ADDITIONAL INDEX WORDS - Trend study area, resuspension, anoxic regeneration, epilimnion

LAKE ERIE CENTRAL BASIN
TOTAL PHOSPHORUS TREND ANALYSIS
FROM 1968 TO 1982

by

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ABSTRACT

The Lake Erie Central Basin trend study area total phosphorus data from 1968 to 1982 was analyzed to determine in-lake responses to the GLWQA phosphorus loading reduction program. The available data for each year were divided into five subsets according to time of year and depth of the water column. Each data subset was regressed as a function of time and total loading to Lake Erie. Linear regression analysis indicates that the in-lake phosphorus concentrations have been decreasing and are well correlated with decreased loadings to the lake. The highest concentration decrease with time of 0.56 ± 0.10 $mg \cdot m^{-3}$ yr^{-1} was obtained by using the data subset which includes epilimnetic concentrations from April to December for each year. This data subset also shows the highest correlation with decreasing lake loadings. Lake Erie offshore phosphorus concentrations have responded to decreasing external phosphorus loadings at a rate of 0.45 ± 0.09 $mg \cdot m^{-3}$ $(m \cdot t \times 10^3)^{-1}$ from 1968 to 1982.

RÉSUMÉ

On a analysé la tendance des données relatives au phosphore total dans le bassin central du lac Érié entre 1968 et 1982, de façon à déterminer la réponse du lac au programme de réduction de la charge en phosphore conformément à l'AQEGL. Les données recueillies chaque année ont été divisées en 5 sous-ensembles selon l'époque de l'année et la profondeur dans la colonne d'eau. Chaque sous-ensemble de données fut soumis à une régression en function du temps et de la charge totale dans le lac Érié. L'analyse de la régression linéaire indique que les concentrations de phosphore dans le lac ont diminué et qu'il y a une bonne corrélation avec la diminution des charges en cet élément dans le lac. La plus forte diminution dec concentrations en fonction du temps, 0,56 ± 0,10 $mg.m^{-3}a^{-1}$, fut obtenue par traitement du sous-ensemble de données portant sur les concentrations de l'épilimnion entre avril et décembre de chaque année. Ce même sous-ensemble montre aussi la plus forte corrélation avec la diminution des charges lacustres. Les concentrations de phosphore au large du lac Érié ont diminué à mesure que la charge en phosphore baissait à raison de 0,45 ± 0,009 $mg.m^{-3}$ $(t.m. \times 10^3)^{-1}$ entre 1968 et 1982.

EXECUTIVE SUMMARY

Lake Erie Central Basin Total Phosphorus

Trend Analysis from 1968 to 1982

Cultural eutrophication in Lake Erie and the other Great Lakes has been attributed to an increase in the in-lake phosphorus concentrations, due to increasing lake loadings. The Great Lakes Water Quality Agreement (GLWQA) was signed in 1972 to reduce nutrient loadings to the Great Lakes. The Lake Erie Central Basin total phosphorus data from 1968 to 1982 was analyzed to determine the in-lake response to the GLWQA phosphorus loading reductions.

The data set for each year was subdivided into five different subsets according to time of year, and according to the water column segmentation. The in-lake total phosphorus concentrations in all five data subsets showed a significant decline ($P < 0.01$).

This study has conclusively shown that both the phosphorus loadings to Lake Erie, and the in-lake concentrations have been decreasing at a rate of 1010 metric tonnes per year, and 0.56 $mg.m^{-3}yr^{-1}$, respectively, over the time period covered by the study.

RÉSUMÉ À L'INTENTION DE LA DIRECTION

Phosphore total du bassin du lac Érié

Analyse des tendances entre 1968 et 1982

L'eutrophisation d'origine anthropique dans le lac Érié et les autres Grand Lacs a été attribuée à une augmentation des concentrations de phosphores dans ce lac, vu l'augmentation des charges lacustres en cet élément. L'accord sur la qualité de l'eau des Grand Lacs (AQEGL) fût signé en 1972 dans le but de diminuer les charges des Grands Lacs en éléments nutritifs. Les données sur le phosphore total du bassin central du lac Érié entre 1968 et 1982 ont été analysées de façon à déterminer la réponse du lac aux réductions de la charge en phosphore conformément à l'AQEGL.

L'ensemble des données pour chaque année fut subdivisé en 5 sous-ensembles différents selon l'époque de l'année et la profondeur dans la colonne d'eau. On a observé une diminution importante ($P < 0,01$) de la concentration lacustre de phosphore total dans chacun des cinq sous-ensembles.

La présente étude a permis de conclure que les charges en phosphore dans le lac Érié ainsi que les concentrations lacustres de cet élément ont diminué respectivement à un taux de 1010 tonnes métriques par année et de 0,56 $mg.m^{-3}a^{-1}$ pendant la période consacrée à la présente étude.

LAKE ERIE CENTRAL BASIN PHOSPHORUS TREND ANALYSIS

INTRODUCTION

Environmental changes in fresh water ecosystems have been of interest to scientists for a considerable time. Changes caused by natural aging, ontogeny (Whiteside 1983), and changes caused by nutrient enrichment through man's impact on the environment, eutrophication, have both been important in the deterioration of water quality in the past century; the latter is thought to have had the most profound effect. Due to its morphology, Lake Erie has felt man's impact the most, because it is the smallest (in water content) and the shallowest of all the Great Lakes. In addition the Lake Erie basin has the highest human population and concentration of industries in the Great Lakes basin. A study on eutrophication of the Great Lakes revealed that man's impact had clearly accelerated eutrophy in Lake Erie (Beeton 1965). Vollenweider (1968) reviewed the subject of eutrophication and concluded that this problem was caused by the simultaneous loading of phosphorus and nitrogen to lakes. Later it was recognized that phosphorus was the most important nutrient responsible for eutrophication, and then, to a lesser extent, nitrogen.

Total phosphorus loadings to Lake Erie have been increasing since 1900 (Sly 1976, Chapra 1977), with the major increase occurring circa 1940 when phosphorus was introduced in detergents. The highest total loading to Lake Erie occurred in 1968, at 27,944 metric tonnes, and have been decreasing since then (Fraser and Willson 1981). This paper analyzes the available total phosphorus data for the Lake Erie Central Basin and reports on the trend that has developed from 1968 to 1982.

METHODS OF DATA ANALYSIS AND DATA SOURCE

The total phosphorus chemical analyses were done according to Philbert and Traversy (1973). Data analysis was restricted to a specific area in the Central basin, referred to as the trend study area. Reasons for using this approach have been documented in Rosa and Burns (1981, 1985). The thermal layers for each station were determined visually from temperature-depth traces, for each station in the trend study area. The epilimnion is defined as the topmost, well mixed, isothermal layer. If the station was found to be isothermal, with depth, it was considered to consist of only one layer, the epilimnion. All total phosphorus (TP) data pertaining to each respective layer, either epilimnion or surface to bottom, was averaged for individual stations in the trend study area. The station mean concentration of all the stations and surveys, was used to calculate the mean concentration for the periods; mid-June to mid-August, whole year (April to December) and spring-fall combined. The total phosphorus seasonal cycle was determined by averaging the monthly cruise mean concentrations for all years. The data collected by CCIW (NWRI) and CLEAR (OSU) was used for the trend analysis reported. Based on the results from of the "interlaboratory comparison network" the compatibility of the two sets of data is well accepted. The lake loading data were obtained from Fraser and Willson (1981), Fraser (1984) and from the Surveillance Work Group Annual Report to the International Joint Commission. The net loading data were obtained from Fraser (1984).

The phosphorus trend analyses reported here, is for the Central Basin offshore trend study area as established by Rosa and Burns (1981, 1984). The variability of chemical constituents with space, time, and depth, especially in the different thermal layers established by summer stratification (Burns 1976), was addressed in this study. The trend analyses reported in this study incorporates data collected by different agencies (Table 1), during the time period from 1968 to 1982. The data collected by EPA Region 5, in 1978 and 1979 was excluded since these data have been previously rejected by other investigators (Rathke et al. 1983, Kasprzyk, 1983).

No attempt was made to remove the seasonal component in the phosphorus trends reported because of the inconsistent sampling frequency and varying number of surveys from year to year. Removing the trend component will likely increase the statistical significance in a test of the slope of the regression line (Rosa and Burns 1981, 1985, Richards 1981). In this study the total water column was divided into two layers; epilimnion, and surface to bottom. The data pertaining to each respective layer was again divided into three time periods within each year. Thus a total of five different data sets resulted. The phosphorus concentration, from each data set, was used to test for trends as a function of time.

RESULTS AND DISCUSSION

The phosphorus reduction programs originated with the reports from the International Joint Commission (1970). Conclusions of a comprehensive study on Lake Erie, Project Hypo (1972), were that the phosphorus loadings to the lake must be reduced immediately if improvements to the deterioration of Lake Erie's water quality were to be improved (Burns and Ross 1972). Three investigators reported on the total phosphorus changes in Lake Erie over time. Lam et al. (1983) reported that the Central Basin total phosphorus concentrations in the epilimnion during the spring have dropped from 25.0 to 17.0 $mg \cdot m^{-3}$ from 1967 to 1978. Kasprzyk (1983) analyzed the Lake Erie data from 1974 to 1980, and concluded that no trend was revealed for the eastern portion of the Central Basin, but a decrease of 1.32 $mg \cdot m^{-3}$ yr^{-1} for the western portion of the Central Basin was observed. El Shaarawi (1984) has also reported a decrease in the Central Basin phosphorus concentration from 24.0 to 11.0 $mg \cdot m^{-3}$, with chlorophyll a responding to the phosphorus decreases during the period 1968 to 1980. The above results are not directly comparable since different areas, data source, and time-depth averaging procedures were used to establish the trends. However, irrespective of the procedure in data analysis used, the above authors have all reported a decreasing trend in the inlake phosphorus concentrations, for the Central Basin of Lake Erie.

The seasonal cycle for total phosphorus using averaged epilimnetic data from 1968 to 1982 is shown in Figure 1. Concentrations in the spring and fall periods are higher than the summer concentrations due to higher external and internal loadings. Internal loading, in the spring and fall periods (isothermal), is a result from wave induced resuspension of sedimented particulate matter (Rosa 1985, Lam and Jaquet 1976). Summer concentrations remain nearly constant due to lower external loadings and moderate biological production. Concentrations reach a minimum in early August and then begin to increase following fall turnover. Anoxic regeneration of soluble reactive phosphorus from reduced sediments may also contribute to this increase. Although most of the anoxic regeneration of phosphorus is confined to the hypolimnion (which is not included in the average) some transfer to the epilimnion may result from vertical mixing, lateral transport, and/or diffusion. Figures 2a to 2e show the relationship between concentration and time. The figures show the standard deviation of the yearly mean concentration, and the resultant regression line as indicated by arrows. In addition total loadings to Lake Erie from 1967-1982 are shown in Figure 2b (upper). The statistical results, using linear regression analysis of the five concentration trend lines and loadings (total and net), are reported in Table 2. The inlake concentrations (Figures 2a to 2e) and the loading data (Figure 2b upper) show a statistically significant ($P < 0.01$) decrease with time, over the study period. Figure 2a has the highest correlation coefficient, and as more data is added from different time periods (spring and fall) Figure 2b, or from different thermal layers (mesolimnion and hypolimnion) Figure 2d, less and less variability is explained about the regression line. This increasing unexplained variability is due to the incompatibility of these data sets as they are combined. In Figure 2c, the reduced correlation cannot be explained using the above reasoning, because data were not added from 2d to 2c but instead data were removed, i.e., spring and fall periods. Figure 2a may be best compared to Figure 2c, because both data sets are from the same time period (mid-June to mid-August). The analysis shown in Figure 2c contains additional data from the mesolimnion and the hypolimnion. The variability introduced by the additional data may be due to the near-linear chemocline in the mesolimnion (Burns and Ross 1972), physical/chemical/biological regenerative processes occurring at the sediment-water interface, and/or resuspension of particulates during the stratified period (Rosa, in prep., Charlton, pers. comm.). Nutrient regeneration under oxic and anoxic environment occurs at the sediment-water interface.

Burns and Ross (1972) found that the anoxic phosphorus regeneration rate in the Central Basin hypolimnion in 1970 was eleven times greater than the oxic rate during the anoxic period. The amount of phosphorus contributed to the hypolimnion by anoxic regeneration is dependent on the extent and duration of anoxia. Furthermore, sediment resuspension can contribute substantial amounts of phosphorus back into the hypolimnion in shallow zones (Rosa 1985). Because these processes are controlled by meteriological conditions (Lam et al. 1983), it is not surprising that variability exists in confined water masses in contact with the sediments, such as the hypolimnion during the thermally stratified period. This explanation is supported by the fact that the epilimnetic concentrations over the same time period (Figure 2a) have the lowest unexplained variability, because the epilimnion is not directly effected by regenerative processes. The net loadings to Lake Erie (input-output) also show a statistically significant ($P < 0.01$) decrease with time, of 894±120 m•t• yr^{-1} over the study period, (Table 2).

Load reductions to Lake Erie (Figure 2b) have been at a rate of 1010 ± 130 m•t•yr^{-1} (Table 2), primarily as a result of a reduction in the Detroit River loads (Fraser and Willson 1981) which contributes a considerable load to Lake Erie. The combined spring (April to June) and fall (September to December) in-lake concentrations (Figure 2e) were tested for trends and show a statistically significant ($P < 0.01$) decrease of 0.32±0.10 mg•m^{-3} yr^{-1} from 1968 to 1982.

The greatest reductions in the in-lake phosphorus concentration, of the five different concentration-time trends, are shown by the epilimnetic concentrations, April to December (Figure 2b). This decrease is equal to 0.56 ± 0.10 $mg \cdot m^{-3} yr^{-1}$. On the other hand, the least reduction of 0.32 ± 0.10 $mg \cdot m^{-3} yr^{-1}$ is shown by the surface to bottom concentrations in the combined spring and fall data (Table 2). The five seasonal data sets were regressed as a function of lake load (Table 2). The concentration data set which best correlated with the lake load was the epilimnetic concentrations from April to December (Figure 2b), while the lowest correlation was shown by the surface to bottom concentration from mid-June to mid-August. Since the external loadings to the lake are highest in the spring and fall periods, and lowest in the summer periods (Lam et al 1983), it would follow then, that epilimnetic concentration from April to December would best describe the in-lake response to reduced loadings. The summer epilimnetic concentrations could, however, describe the biological production response due to decreasing in-lake concentrations, resulting from external loading reductions. The lowest correlations with lake load were found when the surface to bottom data from mid-June to mid-August were used. Thus, the increased variability due to the contribution of internal loading during the stratified period seems to obscure the identification of trends to some extent.

CONCLUSIONS

The Lake Erie Central Basin trend study area phosphorus data was analysed from 1968 to 1982. The data set for each year was subdivided into five different subsets according to time of year, mid-June to mid-August, April to December, and spring-fall; and according to the water column segmentation, epilimnion, and surface to bottom. These data sets were regressed as a function of time (years) and lake load. The in-lake total phosphorus concentrations in all data subsets had a significant decline ($P < 0.01$) during the study period covered by this study. The epilimnetic concentration from April to December showed the highest decrease ($0.56\ mg{\cdot}m^{-3}\ yr^{-1}$) over the study period. This data set had the highest correlation with the lake load, and showed the highest response to decreasing lake loadings $0.45\ mg{\cdot}m^{-3}\ (m{\cdot}t{\cdot}\ x\ 10^3)^{-1}$. Further, these concentration decreases were highly correlated with loading reductions during the same period. The concentration data subsets from April to December were most responsive to reduced lake loading, and the summer data subsets being the least responsive. The lowest response with time and lake loadings was shown by the data subsets which included surface to bottom concentrations from mid-June to mid-August and the combined spring-fall concentrations. This lack of response was due to the contribution and variability of internal loading processes during oxic and anoxic periods. These processes are well known to occur, but as yet have not been quantifiable; therefore, more research is required in quantification of different internal loading processes, especially over the stratified season, when the effects of these processes are primarily confined to the hypolimnion. Although internal processes may somewhat mask in-lake response to reduced lake loadings, this data analysis has conclusively shown that Lake Erie Central Basin offshore phosphorus concentrations have responded to decreased lake loadings irrespective of the different time-depth averaging used.

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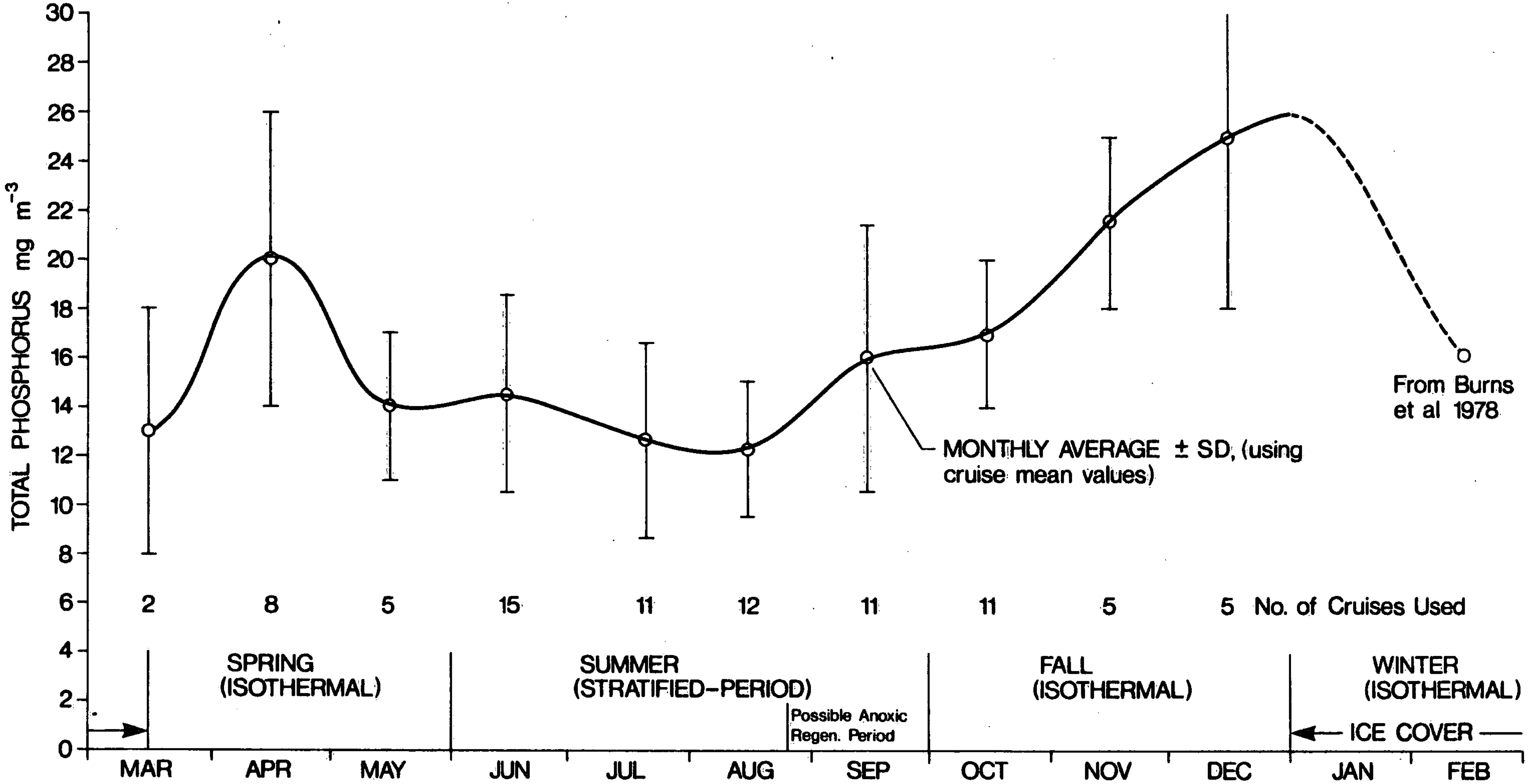
Table 1. Data Source

1968 to 1973 inclusive	CCIW (NWRI)
1974 to 1976 inclusive	CCIW (NWRI)/CLEAR (OSU)
1977 to 1979 inclusive	CCIW (NWRI)
1980 to 1982 inclusive	CLEAR (OSU)

Table 2. Total Phosphorus Trend Analysis Statistical Results

X	Y	Regression Coefficient ± Standard Error	Significance Level	Correlation Coeff.	N
Year	Lake load	-1010±130	P<0.01	-0.91	16
Year	Net load	- 894±120	P<0.01	-0.89	16
Year	*Epilimnion, mid-June to mid-Aug.	-0.51±0.08	P<0.01	-0.88	13
Year	Epilimnion, whole year (Apr. to Dec.)	-0.56±0.10	P<0.01	-0.85	15
Year	Surface to bottom, whole year (Apr. to Dec.)	-0.51±0.10	P<0.01	-0.81	15
Year	*Surface to bottom, mid-June to mid-Aug.	-0.35±0.09	P<0.01	-0.77	13
Year	**Spring & Fall	-0.32±0.10	P<0.01	-0.71	12
Lake-load	*Epilimnion, mid-June to mid-Aug.	0.36±0.11	P<0.05	0.69	13
Lake-load	Epilimnion, whole year (Apr. to Dec.)	0.45±0.09	P<0.01	0.80	15
Lake-load	Surface to bottom, whole year (Apr. to Dec.)	0.41±0.10	P<0.01	0.76	15
Lake-load	*Surface to bottom, mid-June to mid-Aug.	0.23±0.10	P<0.05	0.56	13
Lake-load	**Spring & Fall	0.23±0.09	P<0.05	0.68	12

*No data for years 1969 and 1976
**No data for years 1971, 1977 and 1978.



TOTAL PHOSPHORUS SEASONAL CYCLE FOR THE LAKE ERIE CENTRAL BASIN TREND STUDY AREA (using data from 1968 to 1982.)

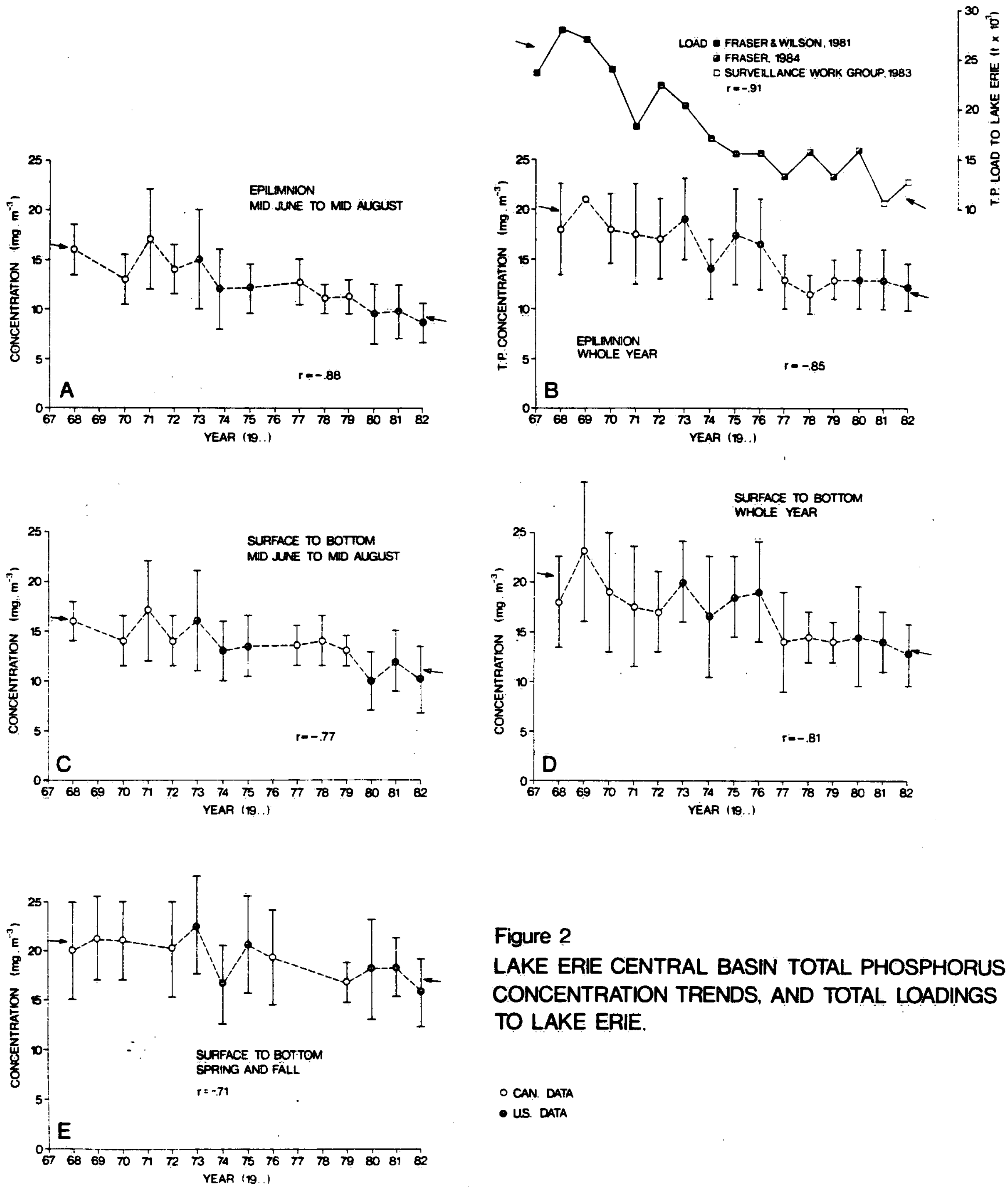


Figure 2

LAKE ERIE CENTRAL BASIN TOTAL PHOSPHORUS CONCENTRATION TRENDS, AND TOTAL LOADINGS TO LAKE ERIE.