PHOSPHORUS CONCENTRATIONS ALONG THE WESTERN SHORE OF LAKE ERIE

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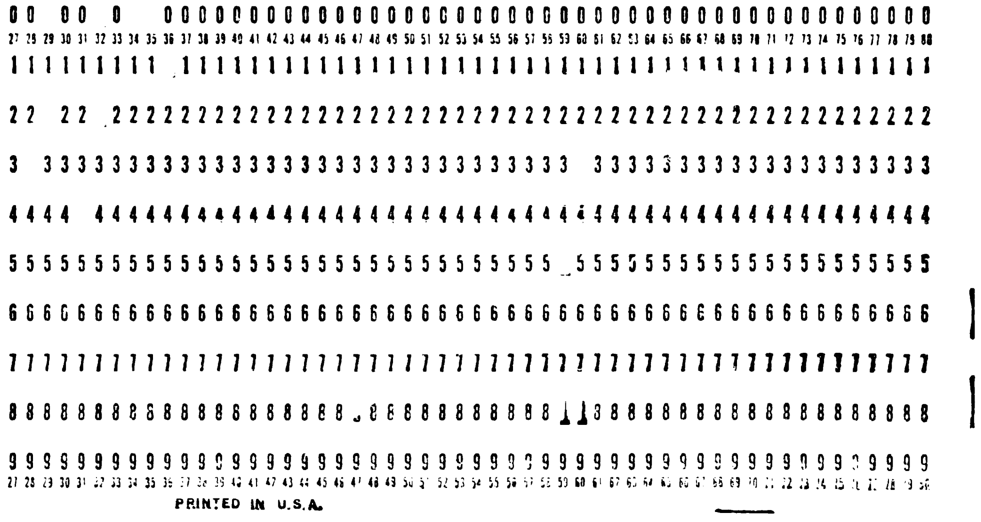

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PHOSPHORUS CONCENTRATIONS ALONG THE WESTERN SHORE OF LAKE ERIE

by

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ABSTRACT

PHOSPHORUS CONCENTRATIONS ALONG THE WEST SHORE OF LAKE ERIE

The concentrations of total and soluble phosphorus in the water and sediments near the west shore of Lake Erie were measured during 1970-1971. The analyses were performed to determine the effect of the heated effluent discharge from the Detroit Edison Monroe Fossil Fuel Power Plant on the aquatic ecosystem. Samples were collected at six lake stations, the Raisin River and the discharge canal from the plant. The study began one year before the plant became operational to obtain background data on the area. During 1971 the power plant experienced intermittant operation.

The phosphorus loading of the Raisin River was determined and compared to previous years data and other tributaries to the western basin of Lake Erie. During 1971 the Raisin River had a decreased phosphorus loading which was caused by a reduced flow into the study area. However, in contrast the sedimentary phosphorus concentrations increased significantly at seven stations during the same period. The increased phosphorus concentrations in the sediments were not related to temperature, dissolved oxygen concentrations, suspended solids or primary productivity. The Raisin River had significantly higher concentrations than all other stations. Approximately 35% of the sedimentary phosphorus was in an available form.

During 1970 the waters of the Raisin River had significantly higher phosphorus concentrations than the other 8 stations. The lake stations and discharge canal had uniform concentrations with no depth variation. During 1971 significant increases occurred at all inshore stations and station 6 in the lake. Increases in the discharge canal were attributed to the diversion of nutrient rich water from the river to the canal. Changes in primary productivity, temperature, and dissolved oxygen concentrations caused no apparent changes in phosphorus concentrations of the water.

The high phosphorus concentrations in the water and sediments of the study area largely prevented the determination of interaction between these concentrations and both chemical and biological changes in the study area. Algal blooms could be supported by a fraction of the phosphorus present in the water. Therefore, although the phosphorus in the water and sediment is in equilibrium, the sedimentary phosphorus concentrations would seldom be affected by biological conditions. The discharge canal was the only area affected by the operation of the power plant. This resulted in elevated temperatures and depressed oxygen levels in 1971. However, the principle factor at these stations was the introduction of nutrient rich water from the Raisin River. This water contained twice the background levels of phosphorus and caused significant increases in the concentration of phosphorus in the sediments and water of the discharge canal.

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INTRODUCTION

A Detroit Edison fossil fuel steam electric plant is under construction near the mouth of the Raisin River at Monroe, Michigan. The plant can generate up to 3,200 megawatts and requires up to 85 m^3/sec of water for its once through cooling system. The first of the plants four units was completed in March, 1971, and was operated intermittently throughout that year. During that period the temperatures of the cooling waters drawn from the lake and river increased a maximum of 10°C. The construction of the plant and the long term increasing phosphorus loadings to the western basin of Lake Erie has introduced the possibility that the heated effluent discharges would affect the complex interactions of algae and fish with regard to nutrient uptake and metabolic rates.

This research is part of a comprehensive ecological study of natural phosphorus levels in the water and sediments of Lake Erie's western basin. These data will be used to explain seasonal or related variations due to physical alterations, especially from the once-through cooling system on the Raisin River.

Lake Erie has gradually become a disposal basin for assorted anthropogenic wastes which raised the nutrient levels in that waterway. Verduin (1964) reported that the soluble phosphorus levels increased from 7.5 to 36.0 μg/l between 1950 and 1961. The Federal Water Pollution Control Administration also reported an increase in soluble phosphorus concentrations from 90 to 120 μg/l in the western basin of Lake Erie between 1963 and 1968. Various nutrients, broadly classified as micro or macronutrients, are essential to the metabolism of algae and aquatic macrophytes; and high levels stimulate their growth. The macronutrients are often the limiting factors. They include nitrogen, phosphorus, and carbon. For example, a relationship has been demonstrated between the growth of algae and the uptake of phosphorus. Thus, the growth of algae could be controlled if the input of phosphorus was reduced by regulating such uses as in detergents and eliminating the input from domestic and industrial wastes.

With the continual nutrient enrichment of Lake Erie, the annual phytoplankton crops have also increased (Arnold, 1969); and the lake has become more eutrophic. As the massive growths of algae blooms die and decay, they deplete the oxygen supply so young fish cannot survive either (Round, 1970). Furthermore, enriching the water with phosphorus also encourages the growth of large filamentous green and blue-green algae at the expense of small diatoms. The larger species are inferior food sources because they cannot be consumed by small zooplankton, an important link in the food chain between algae and fish.

The higher water temperatures shift the equilibrium between sediment and water concentrations and increase the solubility of nutrients in the water. In addition, the rate of organic decomposition and, therefore, of nutrient release is consequently accelerated. During the first year of the study, background or natural nutrient levels were measured to facilitate later comparisons of data when the heated effluent discharge began to elevate temperatures in the waterway.

DESCRIPTION OF THE STUDY AREA

General Description

The western basin of Lake Erie is a relatively small, shallow basin covering an area of 3,108 km^2 with an average depth of 7.3 m and a maximum depth of 19.2 m. A rocky island chain separates it from the larger central basin, which covers 16,317 km^2 with an average depth of 18.3 m (Chawla, 1970). The shallow western basin is generally well mixed and homothermous due to persistent wind driven water movements. Seiches, generally of less than 1 m, occur twice daily with an occasional movement of approximately 2 m. The total water movement results in thorough mixing, frequent resuspension of sediments, and general high turbidity. While the western basin comprises only 5 percent of the total Lake Erie volume, it receives 95 percent of the total tributary flow (Nalepa, 1972). The Detroit River contributes the majority of the inflow. The discharge averaged 5,800 m^3/sec during the study period (National Ocean Survey, 1969-1971). Other significant contributors include the Maumee River averaging 156 m^3/sec (USGS-Ohio, 1970-1971) and the Raisin River with an average of 21 m^3/sec (USGS-Michigan, 1970-1971). The interaction of the Detroit and Maumee Rivers, combined with the prevailing winds from the southeast, generally result in a counterclockwise water movement in the southwestern corner of the basin (Andrews, 1948) and a flow-through time of about two months (Verduin, 1969). The water velocity depends upon the depth and wind velocity. It averaged 1.0 cm/sec over a six-month period in 1970, while the wind velocity averaged

0.85 km/day. Although the water generally moves counterclockwise, the Raisin River discharge into the basin is an exception. Where it enters the lake, the water flows in a southerly direction before joining the major current.

The Monroe Power Plant

The Monroe Power Plant consists of four 800 megawatt power units. Each unit requires 3 pumps to circulate cooling water to condense steam from the turbine operation. Cooling water is supplied by pumping from the Raisin River. To facilitate discharge of the heated effluent, a discharge canal was constructed to carry the water to Lake Erie. The first unit of the plant was completed in March, 1971. While the cooling water was pumped fairly consistently throughout the year, the power generations and, therefore, heating of the water was limited and sporatic.

Sampling Locations

The specific Lake Erie study area centers on the mouth of the Raisin River near Monroe, Michigan, and includes 16.1 km of near shore lake water. Six lake stations (1 to 6) were positioned 1 to 2 km offshore (except No. 6 at 3 km) along a 25° azimuth parallel to the prevailing northeast current and north and south of the river mouth (See Figures 1 and 2). The stations were positioned far enough from shore to be representative of the lake and yet close enough that most would be gradually exposed to the warm water plume. Stations 1 and 6 were located where they could serve as controls throughout the project. The stations were generally 1.5 km apart except for station 6 which was 5.5 km southwest of station 5. The water depth at the lake stations was 5 to 6 m except for station 4 which averaged 3 to 4 m.

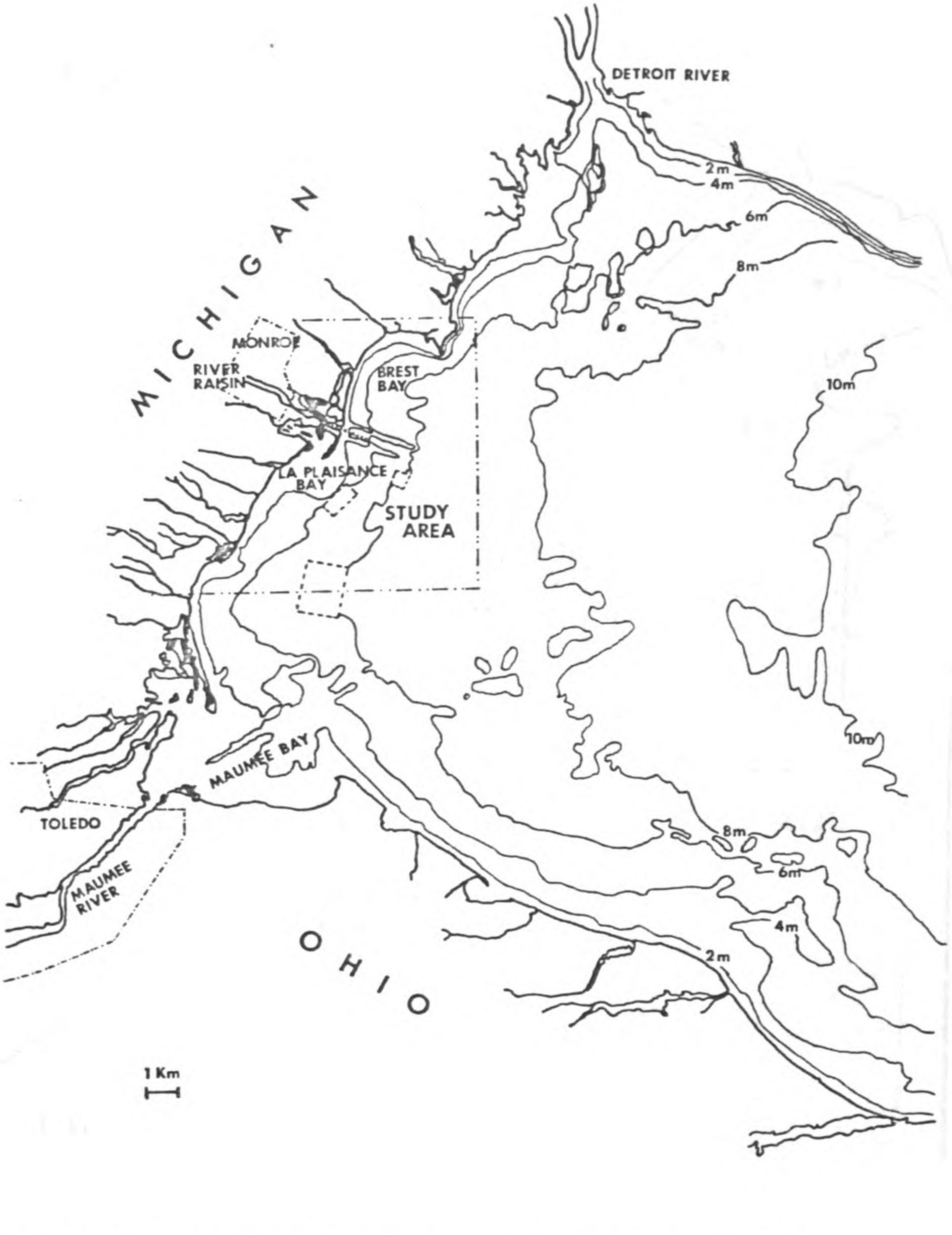

Figure 1. Map of the study area in relation to western Lake Erie.

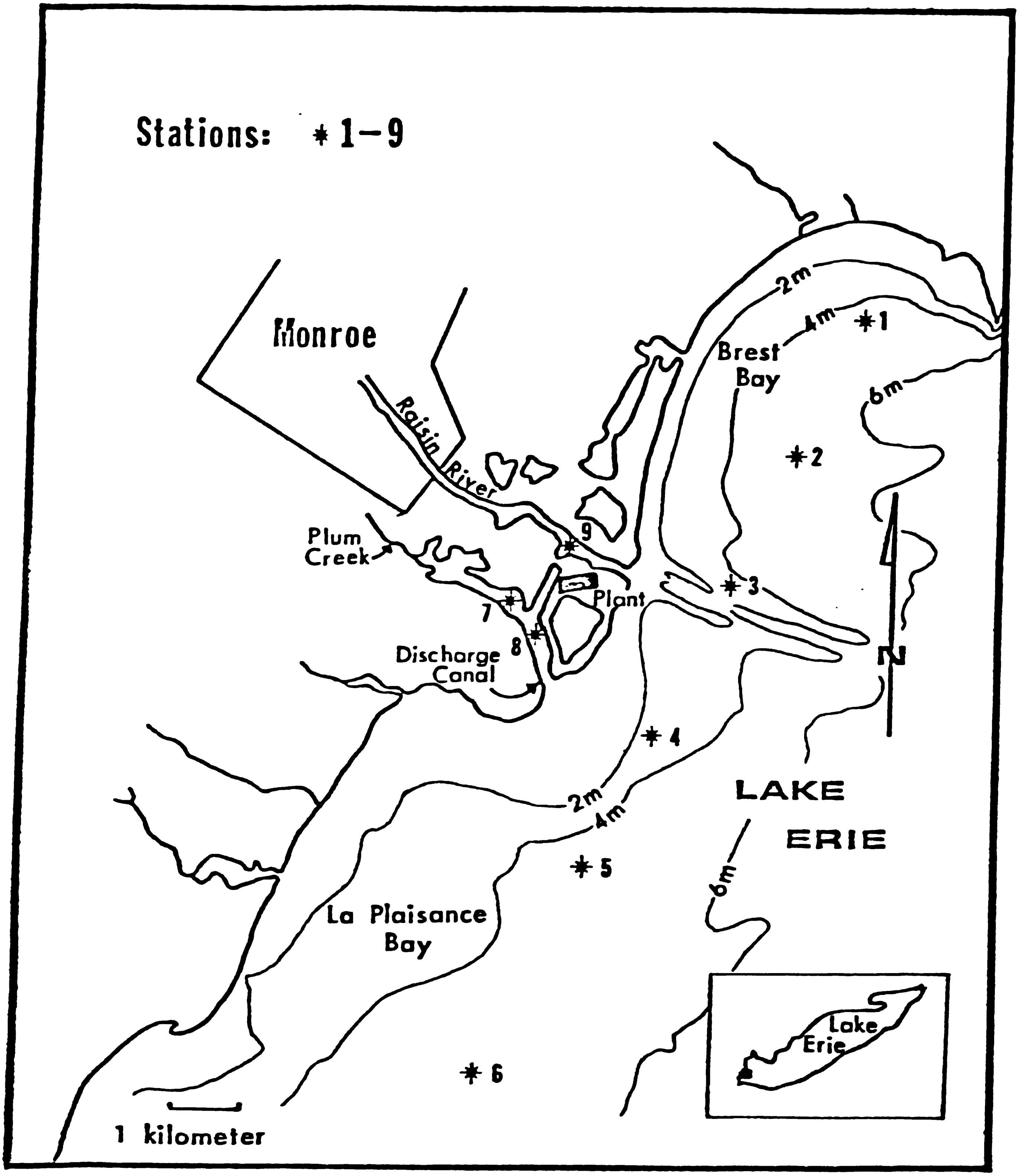

Figure 2. Map of the study area with the location of sampling stations.

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Plum Creek is a shallow embayment with a width of approximately 1 km, an average depth of 1 to 2 m, and flow of <1 m^3/sec into the discahrge canal. Station 7 is located near the intersection of the creek and the discharge canal.

The discharge canal was constructed south of the mouth of the River in 1969-1970 to carry the heated cooling water effluent from the steam-electric plant to the lake. The steep sided canal is approximately 150 m wide and 2,500 m long. It has been dredged to a depth of 6 to 7 m, and station 8 is located near its confluence with Lake Erie.

The Raisin River received substantial amounts of industrial and domestic pollution. Thus, the lower section must be dredged annually to maintain its 7.5 m depth. Since the power plant requires 120 m^3/sec of cooling water for peak capacity operation, the entire flow of the river (21 m^3/sec) is required with the remainder coming from Lake Erie. Station 9 was located on the river slightly upstream from the plant.

MATERIALS AND METHODS

The sampling period extended from May 1, 1970, to February 18, 1972. Samples were collected at approximately two-week intervals from May 1 to November 7, 1970, at all nine sampling stations. During the winter, incomplete collections were made on January 23 and February 18, 1971, at stations 1, 2, 7, and 8. More regular sampling was resumed on April 16 and continued through November 11, 1971, with the following exceptions. No samples were collected in early July, and those collected June 4 and August 17 were not analyzed. Partial collections were taken on December 2, 1972. Triplicate water samples were usually taken from each station at both 0.5 and 2.5 m, except for station 7 where only a 0.5 m sample was collected. The lake stations were marked by buoys, and replicate samples were taken approximately 30 m apart. The water samples were collected in clear Plexiglas, 8.1 liter Van Dorn Bottles. Then 1 liter of each was transferred to 1 liter amber polypropylene bottle. The remaining sample was reserved for phytoplankton and zooplankton analyses. During 1970 the samples were preserved with 2 ml of 8 N sulfuric acid as recommended by Charpiot (1969). However, with this procedure the total soluble phosphorus concentration was overestimated. Apparently the acid caused hydrolysis of organic phosphorus forms, lysis of cells, increased solubility of absorbed phosphorus, or some combination of these (Annett and D'Itri, 1973). Consequently 40 mg/1 of mercuric chloride was then used as a preservation and produced more accurate measurements.

At each station triplicate sediment samples were collected with a Ponar dredge during April, July, and September of 1970 and during May, August, and October of 1971. The samples were then stored in glass bottles at 4°C until they were analyzed.

Analysis for Phosphorus in Natural Waters

Natural waters contain both inorganic and organic phosphorus in particulate and dissolved forms. Therefore, the analyses were divided into two methods. Total phosphorus can be measured with an acid hydrolysis of all organic, metaphosphate, pyrophosphate, and other polyphosphates to orthophosphate. The total soluble phosphorus fraction is obtained by filtering the sample through a 0.45 μ Millipore filter and hydrolyzing the filtrate. Orthophosphate can be determined by analyzing an unhydrolyzed, unfiltered sample directly.

To measure phosphorus by the spectrophotometric method, the phosphorus atom is reacted with molybdate ions as a coordinating group. Because arsenic, silicon, germanium, and phosphorus all react similarly with molybdate to form heteropoly acids, the heteropoly acid of interest is separated from the interfering substances with a solvent extraction. Such methods of extracting these complexes into amyl alcohol were used as early as 1920. Since then, this important technique for extracting heteropoly acids has been applied with the following solvents: esters ketones, aldehydes, ethers, and chloroform-butanol (Olsen, 1967). The chloroform-butanol extraction mixture was chosen for this study because of its selectivity for the phosphomolybdic acid complex in the presence of arsenic, silicon, and germanium. The method used in this research is a modification of the procedure of Wadelin and Mellon (1953) and Sugawara and Kanamore (1961).

Analysis for Phosphorus in Sediments

The phosphorus concentrations in natural waters depend on how much is released from the sediments or introduced from other sources. The sedimentary phosphorus is generally bound in various solid phases, all of which have different solubility equilibria. They are affected by changes in temperature, pH, redox potential, and the concentration of other compounds. The rates and cycles for the transfer of phosphorus from sediments to water and the reverse have been determined (Mortimer, 1941). However, they are at least approximate and only apply in selective cases. The biological processes in the sediments also affect the phosphorus interchange (Gahler, 1969). Benthic organisms alter the sediments, and microorganisms can facilitate dissolving otherwise insoluble inorganic phosphates. In shallow waters physical processes such as wave action from winds, seiches, boats, and the natural flow of water all stir the sediments and may alter the phosphorus balance.

Generally, total phosphorus or fractions in soils or sediments have been analyzed with methods described as availability indexes. They have been widely accepted to measure the quantity of sedimentary phosphorus available for plant growth. With availability determinations the fractions of phosphorus in the soil have been correlated with crop response on acid soils. The phosphorus extracted by dilute solutions of strong acids can be correlated with the crop yield respond to phosphate fertilizers (Jackson, 1958). However, the degree of correlation has been much lower with neutral or alkaline soils. Nelson _et al_. (1953) found that a dilute hydrochloric-sulfuric acid mixture was the most effective of nine extraction solutions for three soil types. Olsen and Dean (1965) describe an extraction method with a 0.05 N hydrochloric acid and 0.025 N sulfuric acid mixture.

Olson and Dean's (1965) technique was used in this research project. However, after filtration through Whatman No. 42 filter paper, the sample was neutralized and run through the extraction process. The total phosphorus in the sediments was determined with the sodium carbonate fusion technique described by Jackson (1958). In preparation for each analytical technique, the sample was mixed in a Waring blender for two minutes. Then a separate aliquot of the homogenized mixture was oven dried at 110°C to determine its moisture content.

RESULTS AND DISCUSSION

Temperature

The lake stations exhibited similar seasonal trends, warming more slowly than the inshore stations in the spring and cooling more slowly in the fall (Figure 3). The discharge canal and Plum Creek began to show the affects of the intermittent heated effluent discharge after the plant began operation in March, 1971. Similar, positive responses are apparent in June, July, and late August. At times the temperature increase approached 10°C at the discharge canal; however, the overall average was much lower due to the interrupted plant operation. Since station 9 was upstream from the plant, it was not affected by the heated effluent. The temperature closely paralleled the lake stations which were quite uniform throughout both years. Some temperature variations could be accounted for by sampling over an 8 to 10 hour period.

Dissolved Oxygen

Dissolved oxygen levels in the lake varied uniformly throughout both years with a general slight decrease from surface to bottom. Stratification was generally minimized by wind induced mixing (Cole, 1972). The Raisin River had depressed dissolved oxygen levels through summer and fall of each year, reflecting the heavy organic loading it receives (Figure 3). During 1971 the plant operation resulted in depressed oxygen levels in the discharge canal and Plum Creek. The cooling waters frequently have low initial dissolved oxygen levels which are accentuated by the heating before discharge.

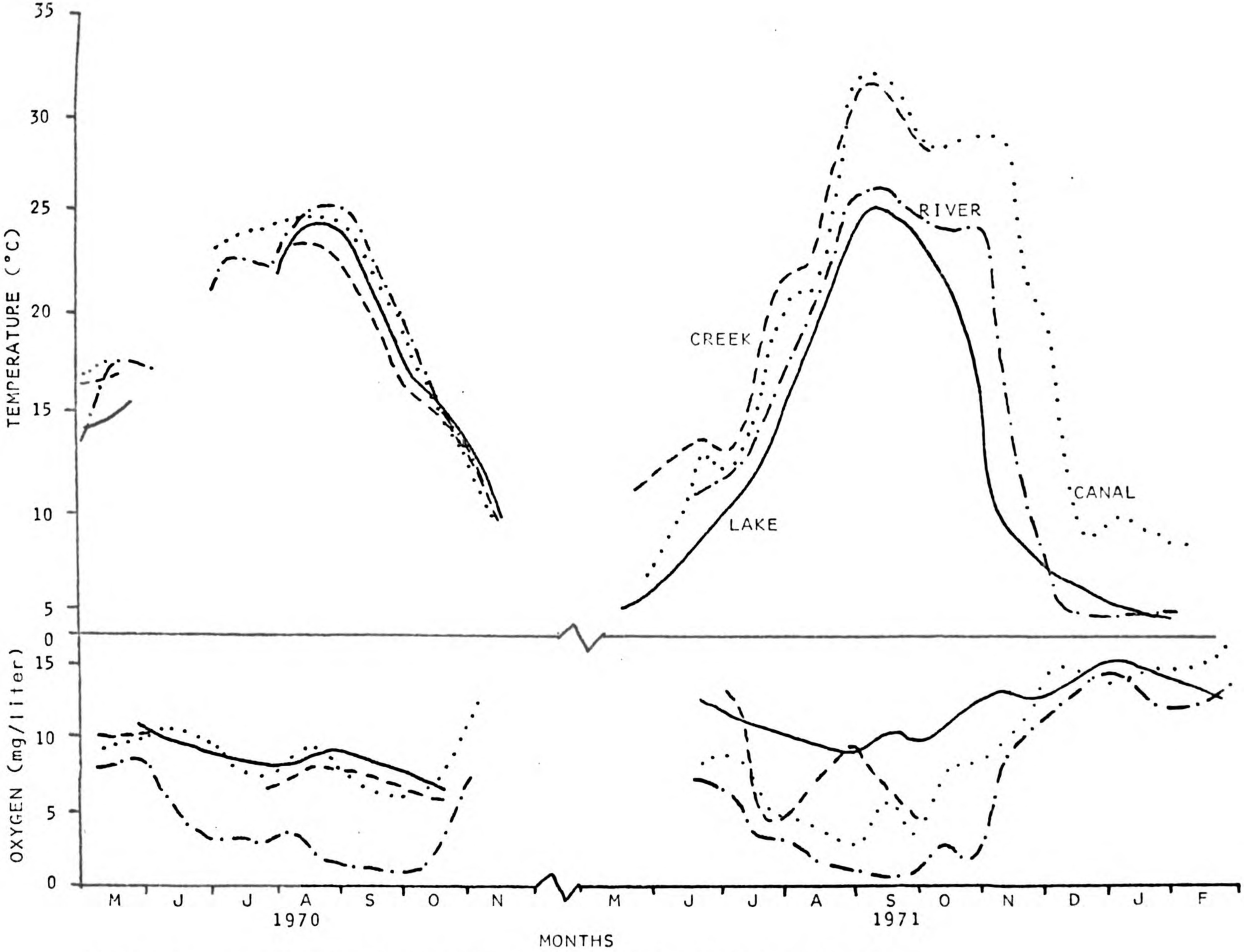

FIGURE 3. TEMPERATURE AND OXYGEN CONCENTRATION DURING 1970-1971.

Suspended Solids

Suspended solids, the total particulate matter larger than 0.45 μ, consisted mainly of detritus, plankton, and resuspended sediments. The Maumee and Detroit Rivers discharged considerable amounts of suspended solids to the western basin where most of them remained (Pinsak, 1967). Nevertheless, turbulence is believed to keep many solids suspended to the water. The levels at inshore stations were generally twice those of the lake stations. In the entire study area concentrations of suspended solids increased in the spring and fall. This was attributed to changes in the river concentration and wind velocity.

Nitrogen

During the 1970-1971 period, all stations measured the highest nitrate concentrations in the spring with the lowest values in August and September. In all instances, concentration differences with depth were negligible. The nitrate concentrations increased gradually from late summer through winter and then more rapidly during the spring thaw. The inshore stations averaged about 50 percent greater nitrate levels than the lake mean. The Raisin River was highest followed by the discharge canal and Plum Creek. In the lake, stations 4 and 5 had the highest average values with a constant, gradual decrease among the northern stations. In addition to agricultural runoff, domestic and industrial wastes probably account for the high nitrate concentrations in the river.

Primary Productivity

At the base of the food chain phytoplankton accounts for essentially all the primary productivity in the study area (Marcus, 1972). The Raisin

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River consistently produced the least while the discharge canal produced the most phytoplankton. Lake levels were always between these two. The canal's gross primary productivity averaged 537 g $C/m^2/274$ days, and the river averaged 276 g $C/m^2/274$ days. Greater diversity was found at the inshore stations. Primary productivity decreased with the depth and seasonal temperatures; but it increased noticeably during 1971, especially at the discharge canal and lake stations. The number of species also dropped (Cole, 1973). During 1970 the stations experienced an increase in primary productivity corresponding with a blue-green algal bloom. Beginning in late July the phytoplankton peaked in late August with normal levels present by mid-September (Marcus, 1972). In 1971 three periods of increased algal volumes were apparent. The largest standing crop occurred in August and again was attributed to blue-green algal. Peak volumes in June and October were caused by green algae (Kreh, 1973).

Sediments

The sediment column can be interpreted as a history of the lacustrine environment. It reflects past changes and present trends in eutrophication, water levels, climate, lake chemistry, and aquatic biota. During four major periods of glaciation, the Lake Erie basin was scoured out of shale, dolomite, and limestone bedrock. The modern lake began approximately 15,000 years ago as the last major ice sheet retreated northward (IJC, 1969). Therefore, the present lake sediments represent an accumulation of the erosion and sedimentation of the past 15,000 years. Glacial deposits in the lake bed are mostly sand, clay, and clay tills, although each basin now holds extensive mud deposits. Kemp and Lewis (1968) reported the non-organic components of the western basin to be 3.2 percent sand, 49.7 percent silt, s

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and 47.1 percent clay while Shock and Brett (1969) found 16.5 percent sand, 32.7 percent silt, and 47.9 percent clay. The inshore stations as well as station 6 and 2 are predominantly silt and clay while stations 3, 4, and 5 are mostly sand. The total iron concentrations range from 26.5 to 32.5 mg/g (dry weight) and average 29.5 mg/g.

The sediments remove much of the phosphorus from solution. Stumm and Leckie (1971) were able to precipitate phosphorus from solution with calcium, aluminum, and iron. The phosphate ions chemically react with Al^{+3} on the plate edges of the clay in the sediments. Phosphorus is also strongly absorbed on ferric hydroxide or organic complexes of ferric hydroxide in oxidized surface muds (Fitzgerald, 1970). In addition to chemical precipitation and absorption, phosphorus is translocated from solution to the sediments: (1) by incorporation into the tissues of allochthonous organisms, (2) as part of autochthanous organisms, (3) through erosion of phosphorus containing minerals and their deposition in unaltered form, and (4) by adsorption on precipitating particles (Wentz and Lee, 1969).

A central concern with regard to sedimentary phosphorus levels is whether or not the phosphorus is released into solution and made available to plants. Current opinions include the following; that sedimentary phosphorus is usually not available for plant uptake through resuspension or dissolution; that phosphorus may be released from sediments by certain chemical-physical phenomenon, such as strongly reducing conditions which occur in autumn before stratified, eutrophic lakes overturn; or that a exchange is brought about by biological activity. The latter two viewpoints have been widely accepted. However, some disagreement remains with regard to which of these mechanisms releases the most phosphorus.

Bacteria and fungi decompose organic matter in the sediments and resolubilize the phosphorus. Their activities depend upon the temperature, pH, amount and type of organic matter, and the chemical and physical composition of the sediments. Microorganisms also solubilize such normally insoluble inorganic phosphates as tricalcium phosphate, ferric phosphate and apatite (Gahler, 1969). The physical processes circulate and accelerate the distribution of the dissolved phosphorus and also resuspended some phosphorus independently. These physical mechanisms include: (1) natural currents and water flow, (2) stirring by boats, fish, seiches, (3) wind action, (4) eddy diffusion, (5) gas formations diffusional processes, (6) physical-biological processes, i.e., the movement of organisms in the sediments. The natural water currents, seiches, and wind action all affect the shallow basin and strong currents.

Phosphorus is stored in the sediment in a dynamic equilibrium with the water. The relative concentrations of phosphorus in each phase also depends upon such factors as temperature, pH, mineral concentrations, redox potential, and oxygen concentrations. Mortimer (1941) stated that the redox potential in the mud controls the distribution of dissolved substances in natural lake systems. When the surface oxidized micro ooze layer is destroyed, larger amounts of material are liberated and released into the water. Many lake muds contain ferric phosphate compounds which, due to their extremely low solubility, cannot penetrate into oxygenated water. When the redox potential is reduced below 0.23 volts or the oxygen levels fall below 0.5 mg/l, the ferric phosphate is reduced to ferrous phosphate which is substantially more soluble. Therefore, at the height of summer stagnation when all the dissolved oxygen is removed from the hypolimnion of a eutrophic lake, the concentration of many ions, including phosphorus, increases dramatically and continues until the autumn overturn when oxidation conditions are restored throughout the lake. After the ferrous phosphates are oxidized to ferric phosphates, the levels of soluble phosphorus decrease rapidly as they translocate into the sediments (Hynes and Greib, 1970; Stumm and Leckie, 1971; Li and Armstrong, 1973; Hayes and Phillips, 1958). Hayes and Phillips (1958) hypothesized that the soluble phosphorus compounds are either absorbed on a gel which is destroyed under reducing conditions, or as a phosphorus compound which is more soluble in its reduced form. The depth at which this exchange occurs in undisturbed sediments has not been established. Hayes (1952) calculated that the phosphate interaction affected no more than the top cm of mud. However, Holden (1961) suggested that the upper 15 cm are involved, and Hayes and Greib (1970) demonstrated the rapid movement of phosphorus ions from a depth of 2 to 4 cm in undisturbed sediments. Phosphorus transport at various depths is caused by the diffusion of pore waters. Phosphorus concentrations in the sediment and pore waters are in equilibrium. Therefore, when phosphorus is chemically or biologically released from the sediments it is transported to the pore waters. These waters are then mixed by molecular diffusion and the physical biological processes previously described.

The physical, biological, and chemical mechanisms interact to cause a migration of phosphorus from sediments even in apparently undisturbed, stagnant waters. Slow diffusions create turbulent eddys which then spread the dissolved substances in the water. Mortimer (1941) calculated that eddy diffusions continue after thermal stratification. They are 20 times greater than molecular heat conductance and 2,000 times as great as a coefficient of molecular diffusion.

Because phosphorus is important in soil fertility, various availability indices have been developed in efforts to determine how much phosphorus in soils may be available for plant uptake. These availability indices are correlated with plant response and yield. Because lake sediments can exchange phosphorus with overlying waters, availability indices have also been used to determine how much phosphorus in sediments may be available for plant uptake. The major forms of phosphate associated with the sediments are bound with aluminum, iron, or calcium containing compounds. The amount of available calcium phosphate is generally determined by a sulfuric acid extraction. Harter (1968) extracted ferrous phosphate complexes with sodium hydroxide while Jackson (1958) extracted both iron and aluminum complexes. Organic phosphorus may be extracted by sodium hydroxide after oxidation with hydrogen peroxide or by ignition. Wentz and Lee (1969) described a hydrochloric acid-sulfuric acid extraction technique similar to that of Jackson (1958). The combined acids extracted calcium phosphates and all loosely bound sorbed phosphorus including more $FePO_4$ than a one acid system extracted. Sediments absorb the most at a neutral or slightly acid pH. Above and below this, the sorption decreases rapidly. The combined acid extraction provided a pH of 1.1 which should be low enough to release all sorbed phosphorus (Wentz and Lee, 1969). The results of sedimentary phosphorus analyses are presented in Tables 1-3.

Numerous authors have reported on the sedimentary phosphorus levels in Lake Erie. Curl (1951) stated that total phosphorus levels in the island area averaged 15,000 µg/kg dry weight. Shock and Britt (1969) reported average values of 700 µg/g total phosphorus (dry weight) for the same area. Verduin (1969) found average total phosphorus levels of 760 µg/g in 1963-64 and 940 µg/g in 1967-68, both in the western basin. The Environmental

Table 1. "Available" phosphorus levels (µg/g-P dry weight) of sediment samples collected throughout the Lake Erie-Raisin River sampling area.

Station #	April 30, 1970	July 6, 1970	September 27, 1970	May 5, 1971	August 8, 1971	October 10, 1971
1A	32	94	86	74	150	113
1B	89	57	76	97	136	110
1C	94	65	35	94	126	89
2A	67	64	106	196	270	152
2B	136	73	106	200	220	203
2C	139	97	136	275	305	223
3A	65	42	48	59	92	57
3B	19	54	64	55	57	84
3C	75	103	86	47	81	69
4A	58	51	28	87	88	42
4B	41	31	43	85	100	54
4C	80	38	71	73	77	64
5A	47	--	110	260	184	189
5B	34	120	132	355	156	159
5C	106	108	92	260	243	260
6A	150	128	144	185	232	401
6B	190	117	133	256	393	418
6C	161	113	145	311	297	272
7A	184	154	181	428	197	510
7B	170	198	227	420	239	453
7C	288	250	188	473	382	403
8A	112	152	136	648	440	475
8B	208	147	156	529	341	362
8C	280	192	198	589	480	379
9A	554	319	566	420	694	460
9B	792	332	542	564	712	369
9C	260	312	519	346	561	335

Table 2. Average "available" phosphorus levels (μg/g-P dry weight) of sediment samples collected throughout the Lake Erie-Raisin River sampling area.

Station #	April 30, 1970	July 6, 1970	September 27, 1970	May 5, 1971	August 8, 1971	October 10, 1971
1	72	72	66	88	137	104
2	114	78	116	224	265	193
3	53	66	66	54	77	70
4	60	40	47	82	88	53
5	62	114	111	292	194	203
6	167	119	141	251	307	364
7	214	201	199	441	273	455
8	200	164	163	589	420	405
9	535	321	539	443	656	388

Table 3. A comparison of "available" and total phosphorus levels (μg g-P dry weight) in sediment samples. Averages of triplicate analyses.

Station	"Available" Phosphorus	Total Phosphorus	% Available
1	137	361	38
2	265	780	34
3	77	208	37
4	88	251	35
5	194	587	33
6	307	904	34
7	273	781	35
8	420	1106	38
9	656	1988	33
			35 - Average

Protection Agency (1973) determined that the total phosphorus levels of the sediments in the central and eastern basins averaged 865 μg/g dry weight of which an average of 75 percent was inorganic phosphorus. The total phosphorus concentration of the sediments at the six lake stations in this study area averaged 515 μg/g (dry weight) and ranged from 208-904 μg/g. A pair-wise comparison of means ($p<0.05$) of the total phosphorus data revealed the following relationships between stations: $\underline{3,\ 4,\ 1},\ \underline{5,\ 2,\ 7,\ 6},\ 8,\ 9$. The total phosphorus content of river station (9) is significantly higher than all the other stations while Plum Creek (7) is significantly higher than three of the lake stations. The discharge canal (8) contained more phosphorus than four of the lake stations. Among lake stations the levels decreased slightly with the progression from the mouth of the Maumee River. The average levels declined to the mouth of the Raisin River where they again increased. Then they declined again farther to the north. Apparently, the northerly currents sweep the nutrient loads of the rivers northward. Little accumulation is evident in these lake sediments, and the water action appears to be sufficient to suspend much of the material and sweep it from the area. A comparison of the percentages of clay and silt at the various stations reveals striking similarities. The stations are listed in order of decreasing magnitude for each parameter as follows:

Total phosphorus: 9, 8, 6, 7, 2, 5, 1, 4, 3
Percent clay and silt: 9, 6, 8, 7, 2, 1, 5, 3, 4

Thus, the total phosphorus is closely linked to the clay and silt fraction of the sediment and an identical comparison was made with the available phosphorus levels. A pair-wise comparison ($p<0.15$) of the available phosphorus data revealed the following relationship between stations: $\underline{4,\ 3,\ 1},\ \underline{2,\ 5}$, 6, 7, 8, 9. All three inshore stations are significantly higher than the lake stations. Among the latter, the concentration decreased northward from the mouth of the river, similar to that of total phosphorus. Table 3 indicates the relative percentage of total phosphorus which is available. For Lake Mendota, Wentz and Lee (1969) used the same extraction technique to determine that 50 percent of the total phosphorus was in the available form. In this study the average was 35 percent, and it was stable throughout all stations. The available phosphorus levels primarily reflect the amounts of soluble and calcium phosphates. Certain iron bound phosphate compounds are not included in the mixed acid extractions. These complexes could be of great importance because under anaerobic conditons the phosphorus may be released to the overlying water. Although the index represents only a portion of the available phosphorus and not the total available phosphorus, the sediment represents a significant reservoir of phosphorus for the lake basin.

The levels of sedimentary phosphorus in the study area are affected by numerous factors including the amount of mixing in the water, temperature, productivity of the overlying water, and the input of allochthanous phosphorus. While most of these variables could cause seasonal changes in the sedimentary phosphorus concentrations, none were apparent in this study. The Environmental Protection Agency (1973) reported seasonal variations in Lake Erie and related the variations to either redox potential in the sediment or phytoplankton uptake. Shock and Britt (1969) also reported that the iron and phosphorus content of the sediments decreased in Lake Erie due to high temperatures and low oxygen levels. Sample determinations revealed uniform diurnal variations in dissolved oxygen levels at the lake stations. During 1970 the Raisin River has consistently lower levels of dissolved oxygen while those in the discharge canal and Plum Creek more closely approximated the lake stations. During 1971 the Raisin River retained its characteristic low levels of dissolved oxygen while the discharge canal and Plum Creek exhibited lower levels in response to the initial use of the condensers. Variations with depth were reported for the lake stations. Some deficiency had occurred near the bottom in June, 1970, and remained until October 10, 1970. During stratification the deficit was more pronounced. Normal diurnal changes occurred at all stations. The oxygen depletion and resultant change in redox potential should decrease the sedimentary phosphorus levels due to translocation to the overlying water. This would most likely occur in either the discharge canal or the Raisin River because of their severe oxygen deficiencies in the summer and fall. The discharge canal had its highest levels of sedimentary phosphorus in April or May each year, followed by a drop in concentration by July and August and the maintenance of these levels through September and October. The Raisin River experienced high levels in April and September of 1970 and August of 1971. There was no apparent relation between dissolved oxygen levels and sedimentary phosphorus levels.

The Environmental Protection Agency (1973) reported that the sedimentary phosphorus content was negatively correlated with temperature. Therefore, phosphorus should be released from the sediments when the temperature increases in the overlying waters as occured at inshore stations during 1971. Elevated temperatures were more often measured in the discharge canal and Plum Creek due to the intermittent operation of the power plant (Cole, 1972). Contrary to expectations, the sedimentary phosphorus levels at these stations were significantly higher ($p<0.01$) during 1971. Apparently factors other than temperatures have a dominant influence on the sedimentary phosphorus content.

The amount of mixing of the water also affects the sedimentary phosphorus levels as the process suspends varying amounts of phosphorus containing material. The levels of suspended solids at the lake stations were highest in the spring and decreased on a gradient from south to north. This correlated with the decreasing concentration of total sedimentary phosphorus levels along the same gradient. Both apparently reflect the heavy loading of phosphorus from the Maumee River as it is carried northward by the prevailing currents and gradually dispersed.

Despite decreased phosphorus loading rates for the western basin in 1971 there was a significant ($p<0.05$) increase in the sedimentary phosphorus levels. All stations experienced increased levels and the analysis of variance indicated significant increases ($p<0.01$) at all stations except 3 and 9. During 1971 the cooling waters drawn from the Raisin River were diverted toward stations 7 and 8 and it was expected that these stations would experience increased sedimentation and sedimentary phosphorus levels. The levels in the Raisin River and station 3, off the mouth of the river, were essentially unchanged in 1971. Increased levels at the other lake stations were unexpected and are apparently unrelated to temperature, dissolved oxygen levels, and loading rates.

Major Tributaries to the Western Basin and Their Phosphorus Loadings

The four major tributaries to the western basin are the Detroit River, Huron River, Raisin River, and Maumee River. The four comprise essentially the entire water input to the basin and thereby determine its water quality. Because of their effect on the study area, the general characteristics and phosphorus loading of each will be discussed.

The Detroit River is dominant in the western basin in terms of quantity of flow, nutrient loading, and current influence. The river begins with the Lake Huron outflow and thereafter receives tributary drainage discharged to the St. Clair - Detroit River systems. Natural drainage water from throughout the various basins as well as extensive municipal and industrial wastes are discharged to the river from throughout the Detroit Metropolitan Area. Bahr (1972) estimated that during 1970 and 1971 the Detroit River contributed 97.5 percent of the total flow into the basin and 83.4 percent of the total phosphorus. Approximately 20 percent of the phosphorus was in the Lake Huron outflow while the remainder was added before the water reached Lake Erie. Municipal sources account for 55 percent of the total phosphorus, industrial sources 10 percent, and agricultural and assorted runoff 35 percent (IJC, 1969). During the study period the average discharge of the Detroit River was 212,000 cfs which contained a total of 30,655,260 lb of phosphorus in 1970 and 23,808,771 lb of phosphorus in 1971 (Bahr, 1972). When compared with the estimate of 35,200,000 lb of phosphorus discharged in 1966 (IJC, 1969), a gradual decrease in phosphorus loading is indicated.

The Huron River contributes a minor portion of both flow and phosphorus to the western basin. Although its drainage basin includes large areas of Metropolitan Detroit, Ann Arbor, and Ypsilanti, it accounted for only 0.25 percent of the total flow and 1.15 percent of the total phosphorus discharged during the study period.

The Maumee River contributed only 1.98 percent of the total flow to the western basin but 14.3 percent of the total phosphorus. During 1970 the Maumee River had a total phosphorus load of 5,234,781 lb and 3,082,479 lb during 1971 (Bahr, 1972). The river is the largest source of suspended solids to the basin and accounts for 40 percent of the total tributary output. The primary source is a large eroded sediment load from surrounding agricultural areas and also municipal wastes.

The Raisin River has a drainage area of 1.042 sq mi and contributes 0.24 percent of the entire flow to the western basin. It receives municipal effluent from the City of Monroe and various industrial wastes including reprocessed paper waste and plating plant discharges. Approximately 47 percent of the phosphorus loading is from municipal-industrial sources, and 53 percent is from assorted runoff. A yearly dredging operation is maintained in the last 2 km of the river to remove the organic sludge buildup (Kreh, 1973).

With flow data from the U.S. Department of the Interior, Geological Survey, and phosphorus concentrations determined in this study, the amounts of phosphorus flowing into the study area from the Raisin River were calculated. The average daily flow rate for the Raisin River was 588 cfs and 451 cfs respectively for 1970 and 1971. The average flow rates on sampling days were 405 and 179 cgs respectively. Therefore, the phosphorus loading (Table 12) was calculated from the average daily flow rates and phosphorus concentrations. Bahr et al. (1972) determined a total phosphorus loading for the Raisin River with flow data from the Geological Survey and phosphorus concentrations reported by various federal and state agencies. For 1970 and 1971 they determined that the loadings were 356,833 and 320,611 lb of phosphorus respectively. The major sources of differences between calculations in the two studies were the concentrations of phosphorus.

Bahr et al. (1972) also calculated the total phosphorus loading for the entire western basin of Lake Erie (Table 13). Flow data were taken for the mouths of the individual rivers, and the average phosphorus concentrations were obtained from several federal and state agencies. The four major tributaries carry significant waste loads consisting of municipal and industrial effluents and agricultural runoff. Municipal-industrial wastes account for 83 percent of the total phosphorus. Other minor sources of phosphorus include vessel wastes, dredging spoils and atmospheric fallout. Dredging spoils now add less than previously because they are taken to diked areas instead of being dumped in deep water disposal sites away from the river channel. The phosphorus loading decreased in each of the four rivers over the study period. The total loading to the basin reflected this as did a comparison with an estimated load of 30.1 short tons of phosphorus in 1967 (IJC, 1969). During 1970 and 1971 the western basin had loading rates of 0.63 gP/m^3/year and 0.47 gP/m^3/year respectively. Shannon and Brezonik (1972) studied the relationship between lake trophic states and phosphorus loading rates. A comparison with their values indicated a hyper eutrophic situation.

Table 4. Total phosphorus loading of the Raisin River, 1970-71.

	1970	1971	Total
Average concentration (mg/l-P)	0.24	0.28	0.26
Average daily flow (cfs)	588	451	520
Pounds per year phosphorus	277,400	248,200	525,600

Table 5. Phosphorus loading in the western Lake Erie basin during 1970 and 1971 (from Bahr, 1972).

	Flow Rate (cfs)		% Streamflow Contributed		Loading (Pounds Phosphorus)	
1970	1970	1971	1970	1971	1970	1971
Detroit River	205,000	219,000	97.16	97.9	30,655,260	23,808,771
Huron River	594	477	0.28	0.22	446,271	355,280
Raisin River	588	451	0.28	0.20	356,833	320,611
Maumee River	4,826	3,765	2.28	1.69	5,234,781	3,082,479
					36,693,145	27,567,141

Movement of Phosphorus Through the Western Basin of Lake Erie

Water movement in the western basin of Lake Erie is dominated by the flow of the Detroit River. Its influence is sometimes recognizable as far as the Ohio shore of the lake. The river flows through the middle of the basin and separates the Canadian and American influent waters. Inputs from the Canadian rivers are contained along the northeast area of the basin while those from the American rivers are contained in the southern and western areas (Figures 4 and 5). As a result, the waters from the Maumee and Raisin Rivers are restricted to coastal areas and remain relatively rich in nutrients. In the western basin outside the immediate influence of the Detroit River, the currents vary in direction and speed in correlation with the direction and intensity of the wind and seiches. The water flows in a northerly direction along the Michigan shore under all winds except those from the north, northwest, and northeast. After flowing almost due south into the basin, the dominant flow of the Detroit River progresses east toward Pelee Passage on the Canadian site and the water quality improved by dilution. The International Joint Commission (1969) reported that the average total phosphorus concentration in the western basin ranged from 160 μg/l at the mouth of the Detroit River to 50 μg/l at Pelee Point. Approximately 84 percent of the influent phosphorus remains in the lake primarily in the western basin. Bahr (1972) estimated that the influent phosphorus levels decreased 60 to 70 percent during passage from the western to eastern basin. This loss was primarily due to translocation to the sediments.

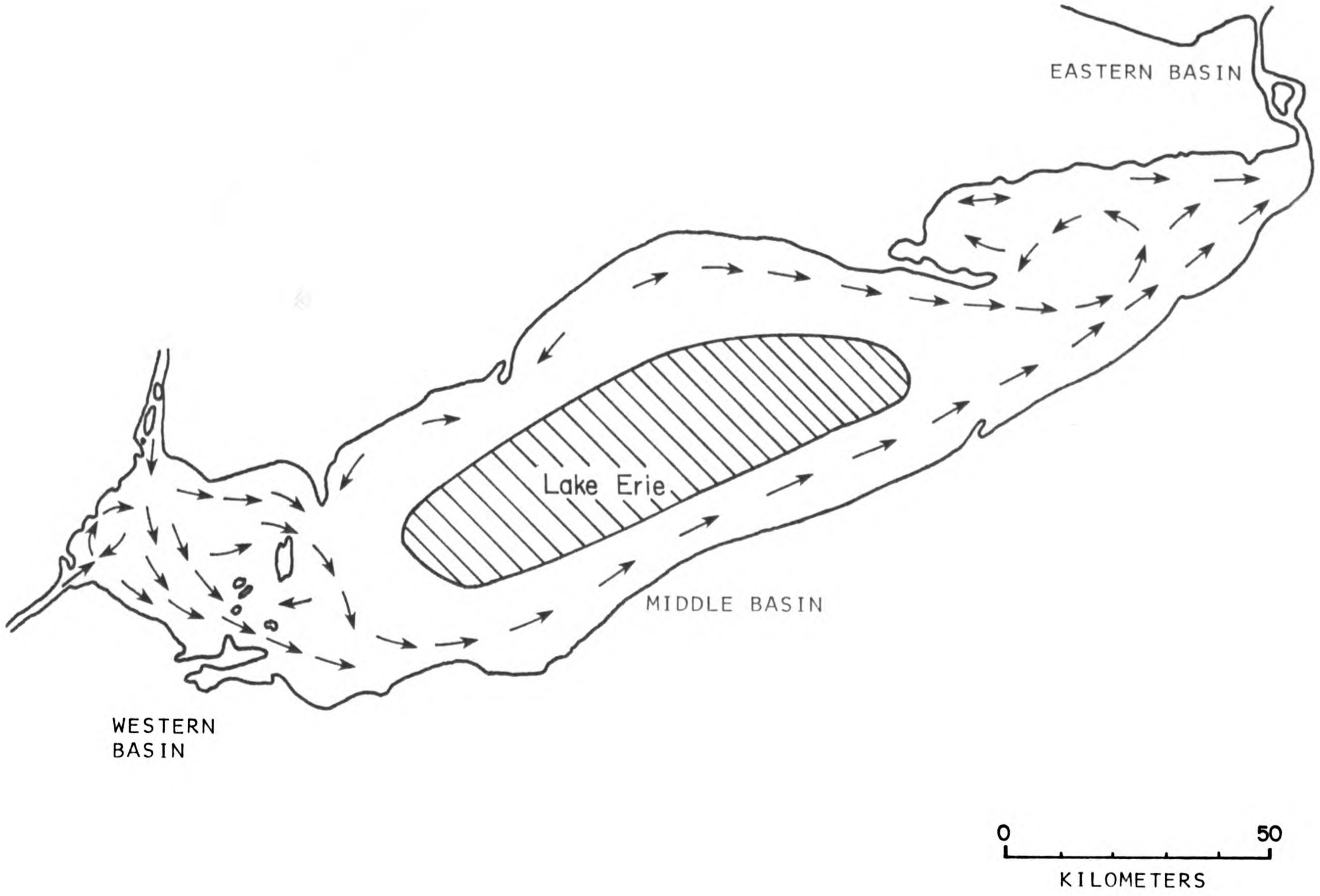

FIGURE 4. WATER MOVEMENTS THROUGHOUT LAKE ERIE.

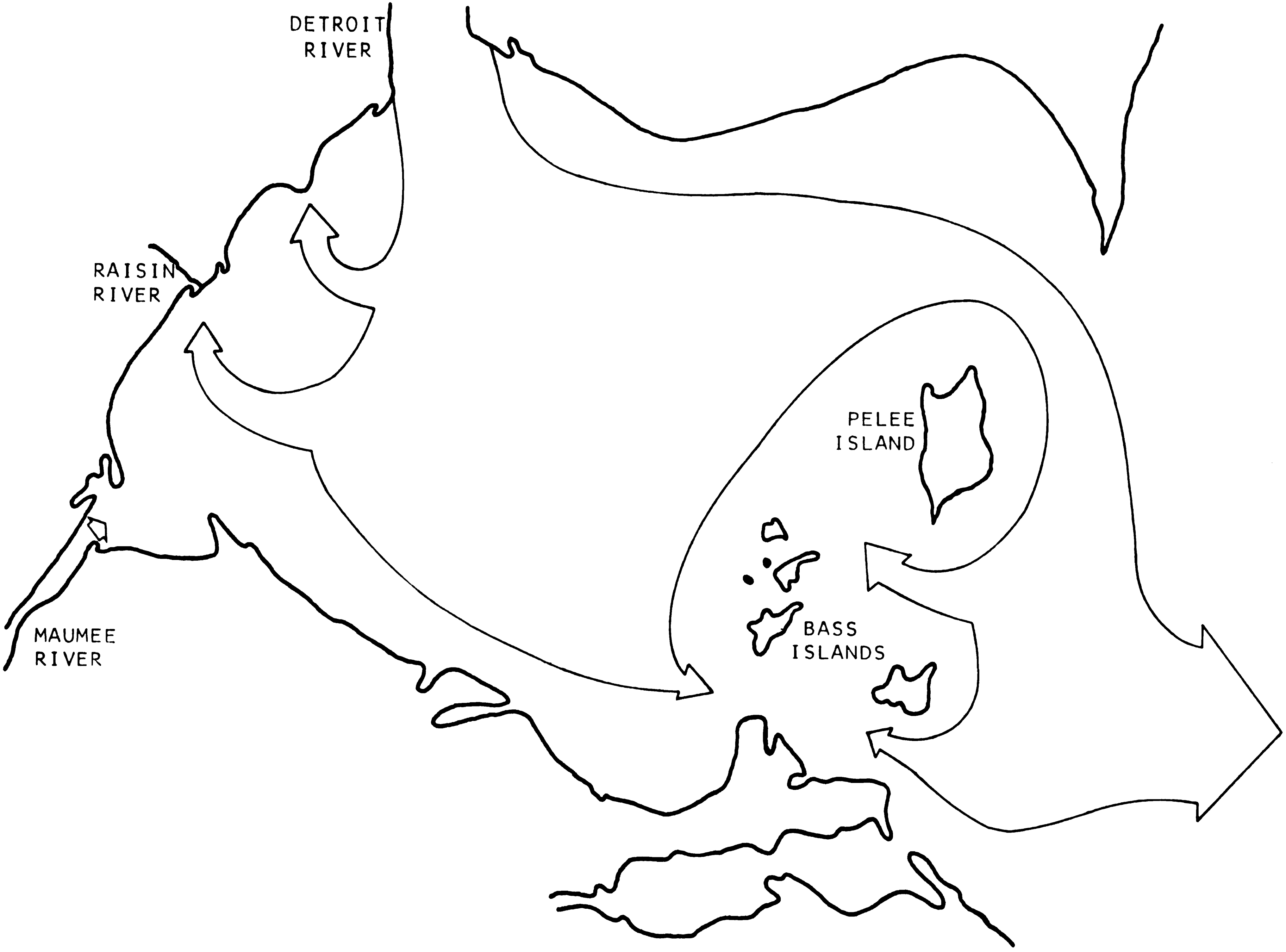

FIGURE 5. WATER MOVEMENTS IN THE WESTERN BASIN OF LAKE ERIE.

Phosphorus Concentrations of the Waters

The phosphorus concentrations of the waters in the study area are dependent upon numerous factors. These include the loadings of tributaries into the study area, the phosphorus content of the sediments, temperature, dissolved oxygen concentrations and other biological and chemical conditions. In addition to concentration, the "availability" of the phosphorus is important. To estimate the amount of phosphorus readily available for biological uptake the soluble phosphorus fraction is generally measured. However, because organically bound phosphorus may be biologically or chemically converted to soluble forms, this fraction must be measured and considered a reservoir of phosphorus along with the sediments. To obtain an accurate estimate of the phosphorus content of the waters in the study area both total and soluble phosphorus determinations were performed. Phosphorus concentrations are compared at different stations over the study period, and their relationship to biological and chemical changes discussed. The data along with ratios of the two fractions are presented in Tables 4-11 and Appendix III.

Phosphorus is an essential element in the growth of aquatic organisms. Phosphrous levels in the water have been related to numerous biological factors. Wong (1968) found that phosphorus uptake was related to primary productivity levels and temperature. Weiss (1969) demonstrated that algae quickly incorporate phosphorus into organic matter and that algae secrete organophosphorus materials. The zooplankton consuming the phytoplankton concentrate the phosphorus further and return a portion of the ingested phosphorus as fecal pellets (Rigler, 1961). Bacteria also quickly absorb phosphorus and provide food for zooplankton. Watt *et al*. (1963) determined that both bacteria and zooplankton incorporate dissolved organic and

Table 6. Average phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Soluble phosphorus

	Collection Number														
Station #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.11	0.06	0.09	0.04	0.05	0.04	0.05	0.04	0.08	0.07	0.07	0.06	0.07	0.12	0.09
2	0.10	0.09	0.07	0.04	0.06	0.04	0.03	0.04	0.16	0.08	0.09	0.05	0.06	0.09	0.07
3	0.12	0.07	0.05	0.04	0.05	0.05	0.06	0.06	0.12	0.07	0.09	0.06	0.06	0.07	0.08
4	0.11	0.10	0.07	0.05	0.05	0.04	0.06	0.05	0.10	0.09	0.11	0.09	0.05	0.08	0.07
5	0.21	0.09	0.04	0.06	0.05	0.05	0.06	0.05	0.11	0.09	0.08	0.06	0.06	0.07	0.13
6	0.09	0.13	0.05	0.06	0.03	0.04	0.05	0.05		0.05	0.09	0.04	0.06	0.07	0.06
7	0.11	0.13	0.06	0.08	0.04	0.05	0.07	0.05	0.10	0.09	0.06	0.04	0.06	0.08	0.08
8	0.07	0.12	0.07	0.06	0.03	0.09	0.08	0.09	0.11	0.08	0.07	0.05	0.05	0.07	0.05
9	0.18	0.12	0.15	0.17	0.10	0.19	0.13	0.20	0.26	0.08	0.25	0.14	0.25	0.15	0.21

Total phosphorus

	Collection Number														
Station #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.17	0.14	0.09	0.06	0.06	0.06	0.07	0.05	0.11	0.09	0.12	0.08	0.08	0.13	0.10
2	0.16	0.12	0.06	0.04	0.06	0.06	0.04	0.06	0.18	0.10	0.11	0.07	0.07	0.11	0.09
3	0.19	0.15	0.06	0.07	0.05	0.08	0.10	0.08	0.15	0.09	0.08	0.08	0.06	0.08	0.15
4	0.20	0.14	0.09	0.09	0.08	0.08	0.11	0.06	0.16	0.09	0.13	0.10	0.05	0.12	0.08
5	0.23	0.15	0.04	0.07	0.06	0.08	0.10	0.08	0.13	0.12	0.12	0.06	0.07	0.07	0.18
6	0.12	0.14	0.06	0.08	0.06	0.08	0.08	0.07		0.09	0.11	0.06	0.06	0.09	0.08
7	0.19	0.18	0.08	0.10	0.06	0.08	0.24	0.08	0.14	0.14	0.07	0.06	0.08	0.10	0.09
8	0.13	0.17	0.08	0.07	0.06	0.13	0.14	0.13	0.12	0.10	0.10	0.05	0.09	0.10	0.10
9	0.27	0.21	0.18	0.20	0.11	0.23	0.22	0.26	0.29	0.34	0.33	0.23	0.32	0.21	0.30

Table 7. Average phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Soluble phosphorus

	Collection Number														
Station #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.09	0.07	0.06	0.07	0.03	0.04	0.06	0.04	0.10	0.09	0.07	0.05	0.07	0.09	0.05
2	0.09	0.08	0.08	0.04	0.04	0.04	0.06	0.04	0.14	0.07	0.07	0.06	0.06	0.10	0.07
3	0.15	0.07	0.06	0.06	0.05	0.04	0.06	0.04	0.13	0.10	0.08	0.05	0.05	0.07	0.05
4	0.13	0.12	0.06	0.08	0.06	0.04	0.06	0.04	0.12	0.11	0.10	0.05	0.05	0.07	0.07
5	0.14	0.11	0.05	0.06	0.04	0.05	0.07	0.05	0.09	0.09	0.09	0.05	0.07	0.04	0.06
6	0.05	0.09	0.04	0.07	0.05	0.04	0.06	0.05		0.06	0.08	0.04	0.06	0.07	0.06
8	0.11	0.08	0.07	0.08	0.05	0.09	0.06	0.09	0.12	0.16	0.06	0.06	0.05	0.07	0.05
9	0.13	0.07	0.14	0.17	0.10	0.19	0.13	0.19	0.27	0.31	0.29	0.19	0.25	0.16	0.25

Total phosphorus

	Collection Number														
Station #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.16	0.13	0.10	0.08	0.05	0.08	0.09	0.07	0.13	0.12	0.12	0.07	0.08	0.11	0.09
2	0.15	0.11	0.05	0.07	0.04	0.06	0.10	0.06	0.16	0.08	0.11	0.07	0.08	0.15	0.09
3	0.19	0.16	0.07	0.08	0.06	0.07	0.08	0.09	0.14	0.11	0.10	0.05	0.07	0.09	0.09
4	0.18	0.18	0.08	0.09	0.08	0.06	0.09	0.06	0.14	0.14	0.12	0.08	0.07	0.08	0.11
5	0.21	0.15	0.07	0.08	0.07	0.08	0.09	0.07	0.14	0.12	0.11	0.07	0.08	0.06	0.27
6	0.14	0.11	0.06	0.08	0.05	0.06	0.08	0.06		0.10	0.11	0.06	0.09	0.11	0.08
8	0.16	0.14	0.08	0.10	0.09	0.12	0.15	0.11	0.14	0.23	0.08	0.07	0.09	0.14	0.09
9	0.25	0.16	0.16	0.14	0.11	0.25	0.22	0.23	0.30	0.36	0.23	0.29	0.30	0.19	0.33

Table 8. Average total phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

	Collection Number								
Station #	1	2	3	4	5	6	7	8	9
1	--	0.06	0.13	0.10	0.11	0.13	0.13	0.13	0.12
2	0.09	--	0.10	0.08	0.11	0.14	0.13	0.10	0.11
3	--	--	0.09	0.10	0.10	0.12	0.14	0.10	0.12
4	--	--	0.10	0.07	0.12	0.14	0.16	0.11	0.12
5	--	--	0.11	0.08	0.11	0.15	0.16	0.12	0.10
6	--	--	0.11	0.10	0.11	0.14	0.13	0.12	0.10
7	0.24	0.30	0.12	0.10	0.09	0.22	0.27	0.25	0.25
8	0.07	--	0.13	0.13	0.16	0.22	0.22	0.24	0.27
9	--	--	0.22	0.28	0.23	0.30	0.32	0.36	0.38

	Collection Number								
Station #	10	11	12	13	14	15	16	17	18
1	0.12	0.15	0.10	0.05	0.07	--	0.12	--	0.09
2	0.13	0.11	0.10	0.05	0.08	--	--	--	--
3	0.09	0.09	0.09	0.04	0.08	--	0.09	0.08	0.06
4	0.12	0.10	0.06	0.05	0.09	0.13	0.11	0.13	--
5	0.10	0.10	0.06	0.07	0.12	--	--	--	--
6	0.10	0.10	0.08	0.09	0.15	--	--	--	--
7	0.25	0.25	0.22	0.12	0.16	0.21	0.24	0.24	0.20
8	0.27	0.26	0.19	0.12	0.27	0.21	0.24	0.24	0.23
9	0.32	0.39	0.26	0.21	--	0.23	0.30	0.31	0.51

Table 9. Average total phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	Collection Number								
	1	2	3	4	5	6	7	8	9
1	--	0.07	0.12	0.12	0.10	0.15	0.14	0.11	0.16
2	0.09	--	0.10	0.12	0.11	0.11	0.13	0.11	0.16
3	--	--	0.17	0.08	0.10	0.13	0.14	0.09	0.11
4	--	--	0.11	0.11	0.08	0.14	0.23	0.11	0.12
5	--	--	0.09	0.13	0.11	0.15	0.15	0.11	0.09
6	--	--	0.07	0.09	0.09	0.13	0.10	0.10	0.11
8	0.07	--	0.14	0.19	0.16	0.25	0.27	0.25	0.29
9	--	--	0.22	0.28	0.25	0.33	0.29	0.37	0.33

Station #	Collection Number								
	10	11	12	13	14	15	16	17	18
1	0.15	0.14	0.11	0.05	0.07	--	0.12	--	0.08
2	0.14	0.11	0.12	0.08	0.09	--	--	--	--
3	0.12	0.10	0.08	0.09	0.08	--	0.10	0.08	0.06
4	0.12	0.36	0.08	0.06	0.11	0.14	0.11	0.13	--
5	0.10	0.10	0.09	0.07	0.11	--	--	--	--
6	0.11	0.11	0.09	0.08	0.14	--	--	--	--
8	0.27	0.30	0.19	0.11	0.25	0.22	0.24	0.24	0.23
9	0.41	0.44	0.30	0.19	0.25	0.23	0.32	0.32	0.52

Table 10. Average soluble phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	1	2	3	4	5	6	7	8	9
	Collection Number								
1	--	0.05	0.10	0.08	0.09	0.10	0.09	0.09	0.10
2	0.06	--	0.07	0.06	0.08	0.10	0.11	0.08	0.10
3	--	--	0.06	0.08	0.07	0.08	0.11	0.09	0.10
4	--	--	0.08	0.06	0.08	0.09	0.13	0.09	0.12
5	--	--	0.10	0.06	0.09	0.11	0.13	0.09	0.09
6	--	--	0.09	0.08	0.08	0.09	0.08	0.11	0.09
7	0.20	0.24	0.10	0.08	0.06	0.14	0.18	0.16	0.22
8	0.06	--	0.09	0.10	0.12	0.14	0.18	0.18	0.21
9	--	--	0.15	0.23	0.15	0.22	0.25	0.29	0.32

Station #	10	11	12	13	14	15	16	17	18
	Collection Number								
1	0.08	0.11	0.06	0.03	0.06	--	0.05	--	0.05
2	0.11	0.08	0.06	0.04	0.07	--	--	--	--
3	0.08	0.06	0.07	0.04	0.08	--	0.05	0.04	0.03
4	0.09	0.06	0.04	0.05	0.08	0.12	0.06	0.07	--
5	0.07	0.08	0.05	0.05	0.08	--	--	--	--
6	0.08	0.07	0.07	0.07	0.11	--	--	--	--
7	0.17	0.11	0.10	0.06	0.16	0.16	0.17	0.18	0.14
8	0.15	0.14	0.08	0.09	0.17	0.16	0.15	0.17	0.16
9	0.23	0.24	0.10	0.11	0.14	0.18	0.23	0.22	0.38

Table 11. Average soluble phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	Collection Number																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	--	0.05	0.08	0.10	0.08	0.12	0.11	0.09	0.13	0.11	0.09	0.07	0.03	0.07	--	0.07	--	0.04
2	0.08	--	0.06	0.09	0.08	0.09	0.10	0.08	0.11	0.09	0.07	0.06	0.04	0.08	--	--	--	--
3	--	--	0.11	0.06	0.07	0.08	0.13	0.08	0.08	0.09	0.06	0.05	0.05	0.08	--	0.05	0.04	0.05
4	--	--	0.07	0.08	0.06	0.11	0.17	0.09	0.10	0.10	0.28	0.04	0.04	0.09	0.12	0.07	0.07	--
5	--	--	0.06	0.07	0.09	0.11	0.12	0.09	0.07	0.08	0.07	0.06	0.06	0.07	--	--	--	--
6	--	--	0.05	0.08	0.07	0.10	0.08	0.09	0.10	0.08	0.07	0.06	0.06	0.10	--	--	--	--
8	0.06	--	0.09	0.14	0.11	0.18	0.23	0.18	0.21	0.16	0.15	0.08	0.09	0.17	0.17	0.15	0.17	0.15
9	--	--	0.16	0.20	0.16	0.21	0.21	0.27	0.27	0.26	0.23	0.09	0.08	0.25	0.28	0.23	0.22	0.39

Table 12. The average ratio of total:soluble phosphorus of water samples collected throughout the study area during 1970.

Station	May 1	May 15	May 27	June 10	June 24	July 7	July 21	
1	1.69	1.97	1.24	1.32	1.35	1.60	1.47	
2	1.51	--	--	1.27	1.14	1.73	1.48	
3	1.46	2.07	1.09	1.34	1.18	1.63	1.50	
4	1.59	1.44	1.27	1.33	1.45	1.62	1.61	
5	1.21	1.42	1.26	1.29	1.28	1.57	1.54	
6	1.79	1.11	1.36	1.25	1.42	1.71	1.12	
8	1.62	1.55	1.12	1.27	2.04	1.42	2.12	
9	1.67	1.88	1.13	1.26	1.10	1.23	1.68	
Average	1.57	1.63	1.21	1.29	1.37	1.56	1.56	
Station	Aug. 4	Aug. 18	Sept. 1	Sept. 15	Sept. 27	Oct. 10	Oct. 25	Nov. 7
1	1.54	1.38	1.28	1.65	1.26	1.20	1.13	1.35
2	1.54	1.11	1.23	1.35	1.30	1.29	1.36	1.26
3	1.64	1.14	1.14	1.02	1.21	1.29	1.24	1.85
4	1.44	1.36	1.16	1.17	1.24	1.29	1.34	1.48
5	1.41	1.34	1.31	1.35	1.37	1.12	1.18	1.53
6	1.39	1.11	1.63	1.29	1.44	1.25	1.46	1.31
8	1.40	1.09	1.43	1.42	1.12	1.71	1.66	1.96
9	1.26	--	1.19	1.22	1.59	1.43	1.34	1.36
Average	1.45	1.22	1.30	1.31	1.32	1.32	1.34	1.51

Table 13. The average ratios of total:soluble phosphorus of water samples collected throughout the study area during 1971-1972.

Station	April 16	May 1	May 20	June 17	July 15	July 29	Sept. 2
1	1.37	1.25	1.33	1.23	1.38	1.33	1.22
2	1.55	1.33	1.43	1.31	1.22	1.29	1.25
3	1.48	1.35	1.40	1.54	1.17	1.12	1.22
4	1.43	1.33	1.37	1.38	1.34	1.23	1.08
5	1.25	1.60	1.62	1.34	1.27	1.21	1.19
6	1.25	1.16	1.11	1.39	1.38	1.16	1.12
8	1.48	1.30	1.46	1.47	1.20	1.39	1.34
9	1.46	1.29	1.53	1.45	1.35	1.30	1.18
Average	1.25	1.33	1.41	1.39	1.29	1.25	1.20

Station	Sept. 16	Oct. 2	Oct. 15	Oct. 30.	Nov. 12	Dec. 19	Jan. 11	Feb. 18
1	1.41	1.43	1.59	1.47	1.05	1.94	--	1.72
2	1.36	1.45	1.78	1.63	1.14	--	--	--
3	1.29	1.54	1.35	1.32	1.02	1.90	2.04	1.57
4	1.25	1.35	1.83	1.30	1.13	1.67	1.84	--
5	1.32	1.40	1.44	1.56	1.45	--	--	--
6	1.29	1.48	1.26	1.28	1.43	--	--	--
8	1.78	1.92	2.31	1.33	1.54	1.59	1.42	1.45
9	1.49	1.73	2.85	2.11	--	1.34	--	1.35
Average	1.40	1.54	1.80	1.50	1.25	1.69	1.77	1.52

dissolved inorganic phosphorus into particulate phosphorus and then release both dissolved forms. Al-Khaly (1969) determined that phosphorus is absorbed across the gills of fish and is deposited in the bones and muscle. Macrophytes also take up mainly inorganic phosphorus with probable luxury storage (Gossett, 1971).

The total and soluble phosphorus levels in the study area were generally high and erratic ranging from 0.06 mg/l to 0.53 mg/l (Figure 6). The analysis of variance indicated no significant ($p<.01$) difference in concentration between the 0.5 m and 2.5 m depths. During 1970 the total and soluble phosphorus concentrations were uniform throughout stations 1 through 8 (Tables A9 to A12). Station 9 was significantly ($p<.05$) higher than all other stations on all but two collection dates. Despite the decreased 1971 phosphorus loadings from the Maumee and Raisin Rivers, significant increases occurred at stations 6, 7, 8 and 9 during 1971. The increased concentrations at stations 7 and 8 were attributed to the diversion of nutrient rich water from the river to the discharge canal. The increased concentration at station 9 was attributed to lower flow rates and higher phosphorus concentrations in the Raisin River. Throughout 1971 station 9 was significantly higher in concentration that the lake stations. After June of 1971 stations 7 and 8 also had concentrations generally significantly ($p<.05$) higher than the lake stations which were again uniform throughout. The lake stations had relatively high phosphorus concentrations in the spring of 1970, possibly due to spring runoff containing high phosphorus loadings. The Raisin River also had high concentrations at this time. The phosphorus concentrations, then cycled from a gradual decrease, to a peak concentration in August, and a gradual decrease once again. During 1971 data are lacking

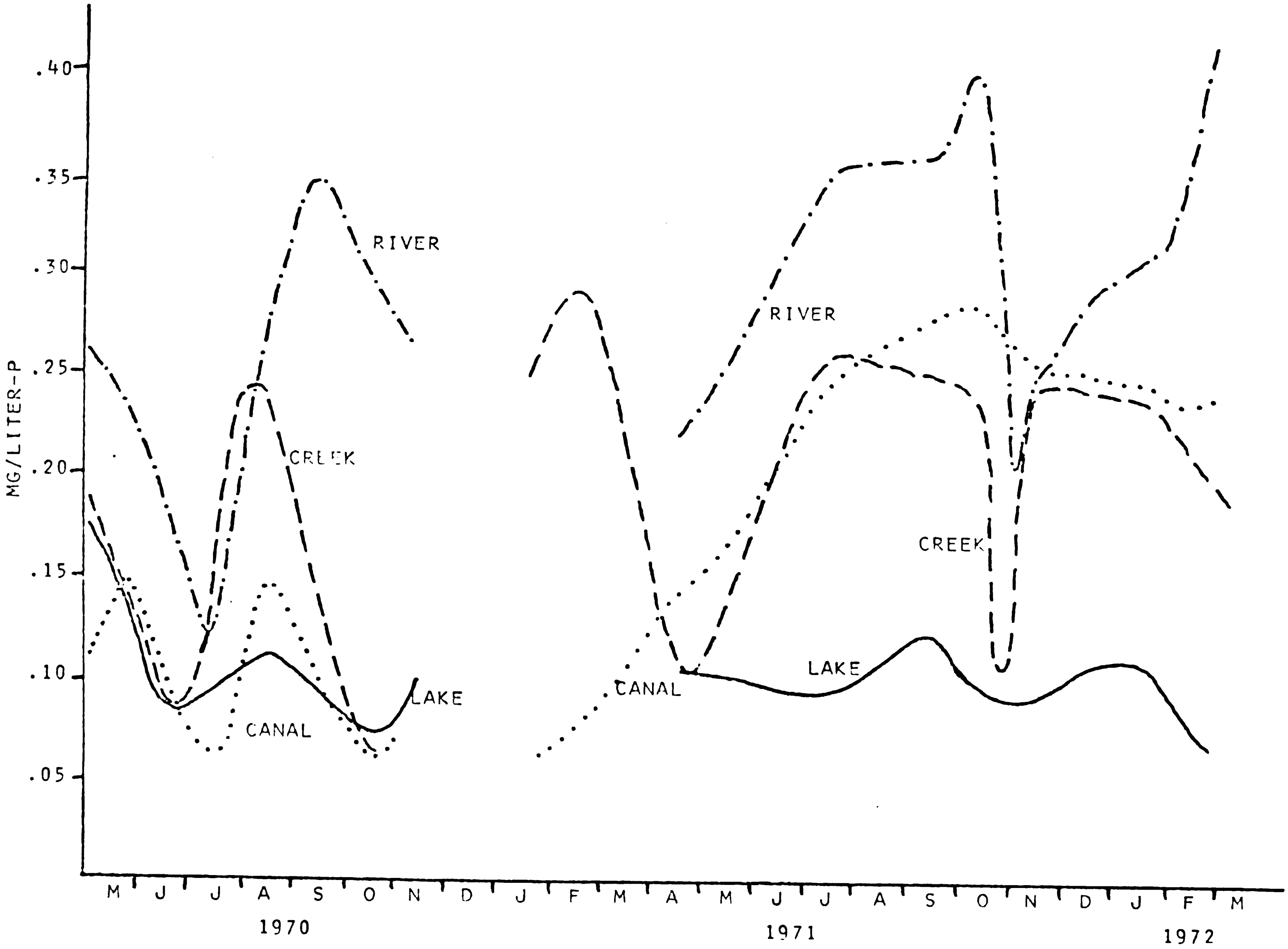

FIGURE 6. TOTAL PHOSPHORUS CONCENTRATIONS THROUGHOUT THE STUDY AREA.

for the spring period, however, a similar cycle appears to have occurred in the lake stations. Beginning with low concentrations in April a gradual increase occurred until the June-July peak and gradual decrease thereafter. The inshore stations exhibited a disruption in the pattern due to the diversion of flow to the discharge canal during 1971. The discharge canal experienced gradually increased phosphorus concentrations from 0.06 mg/l to 0.25 mg/l and the maintenance of these levels. Plum Creek experienced a cycle similar to 1970 with the exception that high levels were maintained in the fall except for one October sample. The Raisin River had high erratic values throughout 1971.

Significant increases in total and soluble phosphorus occurred during the August 1970 phytoplankton bloom. In 1971 the phosphorus levels were higher throughout the months of April to October. Although phosphorus concentrations were elevated during periods of increased primary productivity, the two factors are not necessarily related. During periods of increased biomass it was expected that large amounts of phosphorus would be incorporated into organic matter, thereby increasing the total:soluble phosphorus ratio. The ratios were higher for inshore stations and varied inconsistently throughout the study periods. There was no significant correlation of the total:soluble phosphorus ratios and primary productivity. Because of the rapid uptake and excretion of dissolved phosphorus by algae, it is possible that total:soluble ratios could remain similar under bloom conditions. During the periods of increased primary productivity, there was no evident decrease in soluble phosphorus concentrations and no apparent loss of phosphorus from the sediments.

With the loss of dissolved oxygen from the water to the point of decreasing sediment redox potentials, it is possible to experience a loss of phosphorus from the sediment to the overlying waters. When comparing the dissolved oxygen values and phosphorus concentrations of this study, the only apparent relationship occurred in September of 1970 in the Raisin River. Upon the depletion of dissolved oxygen a coincident increase of phosphorus concentrations was determined. Because of the nature of the Raisin River with fluctuating phosphorus loadings it is difficult to definitely correlate the two factors. During 1971 there was no apparent change in phosphorus values upon oxygen depletion.

It is also difficult to correlate the phosphorus concentrations and temperature changes. The only stations directly affected by increased temperatures from the plant operation were 7 and 8. These stations were also subjected to the constant input of high nutrient water diverted to the discharge canal. Thus, although significant increases in phosphorus concentrations did occur at the stations it is extremely difficult to attribute these increases wholly to one factor. The increased concentration of phosphorus in the sediments of the stations would indicate that temperature was a minor factor. Assuming a constant phosphorus loading the phosphorus concentration of the water would be expected to rise as the water temperature increased, with a resulting decrease in the sedimentary phosphorus levels. The simultaneous increase of phosphorus concentrations in both water and sediments would indicate a greatly increased phosphorus loading to the area which makes it difficult to evaluate the actual effects of the temperature changes in the system.

CONCLUSION

Phosphorus loadings to the study area decreased during 1971 and may provide encouragement for the future of the region. Phosphorus loadings had undergone gradual, long term increases causing the present eutrophic state. Continued decline could indicate a response to improved wastewater treatment facilities.

Despite decreased phosphorus loading the sedimentary phosphorus levels increased significantly at seven stations in 1971. These increases could not be directly related to primary productivity, dissolved oxygen or temperature. Because the power plant experienced limited operation in 1971 the effects of the heated effluent were limited to stations 7 and 8. These stations both experienced significantly increased sedimentary phosphorus concentrations. The increases were attributed to the increased phosphorus loading to the discharge canal during 1971. The increased loading resulted from the diversion of water from the Raisin River to the discharge canal. Influent concentrations after the diversion were approximately double the background levels of the discharge canal.

Significant increases in the phosphorus concentrations of the waters at stations 6, 7, 8 and 9 occurred in 1971. These increases were unrelated to primary productivity, dissolved oxygen levels or temperature. Increased concentrations at station 9 were attributed to the reduced flow of the Raisin River providing a lack of dilution. The increased levels at stations 7 and 8 were caused by the diversion of high nutrient water from the river to the discharge canal. Station 6 was the only lake station having a significant change in concentration, and the cause was unexplained.

The high phosphorus concentrations in both the water and sediments of the study area prevented the determination of interaction between phosphorus concentrations and chemical and biological changes in the study area. Algal blooms could be supported by a fraction of the phosphorus present in the water and not affect the sedimentary phosphorus levels. As a result there was no significant relationship between primary productivity and phosphorus concentrations. During the study period temperature affects were limited to the discharge canal. However, an overriding factor at these stations was the introduction of high nutrient, cooling water. The occasional dissolved oxygen depletion at some stations could have caused the release of some sedimentary phosphorus. These equilibrium shifts were not of sufficient magnitude to cause a significant change in the high phosphorus concentrations of either the water or sediments.

Therefore, the affect of the power plant has been the diversion of cooling water from the Raisin River to the discharge canal and the resultant increase of phosphorus concentrations at stations 7 and 8. Because the power plant experienced limited operation during the study period, these observations are of limited use in determining long term affects. As the heated effluent plume extends into Lake Erie perhaps more pronounced developments may occur. The high background phosphorus concentrations in the study area indicate that very limited, additional phosphorus related damage will be caused by the heated effluent discharge.

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APPENDICES

APPENDIX I

Procedure for the Analysis of Phosphorus in Natural Waters

When using the chloroform-butonal extraction solvent for phosphorus analysis, both the relative proportion of butanol and chloroform and the acidity of the aqueous solution are critical. A large proportion of butanol causes high sensitivity but also increases interferences. Sugawara (1961) determined a crucial normality range of 0.4 to 0.8 N for the extraction. Therefor, both aqueous volume and the amount of concentrated hydrochloric acid must be carefully controlled to determine the proper pH.

The following equipment, reagents, and procedures were used to analyze for phosphorus in natural waters.

Apparatus:

1. Burrell wrist action shaker
2. 500 ml pear-shaped separatory funnels
3. Flat bottom, round 300 ml boiling flask
4. Boiling chips
5. Graduated cylinders
6. Millipore filter apparatus and 0.45 μ filters
7. Beckman DK-2A spectrophotometer

Reagents:

1. Stock phosphorus solution - Dissolve 0.4394 g of potassium dihydrogen phosphate (KH_2PO_4), which has been dried overnight at 105°C, in distilled water and dilute to 1 liter.

2. Working phosphorus standard solution - Dilute 10 ml of stock phosphorus solution to 1 liter with distilled water. 1 ml of this solution is equal to 1 μg of phosphorus as P.
3. Concentrated hydrochloric acid.
4. Concentrated nitric acid.
5. Sulfuric acid (3.6N) - Add 10 ml of concentrated sulfuric acid to 90 ml of distilled water.
6. Sodium hydroxide (1 N) - Dissolve 4 g of sodium hydroxide in 100 ml distilled water.
7. Sulfuric acid (0.2 N) - Add 2.8 ml concentrated sulfuric acid to 497 ml distilled water.
8. Ammonium molybdate solution (10 percent) - Dissolve 10 g of ammonium molybdate ($[NH_4]_6 Mo_9O_{24} \cdot 4H_2O$) 90 ml distilled water.
9. Phenolphthalein indicator solution - Dissolve 5 g of phenolphthalein ($C_{20}H_{14}O_4$) in 1 ℓ of 50 percent ethyl alcohol. Neutralize with 0.02 N sodium hydroxide.
10. N-butyl alcohol.
11. Chloroform-butanol solution - Mix 300 ml n-butyl alcohol with 700 ml chloroform.
12. Strong acid solution - Add 300 ml concentrated sulfuric acid to 600 ml distilled water. After cooling add 4 ml concentrated nitric acid and dilute to 1 liter with distilled water.

Preliminary Treatment: To analyze for total phosphorus, a 50 ml sample is quantitatively transferred to a 300 ml flat bottom boiling flask. The graduate is then rinsed with 10 ml of concentrated nitric acid, 4 ml of 3.6 N sulfuric acid and 2 or 3 boiling chips. The sample is heated until white sulfuric acid fumes evolve. At this point only a 1 or 2 ml slurry remains in the flask and all forms of phosphorus have been converted to orthophosphate. To measure total soluble phosphorus, the sample is initially passed through a 0.45 μ Millipore filter. Then the filtrate is treated in the manner described for total phosphorus. For an orthophosphorus determination, the sample does not require any preliminary treatment.

Extraction Procedure: Since the quantitative extraction of the phosphomolybdic acid complex into the chloroform-butanol mixture is a function of the pH of the aqueous solution, special precautions must be taken to insure that the acidity of the sample is correct. Following preliminary treatment the aqueous sample is neutralized. Then 4 ml of concentrated nitric acid are added, and the total volume is brought to 50 ml with distilled water.

For either the total phosphorus or total soluble phosphorus analysis, approximately 10 ml of distilled water and 2 drops of phenolphthalein indicator are added to each flask. Next the solution is titrated with 1N sodium hydroxide to the pink endpoint. Then it is back-titrated to a colorless endpoint with 0.2 N sulfuric acid. The neutralized sample is then transferred to a 50 ml graduate cylinder, and the boiling flask is rinsed with 4 ml of concentrated hydrochloric acid and two 10 ml portions of distilled water. They are also added to the graduate cylinder. The sample is then diluted to 50 ml and transferred to the separatory funnel. For the orthophosphate determination 46 ml of the sample and 4 ml of concentrated hydrochloric acid are transferred directly to the separatory funnel. For these tests the samples were always checked to insure that the solutions were neutral. However, the natural waters were usually in the pH range where no neutralizing procedure was required. The following steps in the determinations are identical for all phosphorus forms. First, 15 ml of the chloroform-butanol solution is added to the solution. Then the funnel is stoppered and shaken for five minutes with a pause to relieve the pressure. After phase separation the lower organic layer is drained and discarded. A second 15 ml aliquot of the chloroform-butanol solution is added. Then shaking is continued for an additional five minutes. After phase separation the lower layer is again discarded. At this point the aqueous phase containing the orthophosphate is saturated with chloroform-butanol while interferring colored complexes have been extracted into the organic phase and removed.

Saturation is important because the final volume of chloroform-butanol is critical. For each sample, exactly 10 ml of chloroform-butanol mixture must be retained throughout the extraction without loss to the aqueous phase. Otherwise, the concentration would change. The final step is to add 10 ml of the chloroform-butanol mixture and 4 ml of the 10 percent ammonium molybdate solution. The mixture is then shaken for five minutes. After phase separation the absorbance of the lower layer is measured at 310 nm.

To establish a standard curve with the working standard solution, pipet 0, 3, 7, 10, 13, 17 and 20 μg of phosphorus as P into separate 50 ml graduated cylinders. Add 4 ml of concentrated hydrochloric acid to the samples and then fill to volume with distilled water. The samples are then transferred to separatory funnels and carried through the extraction procedure. In these tests after a standard curve was established, the 0 and 10 μg standards were checked daily for possible contamination and to insure that the instrument was operating properly. The standard curve was very stable. The absorbance of the samples was determined with a Beckman DK-2A spectrophotometer. The scale expansion feature of this instrument made it possible to detect 0 to 20 μg phosphorus with a sensitivity of 0.2 μg.

During the development of the analytical procedure, the following parameters were refined to optimize the sensitivity:

Wavelength: A wavelength analysis confirmed the maximum absorbance for the phosphomolybdic acid complex was in the range of 306 to 311 nm (Wadlin and Mellon, 1953). As a result, 310 nm was used to analyze the phosphomolybdic acid complex.

Reproduceability: The standard curve was exceptionally stable throughout the period of analysis. During the multistep procedure in the extraction process, the major source of error is likely to be the technician. When the analytical procedure has been mastered, 10 μg replicate standards are easily reproduced within ± 0.005 absorbance units or 0.1 μg. Several spiked samples demonstrated 90 to 100 percent recovery.

Interferences: The major interferences in the determination of phosphorus are arsenic, silicon, and germanium. They are of specific concern in the selective extraction of the phosphorus heteropoly acid. Therefore, 10 μg standards of phosphorus spiked with 50 μg of arsenate and silicate were analyzed. Because the absorbance readings of the spiked samples equaled the unspiked standards, clearly, the high levels of arsenate and silicate did not interfere. Only the phosphomolybdic acid complex was selectively extracted.

Loss of phosphorus during hydrolysis: Two sets of standards, each consisting of 0, 2, 4, 6, 8, and 10 μg-P samples, were established from the standard working solution. One set was hydrolyzed and neutralized according to the procedure described above while the other was analyzed directly. The absorbances for each set were essentially identical, showing no loss upon hydrolysis.

Normality: The normality depends upon the amount of acid and the final volume of the aqueous solution. Sugawara and Kanamori (1961) reported a peak efficiency of the extraction procedure from a 0.4 to 0.8 N solution.

In a similar experiment, as the normality increased, so did the extraction efficiency until an aqueous volume of only 14 ml was reached. The use of a 50 ml volume was a compromise based both on necessity and practicability. To transfer all of the neutralized sample from the boiling flask to the separatory funnel, at least 30 ml was required. The 50 ml volume was easily measured and resulted in a favorable absorbance range for the standard curve.

Preservative: Sulfuric acid was used as a preservative in the first year of the study and 40 mg/l mercuric chloride was substituted thereafter. As reported by Annett and D'Itri (1973) sulfuric acid caused a positive error in the determination of total soluble phosphate due to the hydrolsis of other phosphorus compounds. The total soluble phosphorus levels increased substantially after the acid was added. However, with a mercuric chloride preservative, the soluble phosphate concentrations were stable for at least two weeks. The trends were similar in a study conducted with Lake Erie samples.

Contamination: Since the most likely sources of contamination were the various chemical reagents, these were checked daily. The use of Millipore filters introduced another possible source of contamination in the total soluble phosphorus determination. Therefore, on three occasions five filter pads from three different packages were rinsed with distilled water, and the rinsing water was analyzed for phosphorus. In each instance the results indicated no contamination.

APPENDIX II

Table A1. Total phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Station #	May 1	May 15	May 27	June 10	June 24	July 7	July 21	August 4
1A	0.14	0.15	0.10	0.06	0.07	0.05	0.06	0.05
1B	0.21	0.12	0.07	0.06	0.08	0.06	0.07	0.05
1C	0.15	0.14	0.10	0.06	0.04	0.06	0.08	0.06
2A	0.14	0.12	0.07	0.03	0.06	0.06	0.04	0.06
2B	0.16	0.13	0.05	0.04	0.06	0.06	0.05	0.06
2C	0.14	0.11	0.07	0.06	0.07	0.07	0.04	0.07
3A	0.18	0.14	0.05	0.05	0.05	0.08	0.09	0.08
3B	0.19	0.14	0.06	0.08	0.05	0.07	0.11	0.07
3C	0.20	0.16	0.06	0.07	0.06	0.08	0.09	0.09
4A	0.17	0.13	0.08	0.09	0.08	0.08	0.12	0.06
4B	0.19	0.14	0.09		0.09	0.08	0.09	0.07
4C	0.23	0.16	0.09	0.08	0.07	0.07	0.11	0.08
5A	0.31	0.14	0.05	0.07	0.06	0.09	0.11	0.08
5B	0.20	0.14	0.04	0.08	0.07	0.08	0.10	0.08
5C	0.17	0.16	0.04	0.07	0.04	0.07	0.09	0.07
6A	0.12	0.13	0.07	0.07	0.05	0.08	0.08	0.07
6B	0.11	0.15	0.06	0.11	0.07	0.08	0.09	0.07
6C	0.13	0.13	0.06	0.07	0.07	0.07	0.07	0.07
7A	0.22	0.19	0.07	0.09	0.06	0.09	0.24	0.08
7B	0.14	0.16	0.07	0.10	0.07	0.08	0.22	0.09
7C	0.20	0.18	0.09	0.11	0.05	0.08	0.25	0.08
8A	0.10	0.17	0.09	0.10	0.04	0.13	0.12	0.13
8B	0.12	0.19	0.08	0.05	0.07	0.12	0.17	0.13
8C	0.18	0.16	0.07	0.06	0.06	0.14	0.14	0.13
9A	0.25	0.22	0.18	0.17	0.12	0.22	0.21	0.25
9B	0.32	0.21	0.17	0.18	0.10	0.24	0.22	0.27
9C	0.24	0.20	0.19	0.24	0.10	0.23	0.23	0.25

Table A1 (cont.) Total phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Station #	August 18	September 1	September 15	September 27	October 10	October 25	November 7
1A	0.13	0.06	0.11	0.05	0.06	0.21	0.11
1B	0.10	0.12	0.11	0.06	0.08	0.09	0.11
1C	0.10	0.09	0.13	0.12	0.09	0.08	0.09
2A	0.20	0.12	0.10	0.06	0.07	0.10	0.07
2B	0.18	0.10	0.11	0.07	0.06	0.10	0.09
2C	0.15	0.08	0.12	0.08	0.07	0.12	0.12
3A	0.17	0.09	0.08	0.12	0.05	0.08	0.18
3B	0.16	0.10	0.06	0.07	0.08	0.08	0.16
3C	0.12	0.07	0.11	0.06	0.05	0.08	0.11
4A	0.14	0.06	0.13	0.17	0.06	0.08	0.11
4B	0.16	0.07	0.13	0.06	0.06	0.18	0.09
4C	0.17	0.15	0.13	0.06	0.04	0.09	0.08
5A	0.14	0.11	0.12	0.06	0.07	0.07	0.10
5B	0.13	0.13	0.11	0.06	0.07	0.08	0.10
5C	0.12	0.11	0.13		0.06	0.07	0.33
6A		0.07	0.11	0.09	0.07	0.11	0.07
6B		0.11	0.11	0.05	0.06	0.10	0.08
6C		0.09	0.12	0.04	0.06	0.06	0.08
7A	0.17	0.12	0.07	0.05	0.07	0.10	0.11
7B	0.10	0.13	0.09	0.08	0.07	0.11	0.07
7C	0.14	0.16	0.05	0.05	0.09	0.08	0.09
8A	0.11	0.12	0.10	0.04	0.08	0.09	0.10
8B	0.13	0.11	0.10	0.07	0.08	0.13	0.10
8C	0.11	0.08	0.09	0.05	0.11	0.09	0.09
9A	0.28	0.34	0.22	0.23	0.33	0.19	0.31
9B	0.31	0.40	0.30	0.22	0.37	0.20	0.33
9C	0.27	0.29	0.46	0.24	0.27	0.25	0.25

Table A2. Total phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Station #	May 1	May 15	May 27	June 10	June 24	July 7	July 21	August 4
1A	0.16	0.13	0.11	0.08	0.06	0.08	0.09	0.08
1B	0.15	0.13	0.11	0.07	0.05	0.08	0.09	0.06
1C	0.17	0.12	0.08	0.08	0.05	0.07	0.08	0.07
2A	0.18	0.11	0.05	0.09	0.04	0.07	0.10	0.06
2B	0.15	0.12	0.05	0.04	0.05	0.06	0.09	0.06
2C	0.12	0.11	0.06	0.07	0.04	0.06	0.11	0.06
3A	0.21	0.16	0.07	0.04	0.07	0.07	0.07	0.07
3B	0.18	0.14	0.06	0.08	0.05	0.07	0.09	0.08
3C	0.19	0.17	0.07	0.11	0.05	0.07	0.09	0.07
4A	0.14	0.17	0.09	0.08	0.06	0.06	0.10	0.07
4B	0.21	0.19	0.08	0.08	0.09	0.06	0.08	0.05
4C	0.19	0.19	0.08	0.10	0.09	0.07	0.08	0.06
5A	0.24	0.14	0.06	0.07	0.06	0.08	0.07	0.07
5B	0.17	0.16	0.08	0.08	0.06	0.08	0.08	0.08
5C	0.21	0.14	0.07	0.08	0.08	0.07	0.12	0.07
6A	0.13	0.11	0.06	0.08	0.04	0.05	0.06	0.05
6B	0.14	0.11	0.06	0.10	0.06	0.06	0.08	0.06
6C	0.14	0.10	0.07	0.07	0.05	0.07	0.09	0.07
8A	0.16	0.14	0.09	0.11	0.07	0.12	0.17	0.12
8B	0.18	0.15	0.08	0.13	0.12	0.11	0.14	0.10
8C	0.15	0.12	0.07	0.07	0.09	0.13	0.15	0.12
9A	0.24	0.18	0.15	0.27	0.09	0.25	0.19	0.24
9B	0.26	0.16	0.15	0.24	0.11	0.26	0.22	0.21
9C	0.24	0.14	0.14	0.21	0.12	0.23	0.26	0.24

Table A2 (cont.) Total phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Station #	August 18	September 1	September 15	September 27	October 10	October 25	November 7
1A	0.12	0.13	0.11	0.06	0.10	0.15	0.09
1B	0.12	0.13	0.13	0.05	0.07	0.08	0.10
1C	0.15	0.11	0.12	0.09	0.08	0.10	0.08
2A	0.14	0.07	0.12	0.05	0.06	0.11	0.08
2B	0.15	0.11	0.09	0.07	0.10	0.21	0.09
2C	0.18	0.06	0.11	0.10	0.09	0.12	0.09
3A	0.15	0.14	0.09	0.06	0.05	0.07	0.08
3B	0.18	0.10	0.10	0.05	0.10	0.10	0.07
3C	0.10	0.08	0.10	0.05	0.07	0.10	0.12
4A	0.14	0.12	0.09	0.10	0.06	0.07	0.09
4B	0.13	0.13	0.14	0.06	0.08	0.08	0.13
4C	0.16	0.18	0.14	0.07	0.06	0.09	0.12
5A	0.16	0.14	0.12	0.06	0.10	0.06	0.13
5B	0.13	0.15	0.11	0.09	0.09	0.06	0.29
5C	0.14	0.08	0.11	0.07	0.06	0.05	0.38
6A		0.10	0.11	0.04	0.08	0.08	0.07
6B		0.09	0.10	0.10	0.10	0.14	0.08
6C		0.11	0.11	0.04	0.08	0.11	0.08
8A	0.13	0.15	0.08	0.05	0.07	0.13	0.06
8B	0.14	0.42	0.08	0.12	0.07	0.14	0.09
8C	0.16	0.12	0.09	0.04	0.07	0.15	0.11
9A	0.32	0.34	0.28	0.26	0.30	0.23	0.35
9B	0.27	0.30	0.34	0.36	0.34	0.15	0.31
9C	0.30	0.43	0.37	0.25	0.26	0.20	0.32

Table A3. Soluble phosphorus levels (mg/1-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Station #	May 1	May 15	May 27	June 10	June 24	July 7	July 21	August 4
1A	0.11	0.06	0.08	0.02	0.06	0.04	0.05	0.04
1B	0.13	0.07	0.07	0.03	0.06	0.04	0.05	0.04
1C	0.08	0.06	0.12	0.06	0.04	0.05	0.05	0.04
2A	0.10	0.08	0.06	0.03	0.05	0.03	0.03	0.04
2B	0.13	0.08	0.07	0.04	0.06	0.04	0.04	0.05
2C	0.08	0.10	0.07	0.06	0.06	0.04	0.03	0.03
3A	0.14	0.07	0.04	0.04	0.04	0.06	0.07	0.06
3B	0.11	0.06	0.07	0.04	0.05	0.05	0.07	0.05
3C	0.10	0.09	0.05	0.05	0.05	0.05	0.05	0.06
4A	0.10	0.10	0.07	0.04	0.05	0.05	0.07	0.06
4B	0.12	0.11	0.06		0.05	0.04	0.06	0.05
4C	0.11	0.10	0.07	0.05	0.06	0.04	0.05	0.04
5A	0.30	0.09	0.05	0.07	0.06	0.05	0.06	0.06
5B	0.19	0.09	0.04	0.05	0.06	0.05	0.06	0.05
5C	0.15	0.10	0.03	0.06	0.04	0.05	0.05	0.05
6A	0.11	0.13	0.05	0.06	0.04	0.04	0.05	0.05
6B	0.09	0.14	0.05	0.07	0.03	0.04	0.05	0.04
6C	0.07	0.12	0.05	0.06	0.03	0.04	0.05	0.05
7A	0.09	0.13	0.07	0.09	0.05	0.05	0.09	0.05
7B	0.10	0.13	0.06	0.07	0.05	0.05	0.06	0.05
7C	0.13	0.12	0.06	0.07	0.03	0.04	0.05	0.04
8A	0.04	0.12	0.07	0.09	0.04	0.09	0.06	0.09
8B	0.07	0.10	0.08	0.04	0.02	0.09	0.09	0.09
8C	0.11	0.13	0.07	0.05	0.02	0.09	0.08	0.08
9A	0.22	0.12	0.15	0.17	0.10	0.19	0.13	0.20
9B	0.21	0.11	0.16	0.17	0.10	0.21	0.13	0.20
9C	0.11	0.14	0.14	0.18	0.09	0.18	0.14	0.19

Table A3 (cont.) Soluble phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Station #	August 18	September 1	September 15	September 27	October 10	October 25	November 7
1A	0.07	0.06	0.07	0.05	0.06	0.21	0.09
1B	0.09	0.08	0.07	0.06	0.07	0.08	0.11
1C	0.07	0.08	0.07	0.07	0.07	0.07	0.08
2A	0.17	0.09	0.08	0.05	0.05	0.10	0.06
2B	0.17	0.09	0.09	0.05	0.06	0.09	0.06
2C	0.14	0.06	0.09	0.06	0.06	0.08	0.10
3A	0.14	0.08	0.10	0.07	0.05	0.07	0.08
3B	0.13	0.08	0.09	0.06	0.07	0.07	0.07
3C	0.10	0.06	0.09	0.05	0.05	0.07	0.08
4A	0.11	0.06	0.12	0.16	0.05	0.06	0.06
4B	0.07	0.06	0.11	0.05	0.05	0.09	0.07
4C	0.13	0.15	0.11	0.06	0.04	0.08	0.07
5A	0.12	0.08	0.06	0.05	0.06	0.06	0.05
5B	0.11	0.11	0.09	0.06	0.06	0.07	0.07
5C	0.10	0.09	0.10		0.06	0.07	0.27
6A		0.06	0.08	0.06	0.05	0.06	0.06
6B		0.06	0.09	0.03	0.06	0.09	0.07
6C		0.04	0.10	0.03	0.06	0.06	0.05
7A	0.11	0.09	0.07	0.03	0.06	0.05	0.11
7B	0.09	0.09	0.06	0.05	0.06	0.10	0.07
7C	0.09	0.09	0.06	0.04	0.06	0.08	0.06
8A	0.10	0.08	0.06	0.04	0.05	0.07	0.04
8B	0.11	0.08	0.07	0.07	0.05	0.07	0.06
8C	0.11	0.07	0.07	0.05	0.04	0.08	0.04
9A	0.28	0.29	0.19	0.09	0.26	0.12	0.19
9B	0.28	0.29	0.29	0.15	0.26	0.16	0.20
9C	0.23	0.26	0.26	0.17	0.23	0.16	0.23

Table A4. Soluble phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Station #	May 1	May 15	May 27	June 10	June 24	July 7	July 21	August 4
1A	0.13	0.08	0.07	0.06	0.05	0.05	0.06	0.05
1B	0.07	0.07	0.06	0.06	0.03	0.03	0.05	0.04
1C	0.06	0.06	0.06	0.08	0.02	0.04	0.06	0.03
2A	0.12	0.08	0.06	0.05	0.03	0.04	0.06	0.04
2B	0.08	0.09	0.09	0.04	0.04	0.04	0.03	0.04
2C	0.08	0.07	0.08	0.04	0.04	0.03	0.10	0.04
3A	0.18	0.08	0.07	0.04	0.05	0.04	0.06	0.03
3B	0.16	0.06	0.05	0.06	0.05	0.04	0.05	0.04
3C	0.10	0.08	0.06	0.09	0.04	0.03	0.06	0.04
4A	0.09	0.12	0.07	0.06	0.06	0.04	0.06	0.04
4B	0.16	0.12	0.07	0.08	0.07	0.04	0.07	0.04
4C	0.13	0.13	0.06	0.09	0.04	0.05	0.05	0.04
5A	0.10	0.11	0.03	0.05	0.06	0.05	0.06	0.05
5B	0.15	0.11	0.06	0.06	0.03	0.05	0.07	0.05
5C	0.18	0.12	0.06	0.06	0.04	0.05	0.07	0.06
6A	0.04	0.09	0.06	0.06	0.04	0.03	0.06	0.04
6B	0.06	0.10	0.04	0.08	0.06	0.04	0.05	0.05
6C	0.06	0.08	0.03	0.07	0.04	0.05	0.06	0.05
8A	0.14	0.08	0.08	0.07	0.03	0.08	0.07	0.09
8B	0.10	0.07	0.06	0.11	0.05	0.09	0.06	0.08
8C	0.09	0.10	0.07	0.05	0.06	0.09	0.06	0.09
9A	0.11	0.08	0.14	0.17	0.09	0.19	0.13	0.20
9B	0.15	0.07	0.14	0.18	0.10	0.20	0.14	0.18
9C	0.13	0.07	0.14	0.17	0.10	0.19	0.12	0.19

Table A4 (cont.) Soluble phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1970.

Station #	August 18	September 1	September 15	September 27	October 10	October 25	November 7
1A	0.09	0.09	0.08	0.05	0.07	0.14	0.04
1B	0.10	0.10	0.07	0.05	0.06	0.07	0.06
1C	0.10	0.09	0.07	0.06	0.07	0.06	0.05
2A	0.13	0.07	0.06	0.05	0.06	0.09	0.07
2B	0.14	0.09	0.08	0.06	0.07	0.11	0.07
2C	0.15	0.04	0.08	0.06	0.05	0.09	0.07
3A	0.13	0.13	0.09	0.06	0.04	0.07	0.04
3B	0.16	0.08	0.07	0.05	0.05	0.07	0.06
3C	0.11	0.08	0.09	0.05	0.05	0.06	0.06
4A	0.10	0.10	0.08	0.06	0.06	0.06	0.06
4B	0.12	0.10	0.09	0.05	0.05	0.07	0.09
4C	0.13	0.14	0.14	0.04	0.03	0.08	0.07
5A	0.11	0.09	0.10	0.04	0.09	0.05	0.08
5B	0.07	0.10	0.09	0.05	0.07	0.04	0.15
5C	0.10	0.08	0.08	0.05	0.06	0.04	0.25
6A		0.05	0.09	0.04	0.05	0.05	0.06
6B		0.06	0.07	0.05	0.08	0.07	0.06
6C		0.08	0.08	0.04	0.06	0.08	0.05
8A	0.12	0.09	0.05	0.05	0.05	0.08	0.03
8B	0.11	0.31	0.06	0.08	0.04	0.06	0.05
8C	0.12	0.07	0.07	0.04	0.05	0.08	0.06
9A	0.30	0.33	0.28	0.18	0.26	0.13	0.24
9B	0.26	0.29	0.26	0.21	0.26	0.15	0.24
9C	0.26	0.31	0.34	0.18	0.24	0.19	0.27

Table A5. Total phosphorus levels (mg/l-P) of water samples collected at 0.5

Table A5. Total phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	January 23	February 18	April 16	May 1	May 20	June 17	July 15	July 29	September 2	September 16
1A		0.06	0.12	0.10	0.13	0.15	0.12	0.11	0.11	0.13
1B		0.06	0.14	0.12	0.11	0.10	0.15	0.15	0.09	0.14
1C		0.07	0.12	0.09	0.10	0.13	0.12	0.12	0.12	0.10
2A	0.08		0.10	0.07	0.09	0.12	0.13	0.10	0.13	0.13
2B	0.09		0.10	0.08	0.12	0.18	0.14	0.10	0.10	0.12
2C	0.09		0.10	0.10	0.12	0.13	0.11	0.09	0.10	0.13
3A			0.09	0.09	0.13	0.14	0.16	0.11	0.10	0.09
3B			0.09	0.08	0.09	0.12	0.13	0.09	0.15	0.10
3C			0.08	0.12	0.07	0.10	0.13	0.09	0.10	0.09
4A			0.07	0.09	0.10	0.14	0.16	0.11	0.13	0.12
4B			0.10	0.07	0.12	0.14	0.16	0.12	0.08	0.12
4C			0.12	0.06	0.13	0.14	0.17	0.10	0.15	0.12
5A			0.09	0.10	0.10	0.14	0.13	0.12	0.09	0.10
5B			0.12	0.08	0.12	0.16	0.21	0.12	0.10	0.11
5C			0.11	0.07	0.12	0.16	0.15	0.11	0.10	0.10
6A			0.08	0.09	0.09	0.15	0.21	0.11	0.08	0.11
6B			0.17	0.13	0.10	0.12	0.09	0.11	0.09	0.09
6C			0.08	0.08	0.13	0.15	0.08	0.14	0.14	0.10
7A	0.22	0.31	0.13	0.09	0.11	0.22	0.25	0.26	0.28	0.23
7B	0.23	0.30	0.10	0.08	0.09	0.23	0.31	0.28	0.24	0.25
7C	0.28	0.28	0.14	0.12	0.07	0.20	0.24	0.23	0.22	0.26
8A	0.08		0.12	0.16	0.13	0.21	0.19	0.24	0.32	0.30
8B	0.07		0.11	0.10	0.16	0.27	0.26	0.27	0.24	0.27
8C	0.07		0.16	0.12	0.20	0.17	0.22	0.22	0.24	0.25
9A			0.22	0.27	0.23	0.29	0.21	0.35	0.27	0.31
9B			0.24	0.25	0.21	0.30	0.31	0.32	0.47	0.33
9C			0.21	0.31	0.26	0.32	0.44	0.40	0.39	0.31

Table A5 (cont.) Total phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	October 2	October 15	October 30	November 12	December 2	December 19	January 11	February 18
1A	0.17	0.08	0.05	0.07		0.12		0.11
1B	0.14	0.10	0.05	0.07		0.11		0.07
1C	0.14	0.11	0.04	0.06		0.12		0.08
2A	0.14	0.08	0.04	0.07				
2B	0.11	0.12	0.07	0.10				
2C	0.09	0.09	0.05	0.06				
3A	0.10	0.09	0.05	0.09		0.09	0.10	0.06
3B	0.09		0.04	0.07		0.10	0.08	0.06
3C	0.09	0.09	0.04	0.07		0.09	0.07	0.06
4A	0.11	0.07	0.05	0.09		0.11	0.18	
4B	0.11	0.06	0.05	0.08	0.13	0.11	0.10	
4C	0.09	0.06	0.06	0.11		0.11	0.11	
5A	0.11	0.05	0.07	0.12				
5B	0.09	0.08	0.08	0.10				
5C	0.10	0.05	0.07	0.14				
6A	0.10	0.09	0.08	0.10				
6B	0.09	0.07	0.08	0.10				
6C	0.10	0.09	0.11	0.26				
7A	0.27	0.22	0.11	0.17	0.21	0.26	0.25	0.21
7B	0.24	0.26	0.17	0.18	0.21	0.22	0.24	0.24
7C	0.22	0.18	0.07	0.14	0.22	0.24	0.24	0.16
8A	0.26	0.23	0.11	0.30	0.23	0.23	0.23	0.22
8B	0.27	0.20	0.13	0.18	0.20	0.26	0.25	0.22
8C	0.26	0.15	0.12	0.34	0.20	0.24	0.24	0.24
9A	0.36	0.16	0.18		0.19	0.29	0.32	0.51
9B	0.38	0.32	0.22	0.74	0.28	0.27	0.31	0.52
9C	0.42	0.30	0.24			0.33		0.52

Table A6. Total phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	January 23	February 18	April 16	May 1	May 20	June 17	July 15	July 29	September 2	September 16
1A		0.04	0.12	0.14	0.10	0.14	0.14	0.11	0.15	0.13
1B		0.06	0.14	0.11	0.12	0.13	0.13	0.10	0.22	0.17
1C		0.12	0.10	0.10	0.09	0.19	0.14	0.13	0.14	0.15
2A	0.08		0.10	0.09	0.13	0.09	0.13	0.09	0.16	0.15
2B	0.10		0.09	0.10	0.10	0.13	0.13	0.13	0.17	0.13
2C	0.08		0.10	0.16	0.11	0.11	0.13	0.11	0.15	0.14
3A			0.08	0.07	0.08	0.14	0.15	0.09	0.13	0.10
3B			0.10	0.07	0.13	0.11	0.13	0.09	0.12	0.12
3C			0.33	0.11	0.10	0.13	0.14	0.10	0.07	0.13
4A			0.15	0.12	0.09	0.13	0.17	0.10	0.12	0.12
4B			0.09	0.13	0.07	0.14	0.32	0.11	0.13	0.12
4C			0.10	0.09	0.08	0.15	0.21	0.11	0.10	0.10
5A			0.11	0.13	0.12	0.16	0.14	0.11	0.08	0.09
5B			0.09	0.15	0.09	0.14	0.14	0.11	0.12	0.12
5C			0.08	0.11	0.13	0.14	0.17	0.11	0.07	0.10
6A			0.08	0.08	0.10	0.12	0.10	0.11	0.11	0.12
6B			0.07	0.07	0.10	0.17	0.10	0.11	0.11	0.10
6C			0.07	0.12	0.08	0.11	0.11	0.09	0.11	0.10
8A	0.07		0.14	0.21	0.13	0.28	0.38	0.26	0.25	0.28
8B	0.08		0.13	0.17	0.15	0.27	0.26	0.25	0.33	0.25
8C	0.07		0.14	0.19	0.21	0.21	0.18	0.23	0.29	0.29
9A			0.24	0.31	0.28	0.33	0.20	0.28	0.30	0.40
9B			0.22	0.27	0.22	0.34	0.44	0.42	0.36	0.39
9C			0.21	0.25	0.25	0.31	0.24	0.42	0.33	0.43

Table A6 (cont.) Total phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	October 2	October 15	October 30	November 12	December 2	December 19	January 11	February 18
1A	0.15	0.11	0.04	0.07		0.12		0.08
1B	0.14	0.12	0.05	0.07		0.11		0.08
1C	0.12	0.10	0.05	0.08		0.12		0.08
2A	0.12	0.12	0.10	0.09				
2B	0.11	0.13	0.04	0.11				
2C	0.11	0.12	0.09	0.07				
3A	0.10	0.07	0.08	0.08		0.10	0.09	0.05
3B	0.10	0.09	0.10	0.08		0.09	0.08	0.06
3C	0.09	0.08		0.08		0.10	0.07	0.07
4A	0.10	0.08	0.05	0.09		0.12	0.11	
4B	0.87	0.09	0.09	0.11	0.14	0.10	0.12	
4C	0.11	0.08	0.05	0.12		0.10	0.17	
5A	0.10	0.09	0.06	0.11				
5B	0.11	0.08	0.07	0.12				
5C	0.09	0.11	0.07	0.09				
6A	0.12	0.08	0.07	0.18				
6B	0.11	0.08	0.09	0.11				
6C	0.10	0.12	0.07	0.12				
8A	0.29	0.19	0.09	0.34	0.22	0.25	0.23	0.23
8B	0.30	0.13	0.12	0.19	0.23	0.25	0.24	0.23
8C	0.31	0.21	0.12	0.21	0.20	0.24	0.24	0.22
9A	0.45	0.12	0.15		0.30	0.29	0.33	0.51
9B		0.40	0.19	0.25	0.36	0.34	0.32	0.51
9C	0.44	0.38	0.22			0.32		0.53

Table A7. Soluble phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	January 23	February 18	April 16	May 1	May 20	June 17	July 15	July 29	September 2	September 16
1A		0.05	0.10	0.07	0.10	0.12	0.09	0.09	0.10	0.09
1B		0.04	0.12	0.09	0.09	0.08	0.10	0.09	0.08	0.08
1C		0.06	0.09	0.08	0.07	0.11	0.07	0.09	0.12	0.08
2A	0.07		0.08	0.07	0.06	0.09	0.10	0.08	0.13	0.10
2B	0.06		0.07	0.05	0.09	0.12	0.11	0.08	0.09	0.11
2C	0.06		0.06	0.06	0.08	0.10	0.11	0.08	0.09	0.11
3A			0.07	0.07	0.10	0.09	0.11	0.09	0.08	0.08
3B			0.07	0.07	0.06	0.08	0.12	0.08	0.14	0.08
3C			0.05	0.09	0.05	0.07	0.11	0.09	0.09	0.07
4A			0.05	0.08	0.08	0.13	0.12	0.09	0.13	0.10
4B			0.08	0.05	0.08	0.07	0.13	0.09	0.08	0.09
4C			0.10	0.06	0.09	0.08	0.14	0.09	0.14	0.08
5A			0.09	0.08	0.07	0.11	0.11	0.09	0.09	0.08
5B			0.11	0.05	0.09	0.13	0.14	0.09	0.08	0.07
5C			0.09	0.05	0.10	0.09	0.13	0.10	0.09	0.07
6A			0.07	0.08	0.07	0.12	0.10	0.11	0.08	0.09
6B			0.14	0.10	0.08	0.09	0.08	0.09	0.08	0.07
6C			0.07	0.07	0.09	0.07	0.07	0.12	0.12	0.08
7A	0.18	0.26	0.09	0.07	0.07	0.16	0.21	0.15	0.26	0.16
7B	0.20	0.23	0.08	0.06	0.06	0.13	0.20	0.20	0.21	0.17
7C	0.22	0.23	0.12	0.10	0.05	0.12	0.12	0.14	0.19	0.17
8A	0.06		0.11	0.13	0.09	0.09	0.14	0.18	0.24	0.16
8B	0.05		0.06	0.08	0.11	0.21	0.22	0.19	0.18	0.15
8C	0.07		0.09	0.10	0.15	0.13	0.18	0.16	0.21	0.13
9A			0.17	0.22	0.17	0.21	0.18	0.26	0.22	0.21
9B			0.15	0.21	0.14	0.22	0.15	0.28	0.42	0.23
9C			0.13	0.26	0.15	0.23	0.41	0.33	0.33	0.25

Table A7 (cont.) Soluble phosphorus levels (mg/l-P) of water samples collected at 0.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	October 2	October 15	October 30	November 12	December 2	December 19	January 11	February 18
1A	0.12	0.06	0.03	0.07		0.05		0.05
1B	0.10	0.07	0.03	0.06		0.06		0.06
1C	0.10	0.06	0.03	0.06		0.05		0.05
2A	0.09	0.06	0.04	0.07				
2B	0.09	0.06	0.04	0.07				
2C	0.07	0.07	0.04	0.06				
3A	0.06	0.06	0.05	0.09		0.04	0.04	0.04
3B	0.08	0.08	0.04	0.07		0.05	0.04	0.03
3C	0.05	0.07	0.04	0.07		0.06	0.04	0.02
4A	0.07	0.04	0.05	0.07		0.06	0.10	
4B	0.06	0.03	0.05	0.07	0.12	0.06	0.05	
4C	0.05	0.05	0.04	0.11		0.06	0.06	
5A	0.10	0.05	0.05	0.09				
5B	0.06	0.06	0.05	0.06				
5C	0.07	0.04	0.05	0.10				
6A	0.08	0.09	0.06	0.07				
6B	0.07		0.06	0.07				
6C	0.06	0.06	0.08	0.18				
7A	0.12	0.09	0.07	0.17	0.16	0.17	0.18	0.17
7B	0.11	0.09	0.06	0.17	0.17	0.16	0.18	0.15
7C	0.10	0.11	0.04	0.14	0.16	0.17	0.17	0.10
8A	0.13	0.09	0.09	0.15	0.16	0.15	0.16	0.15
8B	0.15	0.07	0.08	0.17	0.16	0.15	0.18	0.16
8C	0.15	0.09	0.09	0.18	0.16	0.16	0.17	0.17
9A	0.22	0.07	0.14		0.13	0.21	0.23	0.40
9B	0.22	0.11	0.09	0.14	0.23	0.25	0.22	0.37
9C	0.27	0.13	0.11			0.23		0.36

Table A8. Soluble phosphorus levels (mg/1-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	January 23	February 18	April 16	May 1	May 20	June 17	July 15	July 29	September 2	September 16
1A		0.04	0.07	0.11	0.07	0.12	0.12	0.09	0.12	0.11
1B		0.03	0.09	0.09	0.10	0.10	0.11	0.09	0.15	0.10
1C		0.09	0.07	0.09	0.06	0.15	0.09	0.09	0.11	0.12
2A	0.07		0.06	0.07	0.09	0.08	0.10	0.08	0.10	0.10
2B	0.09		0.05	0.08	0.08	0.10	0.11	0.08	0.10	0.08
2C	0.08		0.06	0.12	0.07	0.09	0.10	0.08	0.14	0.09
3A			0.05	0.05	0.06	0.10	0.13	0.08	0.09	0.08
3B			0.06	0.05	0.10	0.07	0.13	0.08	0.09	0.09
3C			0.22	0.07	0.06	0.07	0.12	0.09	0.06	0.09
4A			0.10	0.08	0.05	0.12	0.12	0.07	0.10	0.09
4B			0.06	0.09	0.05	0.10	0.23	0.10	0.11	0.11
4C			0.05	0.06	0.07	0.11	0.15	0.09	0.10	0.09
5A			0.07	0.07	0.10	0.12	0.11	0.09	0.06	0.08
5B			0.07	0.09	0.06	0.10	0.12	0.11	0.08	0.09
5C			0.05	0.06	0.12	0.12	0.13	0.08	0.07	0.08
6A			0.04	0.07	0.07	0.09	0.08	0.09	0.10	0.08
6B			0.05	0.07	0.09	0.12	0.08	0.09	0.10	0.08
6C			0.07	0.10	0.06	0.10	0.09	0.08	0.09	0.08
8A	0.07		0.10	0.17	0.09	0.17	0.35	0.17	0.19	0.17
8B	0.06		0.10	0.12	0.10	0.21	0.19	0.17	0.18	0.15
8C	0.06		0.08	0.13	0.13	0.15	0.16	0.19	0.25	0.16
9A			0.15	0.24	0.17	0.20	0.18	0.20	0.26	0.27
9B			0.17	0.17	0.15	0.23	0.24	0.30	0.29	0.24
9C			0.15	0.19	0.17	0.21	0.20	0.32	0.27	0.26

Table A8 (cont.) Soluble phosphorus levels (mg/l-P) of water samples collected at 2.5 meters throughout the Lake Erie-Raisin River sampling area during 1971-2.

Station #	October 2	October 15	October 30	November 12	December 2	December 19	January 11	February 18
1A	0.10	0.06	0.03	0.07		0.06		0.05
1B	0.09	0.07	0.04	0.06		0.07		0.04
1C	0.09	0.07	0.03	0.08		0.07		0.04
2A	0.08	0.06	0.05	0.06				
2B	0.07	0.06	0.04	0.11				
2C	0.07	0.06	0.03	0.07				
3A	0.07	0.05	0.05	0.07		0.05	0.04	0.04
3B	0.06	0.06	0.05	0.08		0.04	0.04	0.03
3C	0.05	0.05		0.08		0.06	0.04	0.07
4A	0.06	0.04	0.04	0.08		0.07	0.06	
4B	0.73	0.03	0.05	0.09	0.12	0.07	0.07	
4C	0.06	0.05	0.04	0.11		0.07	0.09	
5A	0.07	0.05	0.06	0.07				
5B	0.06	0.04	0.06	0.08				
5C	0.07	0.38	0.06	0.07				
6A	0.07	0.07	0.07	0.14				
6B	0.07	0.07	0.05	0.07				
6C	0.07	0.06	0.07	0.08				
8A	0.15	0.07	0.08	0.16	0.18	0.15	0.16	0.15
8B	0.15	0.07	0.09	0.17	0.17	0.16	0.17	0.15
8C	0.15	0.09	0.09	0.18	0.16	0.15	0.17	0.16
9A	0.21	0.10	0.04		0.27	0.21	0.23	0.39
9B		0.09	0.10	0.25	0.30	0.24	0.22	0.40
9C	0.26	0.09	0.09			0.23		0.38

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APPENDIX III

Table A9. Mean concentration of soluble phosphorus in mg/liter by station.

1 May 70	0.07	0.09	0.10	0.11	0.11	0.12	0.13	0.16	0.18
	6	8	2	1	7*	4	3	9	5
15 May 70	0.07	0.07	0.10	0.10	0.10	0.11	0.11	0.13	0.20
	1	3	9	8	5	6	4	7*	2
27 May 70	0.04	0.05	0.06	0.07	0.07	0.07	0.07	0.08	0.15
	5	6	3	4	7*	8	2	1	9
10 June 70	0.04	0.05	0.05	0.06	0.07	0.07	0.07	0.08	0.17
	2	1	3	5	4	6	8	7*	9
24 June 70	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.06	0.10
	8	6	7*	1	5	2	3	4	9
7 July 70	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.09	0.19
	2	6	1	4	3	5	7*	8	9
21 July 70	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.13
	2	6	1	4	3	5	7*	8	9
4 Aug 70	0.14	0.04	0.05	0.05	0.05	0.05	0.05	0.09	0.19
	1	2	4	6	3	7*	5	8	9
18 Aug 70	0.09	0.10	0.10	0.11	0.12	0.13	0.15	0.27	
	1	7	5	4	8	3	2	9	
1 Sept 70	0.06	0.07	0.08	0.08	0.09	0.09	0.10	0.12	0.30
	6	2	1	3	7*	5	4	8	9
15 Sept 70	0.06	0.06	0.07	0.08	0.09	0.09	0.09	0.11	0.27
	7*	8	1	2	6	5	3	4	9

Table A9. (con't.)

27 Sept 70	0.04 7*	0.04 6	0.05 5	0.06 2	0.06 8	0.06 3	0.06 1	0.07 4	0.16 9
10 Oct 70	0.05 4	0.05 8	0.05 3	0.06 2	0.06 6	0.06 7*	0.07 5	0.07 1	0.21 9
25 Oct 70	0.06 5	0.07 6	0.07 3	0.07 4	0.07 8	0.08 7*	0.09 2	0.10 1	0.15 9
7 Nov 70	0.05 8	0.06 6	0.07 3	0.07 4	0.07 1	0.07 2	0.08 7*	0.15 5	0.23 9

Table A10. Mean concentration of soluble phosphorus in mg/liter by station.

23 Jan 71	0.06 8	0.07 2	0.20 7*						
18 Feb 71	0.05 1	0.24 7*							
16 Apr 71	0.06 2	0.07 4	0.07 6	0.08 5	0.09 3	0.09 1	0.09 8	0.10 7*	0.15 9
1 May 71	0.07 3	0.07 5	0.07 4	0.08 2	0.08 7*	0.08 6	0.09 1	0.12 8	0.21 9
20 May 71	0.06 7*	0.07 4	0.07 3	0.08 6	0.08 2	0.08 1	0.09 5	0.11 8	0.15 9
17 June 71	0.08 3	0.10 2	0.10 6	0.10 4	0.11 5	0.11 1	0.14 7*	0.16 8	0.22 9
15 July 71	0.08 6	0.10 1	0.10 2	0.12 3	0.12 5	0.15 4	0.18 7*	0.20 8	0.22 9
29 July 71	0.08 2	0.09 3	0.09 4	0.09 1	0.09 5	0.10 6	0.16 7*	0.18 8	0.28 9
2 Sept 71	0.08 5	0.09 3	0.10 6	0.11 2	0.11 4	0.11 1	0.21 8	0.22 7*	0.30 9
16 Sept 71	0.08 5	0.08 6	0.08 3	0.09 4	0.10 1	0.10 2	0.15 8	0.17 7*	0.24 9
2 Oct 71	0.06 3	0.07 6	0.07 5	0.08 2	0.10 1	0.11 7*	0.15 8	0.17 4	0.23 9
15 Oct 71	0.04 4	0.05 5	0.06 2	0.06 3	0.07 1	0.07 6	0.08 8	0.10 7*	0.10 9

Table A10. (con't.)

30 Oct 71	0.03	0.04	0.05	0.05	0.06	0.06	0.07	0.09	0.10
	1	2	4	3	5	7*	6	8	9
12 Nov 71	0.07	0.07	0.08	0.08	0.09	0.10	0.16	0.17	
	1	2	3	5	4	6	7*	8	
19 Dec 71	0.05	0.06	0.06	0.15	0.17	0.23			
	3	1	4	8	7*	9			
11 Jan 72	0.04	0.07	0.17	0.18					
	3	4	8	7*					
18 Feb 72	0.04	0.05	0.14	0.16	0.38				
	3	1	7*	8	9				

Table A11. Mean concentration of total phosphorus in mg/liter by station.

16 Apr 70	0.13 6	0.15 2	0.15 8	0.16 1	0.19 7*	0.19 4	0.19 3	0.22 5	0.26 9
1 May 70	0.12 2	0.12 6	0.13 1	0.15 5	0.15 3	0.16 8	0.16 4	0.18 7*	0.19 9
27 May 70	0.06 5	0.06 2	0.06 3	0.06 6	0.08 7*	0.08 8	0.09 4	0.10 1	0.16 9
10 June 70	0.06 2	0.07 1	0.07 3	0.08 5	0.08 6	0.09 4	0.09 8	0.10 7*	0.21 9
24 June 70	0.05 2	0.06 3	0.06 6	0.06 1	0.06 7*	0.06 5	0.08 8	0.08 4	0.11 9
7 July 70	0.06 2	0.07 1	0.07 6	0.07 4	0.07 3	0.08 5	0.08 7*	0.13 8	0.24 9
21 July 70	0.07 2	0.08 1	0.08 6	0.09 3	0.10 5	0.10 4	0.15 8	0.22 9	0.24 7*
4 Aug 70	0.06 2	0.06 1	0.07 6	0.07 4	0.08 5	0.08 3	0.08 7*	0.12 8	0.24 9
18 Aug 70	0.12 1	0.13 6	0.14 5	0.14 7*	0.15 3	0.15 4	0.17 2	0.29 9	
1 Sept 70	0.09 2	0.10 6	0.10 3	0.11 1	0.12 4	0.12 5	0.14 7*	0.17 8	0.35 9
15 Sept 70	0.07 7*	0.09 8	0.09 3	0.11 2	0.11 6	0.12 5	0.12 1	0.13 4	0.33 9

Table All. (con't.)

27 Sept 70	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.09	0.26
	6	7*	8	3	5	1	2	4	9
10 Oct 70	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.31
	4	3	2	6	5	7*	1	8	9
25 Oct 70	0.07	0.09	0.10	0.10	0.10	0.12	0.12	0.13	0.20
	5	3	7*	4	6	1	8	2	9
7 Nov 70	0.08	0.09	0.09	0.09	0.10	0.10	0.12	0.22	0.31
	6	2	7*	8	1	4	3	5	9

Table A12. Mean concentration of total phosphorus in mg/liter by station.

16 Apr 71	0.09	0.10	0.10	0.11	0.12	0.12	0.13	0.13	0.22
	6	2	5	4	1	7*	3	8	9
1 May 71	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.16	0.27
	3	4	6	7*	2	5	1	8	9
20 May 71	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.16	0.24
	7*	4	3	6	1	2	5	8	9
17 June 71	0.12	0.13	0.14	0.14	0.14	0.15	0.22	0.24	0.32
	3	2	6	4	1	5	7*	8	9
15 July 71	0.12	0.13	0.13	0.13	0.16	0.20	0.25	0.27	0.31
	6	2	1	3	5	4	8	7*	9
29 July 71	0.10	0.10	0.11	0.11	0.11	0.12	0.25	0.26	0.37
	3	2	4	6	5	1	8	7*	9
2 Sept 71	0.09	0.11	0.11	0.12	0.14	0.14	0.25	0.27	0.35
	5	6	3	4	2	1	7*	8	9
16 Sept 71	0.10	0.10	0.11	0.12	0.13	0.14	0.25	0.27	0.36
	5	6	3	4	2	1	7*	8	9
2 Oct 71	0.10	0.10	0.10	0.11	0.14	0.23	0.24	0.28	0.41
	3	5	6	2	1	4	7*	8	9
15 Oct 71	0.07	0.08	0.08	0.09	0.10	0.11	0.19	0.22	0.28
	4	5	3	6	1	2	8	7*	9
30 Oct 71	0.05	0.06	0.06	0.07	0.07	0.08	0.12	0.12	0.20
	1	4	3	2	5	6	8	7*	9

Table All. (con't.)

12 Nov 71	0.07	0.08	0.08	0.10	0.11	0.15	0.16	0.26
	1	3	2	4	5	6	7*	8
19 Dec 71	0.10	0.11	0.12	0.21	0.24	0.31		
	3	4	1	7*	8	9		
11 Jan 72	0.08	0.13	0.24	0.24				
	3	4	7*	8				
18 Feb 72	0.06	0.08	0.20	0.23	0.52			
	3	1	7*	8	9			