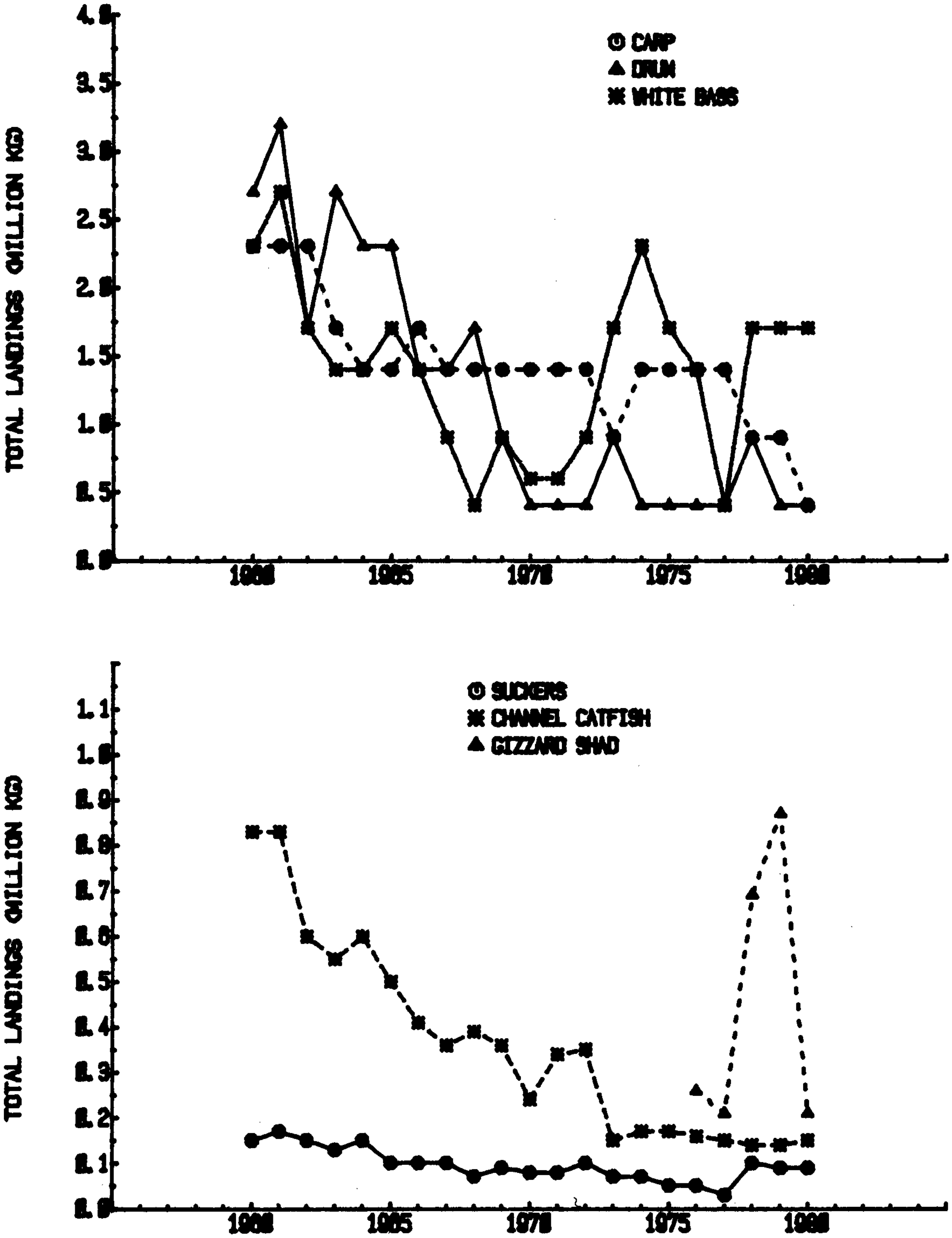


FIGURE 130. TOTAL LANDINGS OF CARP, DRUM, WHITE BASS, GIZZARD SHAD, CHANNEL CATFISH AND SUCKERS FROM 1960 TO 1980.

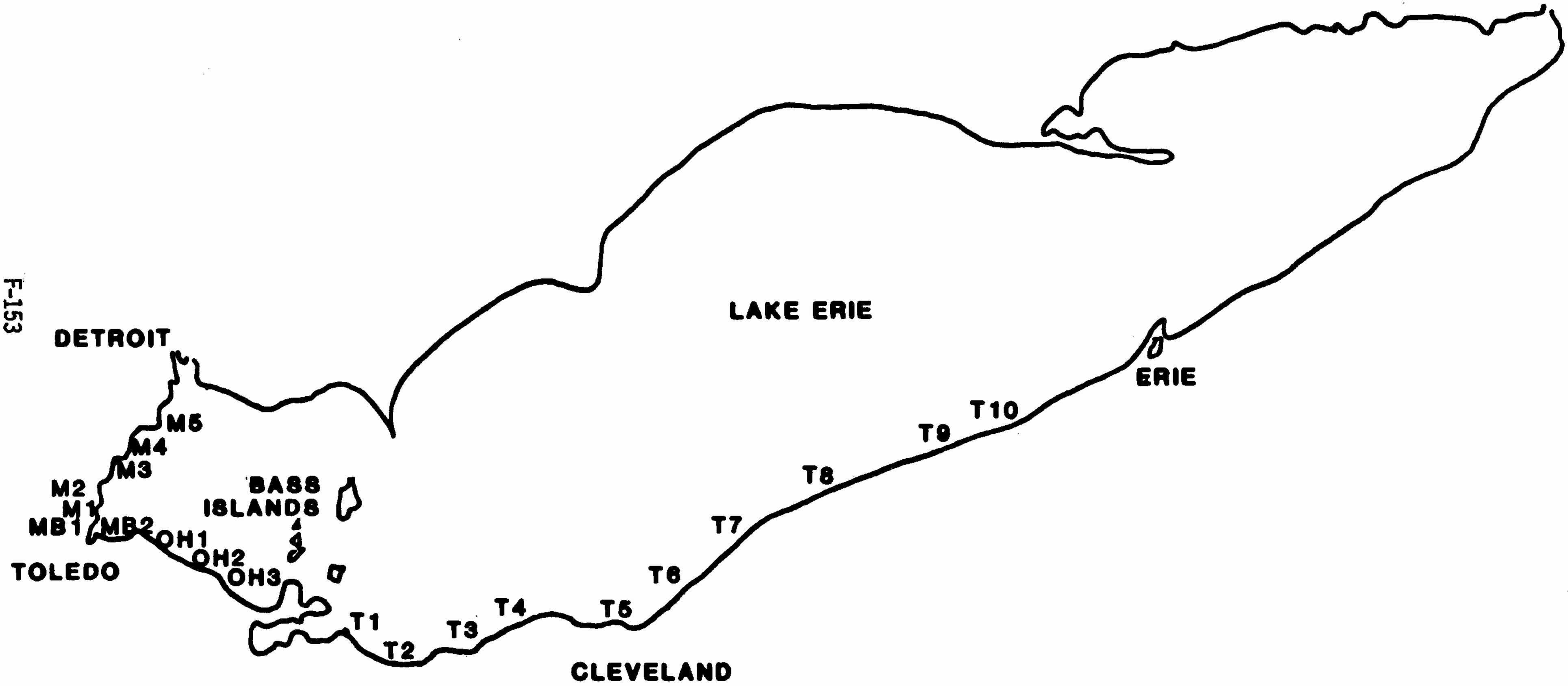


FIGURE 131. WESTERN BASIN (1977) AND CENTRAL BASIN (1978) FISH LARVAL SAMPLING STATIONS.

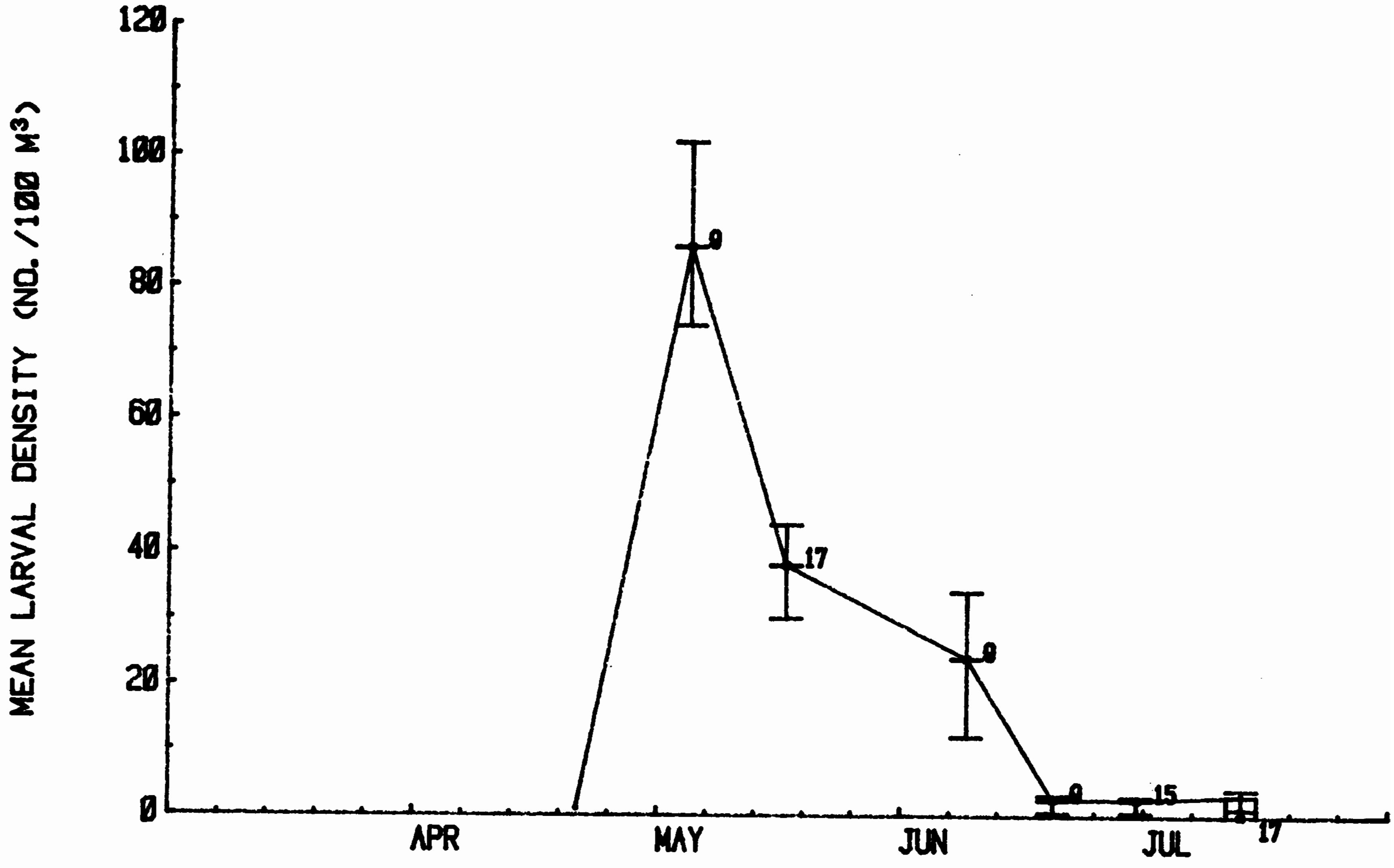


FIGURE 132. MEAN LARVAL YELLOW PERCH DENSITY IN THE WESTERN BASIN DURING 1977.

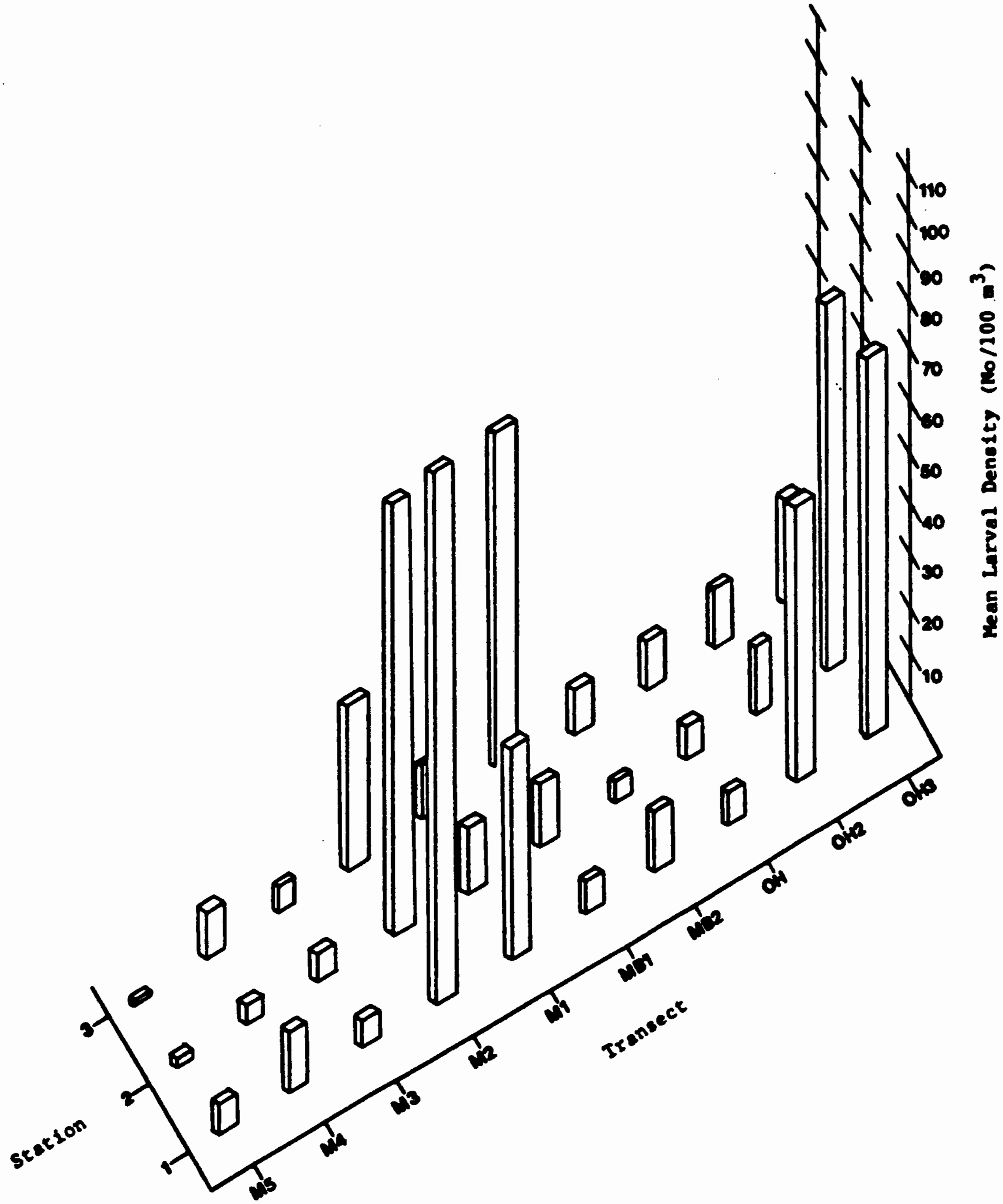


FIGURE 133. MEAN LARVAL YELLOW PERCH DENSITY FOR INDIVIDUAL WESTERN BASIN SAMPLING TRANSECTS DURING 1977.

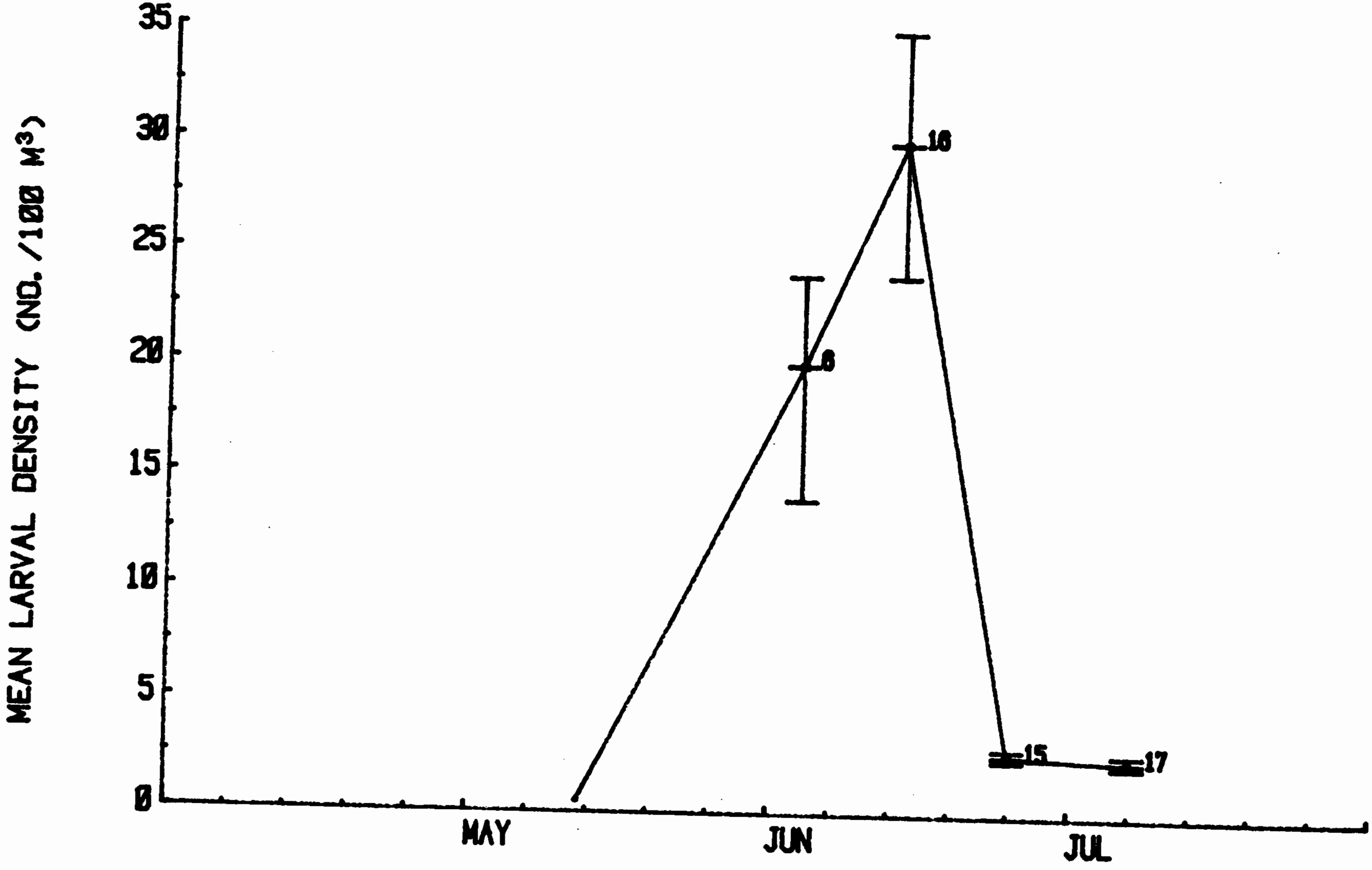


FIGURE 134. MEAN LARVAL WHITE BASS DENSITY IN THE WESTERN BASIN DURING 1977.

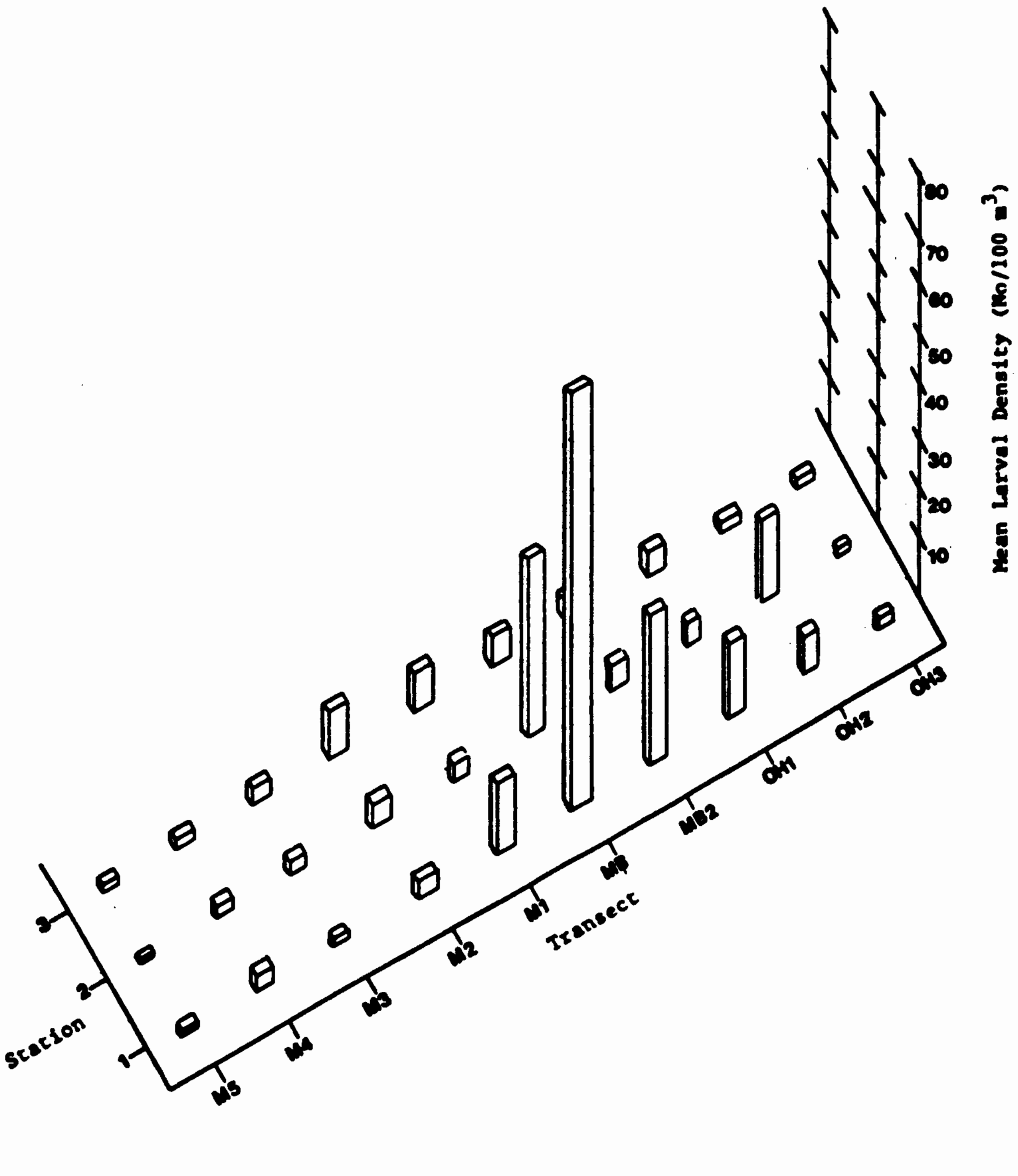


FIGURE 135. MEAN LARVAL WHITE BASS DENSITY FOR INDIVIDUAL WESTERN BASIN SAMPLING TRANSECTS DURING 1977.

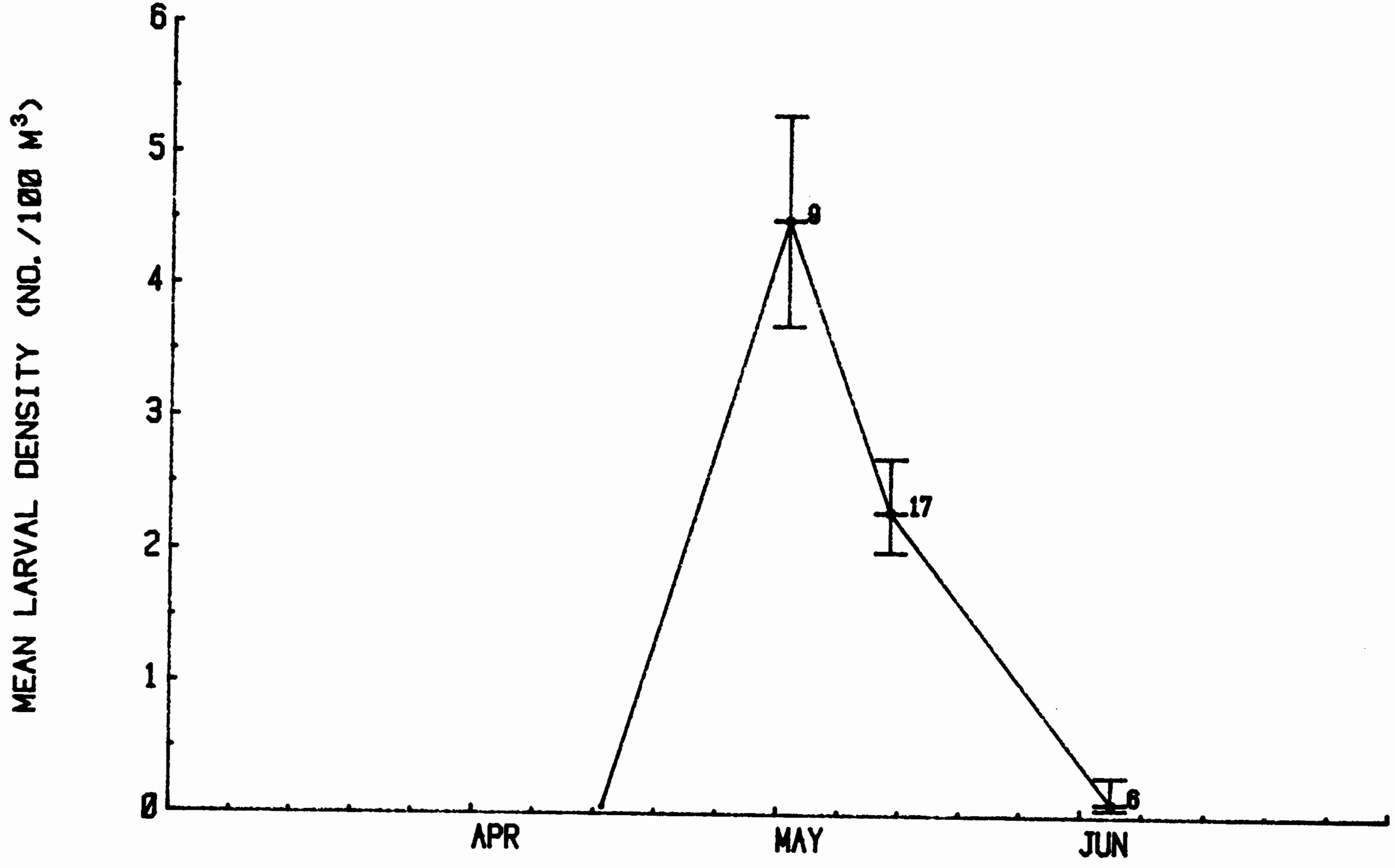


FIGURE 136. MEAN LARVAL WALLEYE DENSITY IN THE WESTERN BASIN DURING 1977.

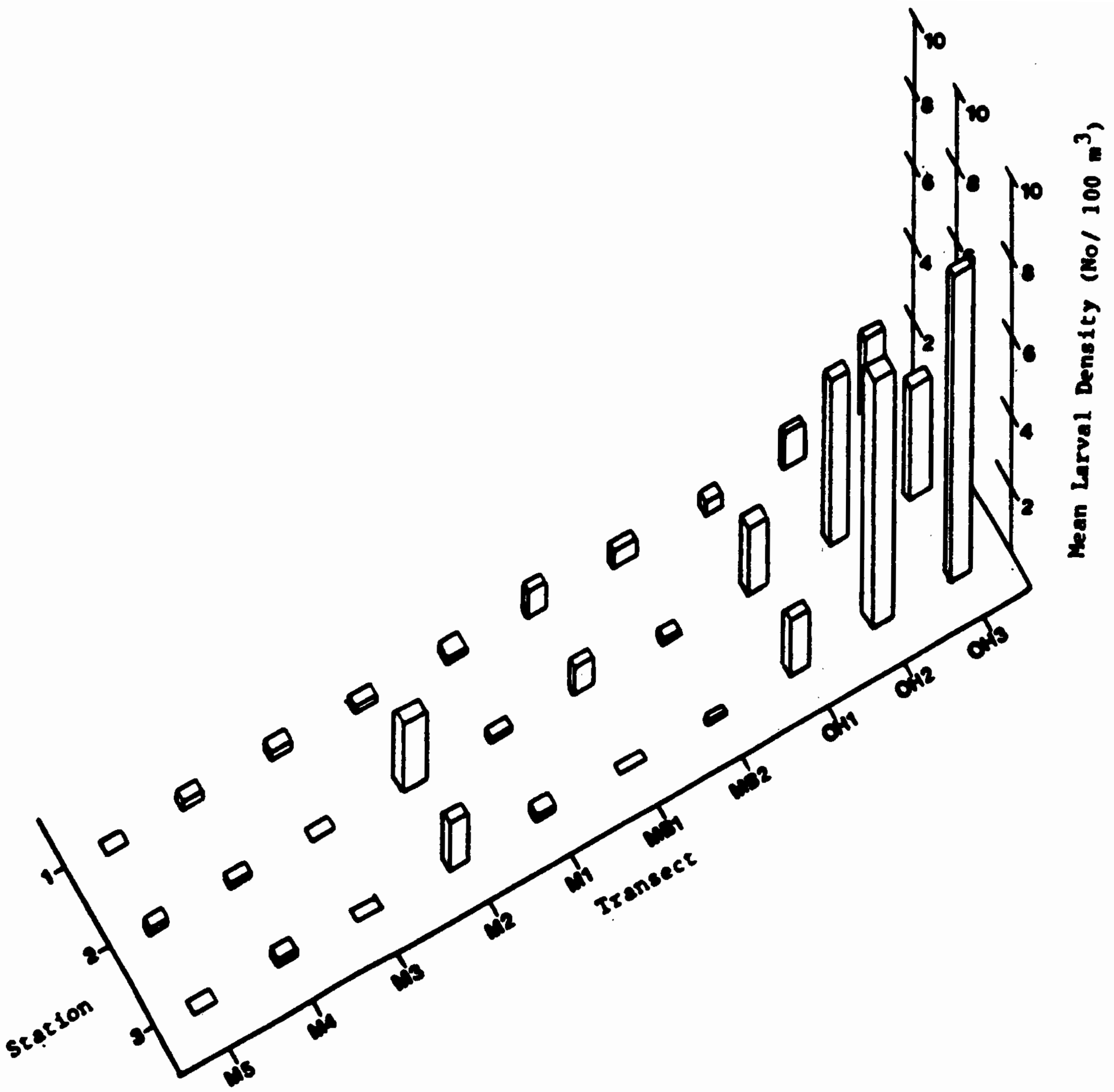


FIGURE 137. MEAN LARVAL WALLEYE DENSITY FOR INDIVIDUAL WESTERN BASIN SAMPLING TRANSECTS DURING 1977.

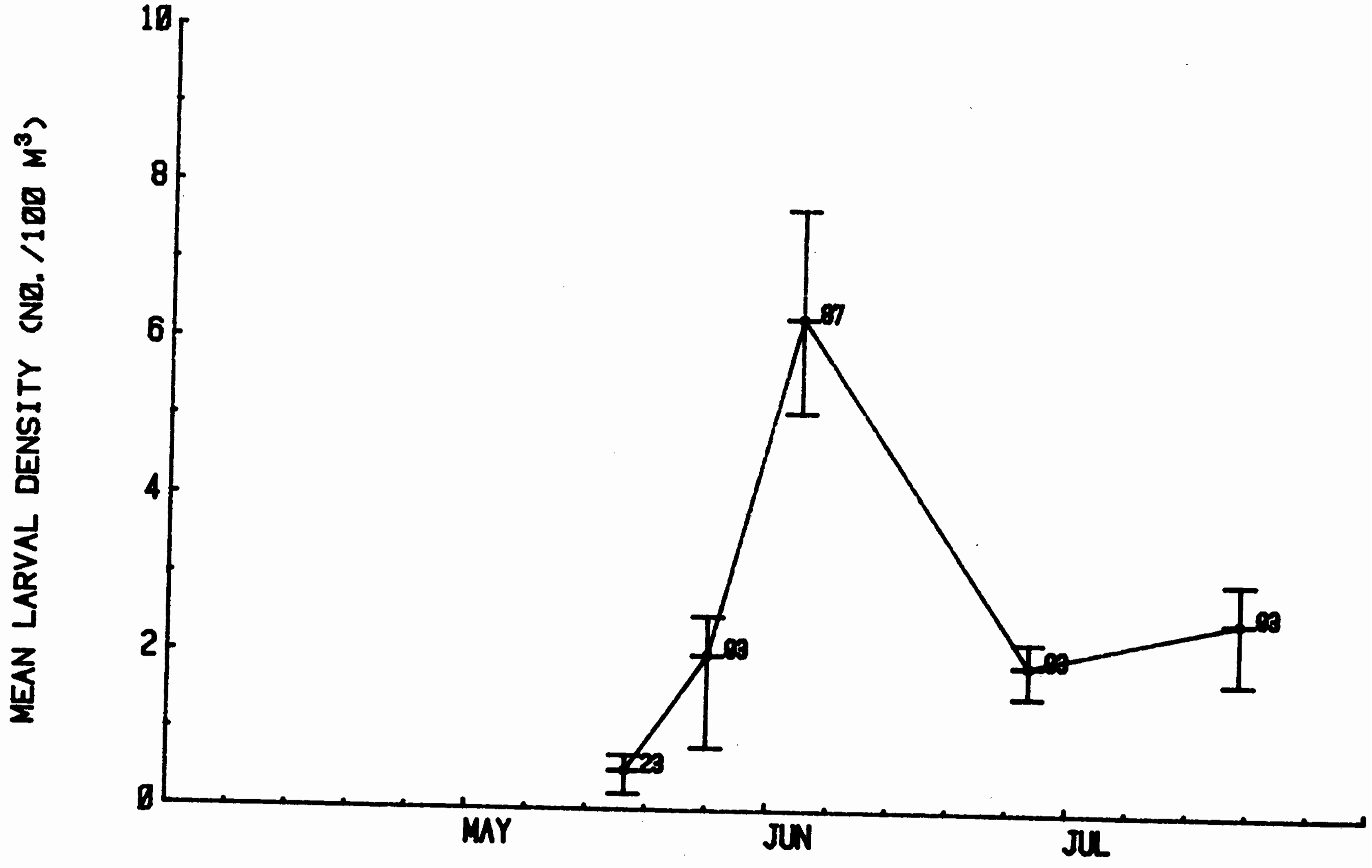


FIGURE 138. MEAN LARVAL YELLOW PERCH DENSITY IN THE CENTRAL BASIN DURING 1978.

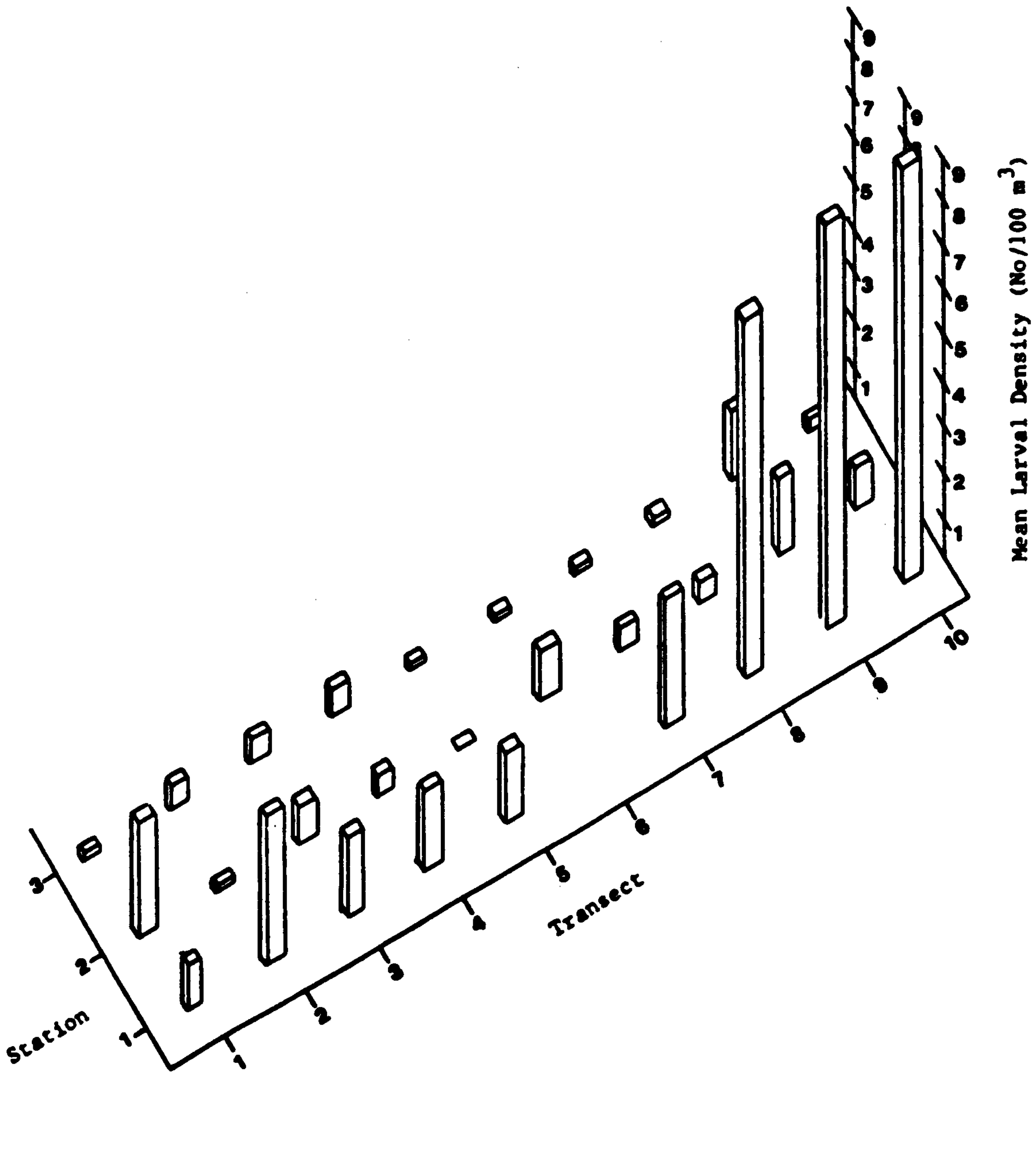


FIGURE 139. MEAN LARVAL YELLOW PERCH DENSITY FOR INDIVIDUAL CENTRAL BASIN SAMPLING TRANSECTS DURING 1978.

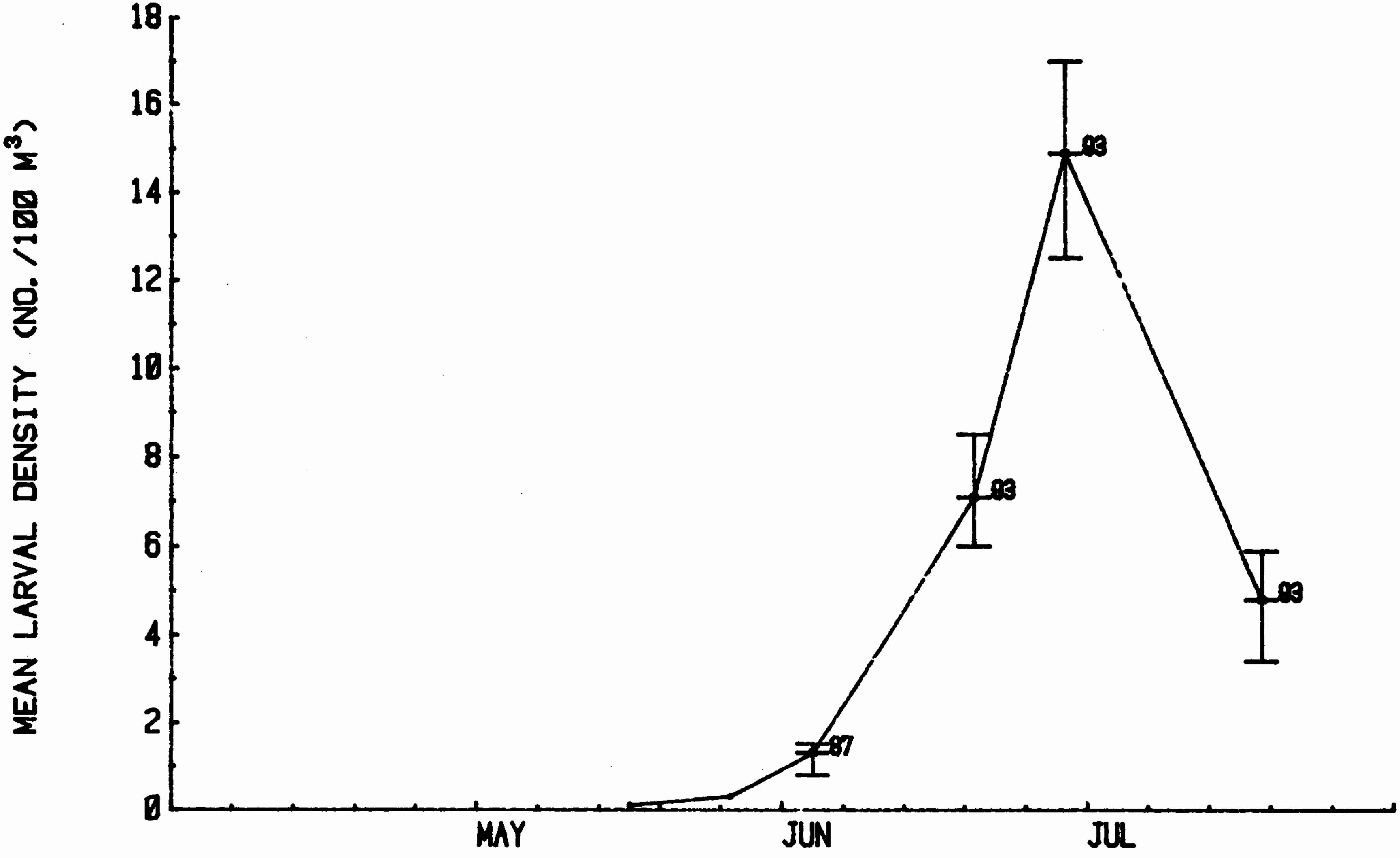


FIGURE 140. MEAN LARVAL SMELT DENSITY IN THE CENTRAL BASIN DURING 1978.

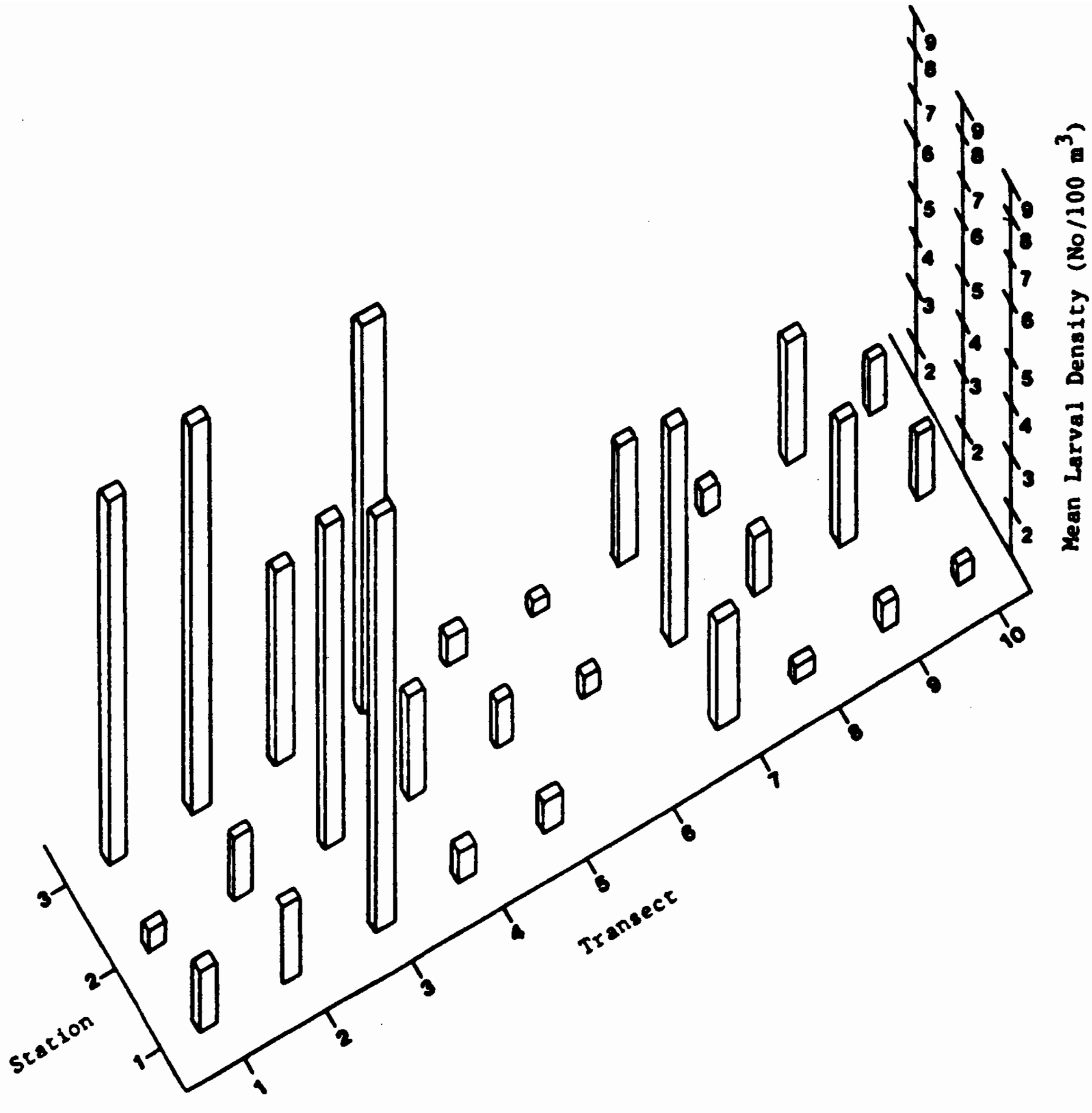


FIGURE 141. MEAN LARVAL SMELT DENSITY FOR INDIVIDUAL CENTRAL BASIN SAMPLING TRANSECTS DURING 1978.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-905/4-84-001	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Lake Erie Intensive Study 1978-1979		5. REPORT DATE January 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) David E. Rathke		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Ohio State University Center For Lake Erie Area Research Columbus, Ohio		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Great Lakes National Program Office 536 South Clark Street, Room 958 Chicago, Illinois 60605		13. TYPE OF REPORT AND PERIOD COVERED Final 1978-1979
		14. SPONSORING AGENCY CODE Great Lakes National Program Office, U.S.EPA, Region V

15. SUPPLEMENTARY NOTES
David Rockwell
Project Officer

16. ABSTRACT

Lake Erie has experienced several decades of accelerated eutrophication and toxic substances contamination. During the latter part of the 1960s, remedial actions were planned and by the latter part of the 1970s, many of these plans were at least partially implemented. The first signs of lake recovery are now being observed through comprehensive monitoring programs. The intent of this report is to summarize the methods, findings and conclusions of the 1978-1979 Lake Erie Intensive Study. The report also contains a set of recommendations to insure continued improvement of the water and biotic quality of Lake Erie.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water quality, Biota, Epilimnion, Hypolimnion, Thermal, Total Phosphorus, Fish Contaminants, Diatoms, Nutrients, Biomass		

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