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COMMUNITY METABOLISM IN THERMALLY
AND ORGANICALLY ENRICHED WATERS
OF WESTERN LAKE ERIE

presented by

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has been accepted towards fulfillment
of the requirements for

M.S. degree in Fisheries

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Major professor

Date 6-13-1980

O-7639

COMMUNITY METABOLISM IN THERMALLY AND ORGANICALLY ENRICHED WATERS OF WESTERN LAKE ERIE

By

Charles C. Warner

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1980

ABSTRACT

COMMUNITY METABOLISM IN THERMALLY AND ORGANICALLY ENRICHED WATERS OF WESTERN LAKE ERIE

By

Charles C. Warner

Gross primary productivity and community respiration were measured in western Lake Erie in the vicinity of the Monroe Power Plant to assess the impact of the once-through cooling system waters on the aquatic ecosystem. Samples were collected from lake and river source waters; the discharge canal, where water temperature increased 6 to 10 C after passage through the condensers; and the thermal plume. Data were collected monthly from May 1970 to June 1971 for preoperational estimates and from June 1971 to September 1975 for postoperational estimates.

The entrainment of the water mass through the power plant usually resulted in a depression of the productivity in the discharge canal waters. Corresponding community respiration rates almost doubled as predicted by temperature elevations. Despressed productivity recovered partially moving through the canal, and a slight stimulation occurred as ambient temperatures were approached in the thermal plume. Respiration rates decreased with water movement through the canal and into the lake as ambient temperatures were reached.

ACKNOWLEDGEMENTS

I wish to thank Dr. R. A. Cole for his help throughout this study and his early criticism and suggestions in preparation of this manuscript. Appreciation is also expressed to my graduate committee members: Dr. N. R. Kevern, Dr. T. M. Burton, Dr. C.D. McNabb, and Dr. F. M. D'Itri for their contributions and prompt review of the manuscript. The assistance of fellow graduate students, especially B. Adams, D. Lavis, and S. Kilkus, with the field work will always be pleasantly remembered. I would also like to thank T. Ecker and C. Annett for the use of their chemical data and J. Wojcik for additional primary productivity data. I am extremely grateful to my wife, Joanne, for her constant encouragement and patience.

Support for this study was made possible through Detroit Edison Company and United States Environmental Protection Agency contracts with the Institute of Water Research and Michigan State University, Department of Fisheries and Wildlife.

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INTRODUCTION

The effects of thermal effluent on the aquatic environment are of great interest as the demand for cooling water may increase as much as 10 fold in coming decades (Denison and Elder, 1976). Because of favorable economic considerations, power plant designers prefer to locate their sites on large bodies of water to take advantage of once-through cooling. Cole (1973) has estimated that by the year 2001 as much as 35% (120 km^3) of Lake Erie's water volume could be used annually for cooling purposes. As the amount of waste heat into Lake Erie increases, the potential for changes in the phytoplankton population exists. This paper describes the impact of the once-through cooling system at the Monroe Power Plant on the algal community along the western shore of Lake Erie.

Being the primary producers of the aquatic community, any significant changes in the phytoplankton populations could influence the rest of the food chain. Algal community metabolism include two functions: gross primary productivity (GPP) and respiration (R). Gross primary productivity is the fixation of carbon resulting from the metabolic activity of the primary producers. The phytosynthetic process also produces oxygen which can be measured to quantify the amount of carbon fixed. Community respiration measures all of the oxygen used by respiring organisms to oxidize organic carbon to carbon dioxide. The ratio of gross primary productivity/respiration (GPP/R) can be used as an indicator of the movement of organic material through the system. If the ratio is greater than 1.0 the community will gain biomass, whereas a ratio less than 1.0 implies a decrease in organic material through decomposition.

Primary productivity is regulated by a combination of factors including light, temperature, available nutrients, toxins, and the biomass of the phytoplankton populations. Community respiration is regulated by the abundance of living organisms and an organic substrate to support them. The rate of respiration is influenced by biomass, temperature, nutrient availability, and oxygen concentrations.

The entrainment of phytoplankton populations through the cooling systems of power plants exposes them to an increase in temperature. After passing through the condensers, where they are subjected to mechanical damage and thermal shocking, the phytoplankton enter the receiving waters. Possible stimulation or inhibition of their metabolic rates may occur, depending on the ambient water temperature (Morgan and Stross, 1969). Power plant operation may also effect rates of respiration and productivity by changing the light penetration, changing nutrient availability, both as a result of mixing two different water masses, and exposing populations to chlorine.

The discharge canal area could be a suitable environment for high GPP/R values resulting in an export of biomass into Lake Erie waters. This may have a potentially harmful impact upon the receiving waters, as the decomposition of phytoplankton may require large amounts of oxygen, decreasing concentrations available for aerobic organisms.

The purpose of this research, as part of a comprehensive ecological study, was to measure the community metabolism of the near shore western basin of Lake Erie and evaluate the possible effects of the Monroe Power Plant. Gross primary productivity and community respiration of organisms entrained through the cooling system were measured to determine possible changes in the water quality of the thermal effluent and its impact upon the receiving waters. This research also considered changes in the near shore water quality. The eutrophication of Lake Erie has been studied extensively in recent years (Davis, 1964; Verduin 1964, 1969, and 1972; Arnold, 1969; and Vollenweider et al., 1974). Recent improvements in municipal and industrial sewage treatment have provided higher water quality effluents to the lake resulting in a slowing of the eutrophication process. The western basin, with a rapid flow through time of about two months (Verduin, 1964), may recover faster than other parts of Lake Erie. The evaluation of these changes, along with the impact of power generating plants, is essential in providing information on which to base future management decisions.

DESCRIPTION OF THE STUDY AREA

Western Basin of Lake Erie

The western basin of Lake Erie covers about 3100 km^2 and has a mean depth of about 7 m. A chain of islands separates it from the rest of the lake which has a mean depth of 19 m (Beeton, 1971). The shallow near shore western basin is generally vertically mixed both thermally and chemically (Marcus, 1971; Kreh, 1972; Ecker, 1976; and Annett, 1977), but under proper conditions it may stratify (Carr et al., 1965). The action of seiches, generally less than 1 m but occasionally 2 m, occurs twice daily. The wind generated water movement results in the thorough mixing of the water column and high trubidity from the resuspension of sediments. These suspended solids are largely the result of agricultural disturbance in the watershed (Cole, 1972).

The western basin receives about 95% of its water from the inflow of the Detroit River, about 2.5% from the Maumee River, and less than 0.5% from the Raisin River. The prevailing southwest wind and inflowing Detroit River water are responsible for the clockwise movement of water in the southwestern corner of the western basin (Kovacik, 1972). The western basin receives about 90% of the total water discharged into Lake Erie, but occupies only about 5% of the total lake volume. The water quality of the western basin depends almost entirely on that of the incoming water, because of its rapid flushing rate. The Detroit River is the largest contributor of nitrogen and phosphorus into the basin (Harlow, 1966). However, the Maumee River contributed about 25% of the phosphorus in the basin in the 1960's (FWPCA, 1968), which is much greater than expected from discharge rates.

Raisin River

The Raisin River also had a strong impact on the study site since much of the power plant intake water came from it, even though the volume contribution to Lake Erie was extremely small. The lower Raisin River is dredged annually by the U.S. Army Corps of Engineers to remove accumulated sediment. It was highly polluted with municipal and industrial wastes until recently (1972). Anoxia was very common in the summer throughout the water column, but recent modifications to the Monroe sewage treatment plant improving the quality of the effluent have lessened the harmful effects. Two paper companies contributed much of the biodegradable organics while a chrome plating plant added various metal ions to the effluent.

The Monroe Power Plant

A 3200 megawatt coal fired steam electric generating station utilizing once-through cooling is operated by the Detroit Edison Company at Monroe, Michigan. The first of four units came on line in June 1971. Subsequent units were added annually with the final unit completed in the spring of 1974. Following initial start up, there were numerous operational problems resulting in varying power production levels and heat discharge into the lake. However, the pumping rate of the cooling water remained fairly constant, initially about 22 m^3/second and increasing with the completion of additional units to 85 m^3/second with all units in operation. There has been considerable variation in the elevation of the cooling water temperature as it crosses the condensers, having a maximum increase of 11 C and an average of 7 to 8 C.

The power plant is located on a filled portion of the Raisin River delta on the western shore of Lake Erie (Figure 1). The intake of the once-through cooling system is located in the river about 1 km from the mouth. When the pumping rate of the power plant exceeds the discharge rate of the Raisin River, additional water from Lake Erie provides the difference by inflow through the river mouth. The Raisin River discharge rates varied from a high of 120 m^3/second in the spring to a low of 3 m^3/second in the late summer. Thus, the river contributes most of the intake cooling water in the spring and the lake contributes most in the late summer. Conductivity data indicate the river water tends to override the incoming lake water during times of high flow and some of this water may escape to the lake (Cole, 1976).

After passing through the plant cooling condensers, the heated water is released into a discharge canal. This canal is 2600 m long and averages 175 m in width. The upper half has been dredged to a depth of 7 m and the lower half to a depth of 3 m. This canal was not subjected to operational conditions until the first unit came on line in 1971. During 1970 it functioned only as an embayment of Lake Erie, with the water exchange occurring mainly during storms and seiches. This canal has a fully operational flow through time of approximately four hours, where about 14% of the heat is lost to the air. Upon discharge into the lake, the plume waters return to ambient temperature in 15 to 45 hours (MSU, 1974).

In addition to chlorine released by the sewage treatment plant, the power plant also chlorinates the cooling water to prevent the growth of bacterial slimes on the inside walls of the condensers. This treatment occurs twice a day in the summer and once a day in the winter, with a

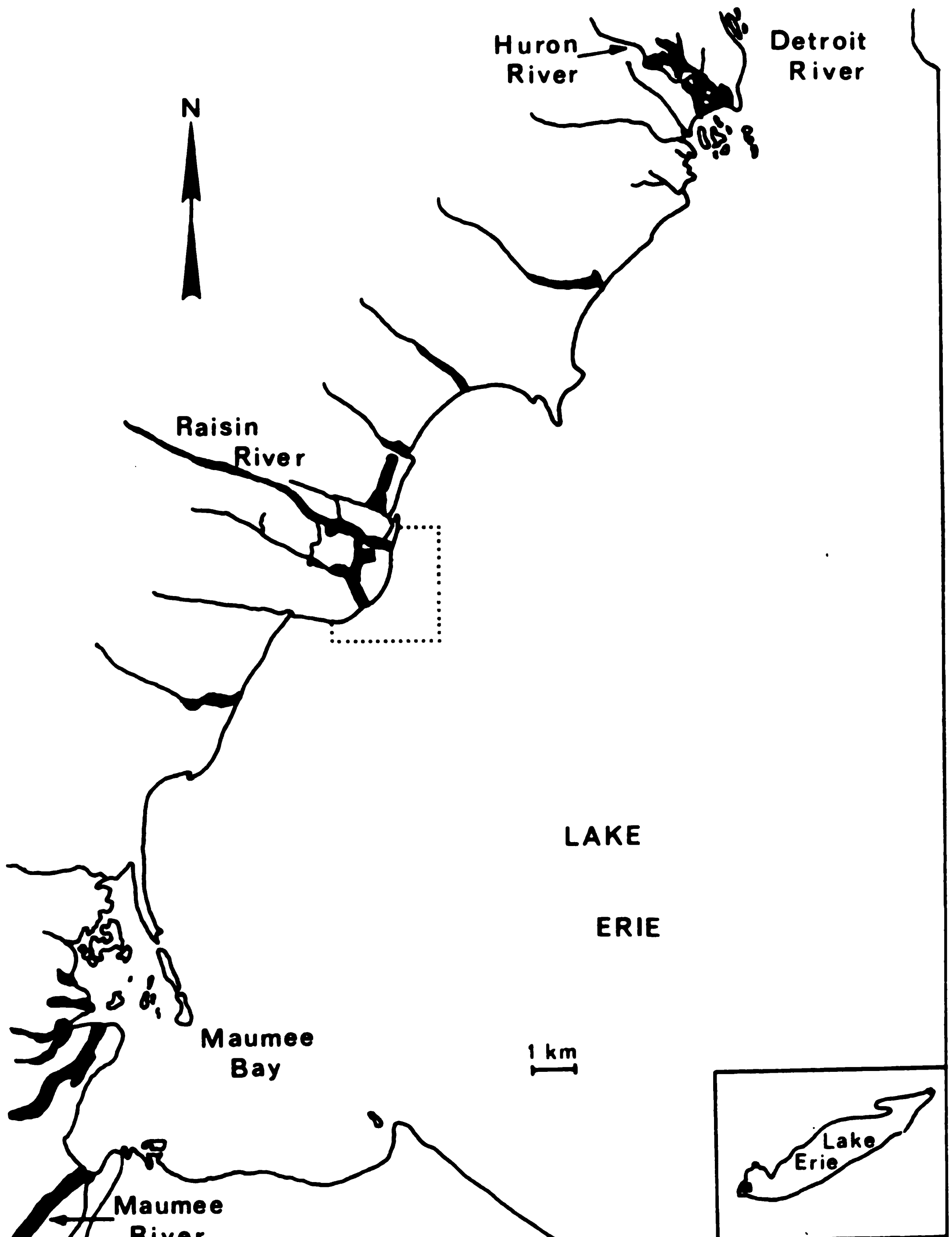


Figure 1. Map of the study area in relation to western Lake Erie.

desired concentration of less than 0.5 mg/l total residual chlorine at the head of the discharge canal.

Sampling Locations

The Detroit Edison Sites

Gross primary production and community respiration studies were conducted as part of the Detroit Edison supported environmental impact assessment of the Monroe Power Plant. Three sites (Figure 2) were sampled from May 1, 1970 through October 24, 1974 on a biweekly basis, as weather permitted (Table A1). Winter sampling from November through early March was very limited because of highly unfavorable lake conditions. Station 3 was located in the lake, approximately 1.5 km due east of the Raisin River mouth, and had a depth of about 6 m. Station 9, located in the Raisin River about 0.5 m upstream from the power plant intake, had a dredged depth of 7.5 m. Station 8 was located in the discharge canal, approximately 1.3 km from its entrance into Lake Erie, and had a depth of about 7 m.

The U.S.E.P.A. Study Sites

The United States Environmental Protection Agency (USEPA) supported a three year study to determine the effects of entrainment in the cooling system of the power plant. Seven stations (Figure 2) were sampled bimonthly from November 1972 through September 1975 (Table A2). Stations 3, 8, and 9 were the same as the Detroit Edison study sites. Stations 3 and 9 were selected to sample the source waters for the cooling intake. The discharge canal was sampled at the upstream end, station 12; the middle, station 8; and the downstream end, station 14. Two stations

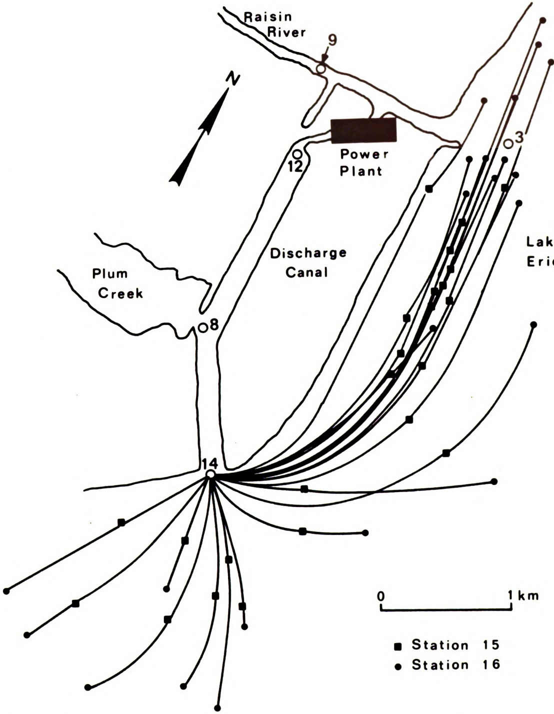


Figure 2. Map showing the vicinity of the Monroe Power Plant and sampling locations in the cooling system. Locations of station 15 and 16 are from samples obtained in the thermal plume which altered position with wind changes.

were located in the lake to follow the water mass as it mixed with the lake. Station 15 was located along the central axis of the thermal plume at a point where the temperature was about one-half the difference between the ambient lake temperature and the lower discharge canal temperature. Station 16 was located along the central axis near the plume edge where the temperature was 1 to 2 C above ambient. These lake stations varied in position, depending on the movement of the lake currents due to wind direction and the river and discharge canal flow.

METHODS AND MATERIALS

The Detroit Edison Sites

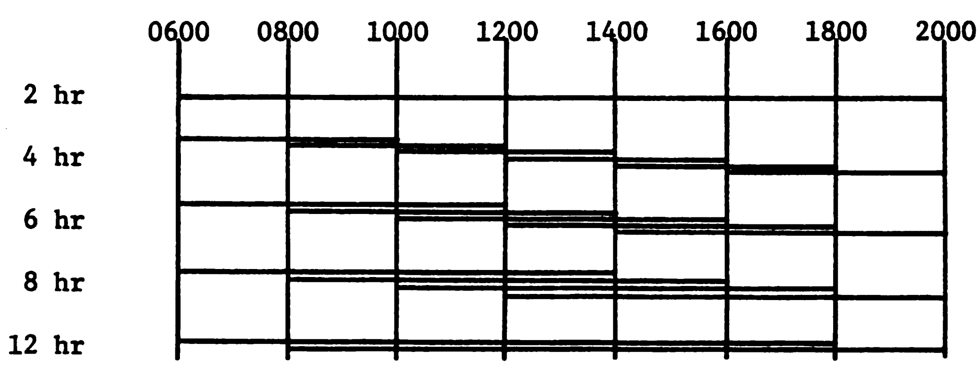
Field Procedures

The Detroit Edison study productivity samples were taken with an 8 liter Van Dorn water bottle from just below the surface and at 0.5 m, 1.5 m, and 2.5 m depths. Duplicate clear and dark 300 ml Pyrex borosilicate glass bottles were filled by gravity flow, with an exchange of at least three volumes. Two water samples were also taken at each depth to determine the initial oxygen concentration. The dark bottles were double wrapped with black plastic tape and then painted white to prevent light and heat from entering. The tops were covered with aluminum foil caps to prevent light from entering through the glass stopper.

The light and dark bottles were returned *in situ* to the corresponding depth of collection. They were attached to a metal rod with clips, one rod at each of the four depths. The rods were supported by a styrofoam float which was anchored at each end to prevent drifting. The floats were oriented so the bottles were not in the shadow formed by the styrofoam as the sun passed overhead.

In situ incubations were conducted near midday, usually between 1000 and 1500 hours. Exposure time was approximately four hours in length. Sample fixation and titration were done using the modified Winkler dissolved oxygen test, as outlined in *Standard Methods* (Anon., 1965). All samples were immediately fixed upon completion of the incubation. Titrations on most occasions were completed within one hour of fixation. Gross primary production and respiration values were determined from dissolved oxygen changes (Strickland, 1960).

Diurnal gross primary productivity was measured on several occasions during the study period at stations 3, 8, and 9, using two different methods. The first involved 3 to 4 consecutive incubation periods of approximately 4 hours during the daylight period. Midpoints of the time intervals were used to position the data points. The other method involved sample exposures for various time periods according to the following idealized schedule when sunrise occurred at 0600 hours:



The initial starting time corresponds to sunrise. The samples, two light and two dark bottles, were incubated at 0.25 m. The above data were used to estimate the percentage of total productivity that occurred during the four hour incubation periods.

Alkalinity and pH measurements were taken once a season from 1600 to 0800 hours the following morning. Alkalinity was determined as described in Standard Methods (Anon., 1965). All pH measurements were taken with a Porto-matic pH Meter. Secchi disc transparency data were taken with a 20 cm disc. During 1973-75, light penetration measurements were taken with a Whitney-Montedoro submarine photometer. Temperature profiles were taken at all stations using a YSI Model 51A combination thermistor meter. Oxygen profiles were made with the same meter, which was standardized against the modified Winkler method.

Daily solar radiation was measured using a Belfort pyroheliometer and a Eppley pyroheliometer. A polar planimeter was used to convert from area to total Langleys per day. Meteorological data were obtained from the U.S. Department of Commerce records taken at Detroit City Airport and Toledo Express Airport.

Nutrient Analysis

Water samples for chemical analysis were taken at approximately the same time as those for community metabolism. Samples were obtained with the same 8 liter Van Dorn water bottle from 0.5 m and 2.5 m. A subsample was preserved in a 4% formaldehyde solution for phytoplankton analysis. Water chemistry samples were preserved with $HgCl_2$ in the field and processed in the water chemistry laboratory operated by the Institute of Water Research at Michigan State University. Laboratory analyses were carried out for chloride, total Kjeldahl nitrogen, total soluble phosphorus, total organic carbon, and suspended solids.

Chloride analyses were accomplished with mercuric nitrate titration of a 25 ml sample to the diphenylcarbazone-mercury complex endpoint. A mixed indicator containing Xylene cyanol FF was used, as outlined in Standard Methods (Anon., 1965).

Total Kjeldahl nitrogen was measured by digesting a 50 ml sample with a mercury catalyst. Ammonia formed in the digestion of nitrogen-containing organic compounds and nitrogen already present as ammonia were distilled and determined by Nesslerization. The micro-Kjeldahl method that was followed was outlined in Standard Methods (Anon., 1965).

Nitrate nitrogen was determined as outlined in Standard Methods (Anon., 1965). Samples containing more than the maximum standard of 0.7 mg/liter had to be diluted to within the standard range. Total nongaseous nitrogen was assumed to be the sum of nitrate nitrogen and total Kjeldahl nitrogen.

Total soluble phosphorus concentrations were determined using a modification of the technique described by Wadelin and Mellon (1953) as described by Annett (1977). The phosphorus atom was reacted with molybdate ions, extracted with chloroformbutanol, and the absorbance was measured spectrophotometrically.

Total organic carbon was determined, after adding HCl to a pH less than 1, on a Beckman single channel carbon analyser as described by the EPA (Anon., 1971).

Total suspended solids were defined as the dry weight gain of a millipore filter (0.45 μ) from a 100 ml water sample passed through the filter. The filters were dried in a desicator, weighed, used to collect the sample, and then dried to a constant weight.

USEPA Sites

USEPA study productivity samples were also measured by the change in oxygen. Three, 300 ml light bottles and three dark bottles were filled with water collected with an 8 liter Van Dorn water bottle and suspended in situ at the depth of collection, 0.5 m in 1972 and 1973 and 0.2 m from 1973 through 1975, at all stations. The bottles were incubated from 0800 to 1230 in the morning period, 1200 to 1800 in the afternoon, and from 2100 to 0100 in the evening. Incubation times varied from 2 to 4.5 hours. Temperature and oxygen profiles, solar radiation, light penetration, pH, and alkalinity measurements were taken using methods described above in the Detroit Edison study.

Data Analysis

Carbon fixation was obtained from oxygen values by using the ratio of 0.312 mg carbon fixed per 1.0 mg oxygen evolved (Westlake, 1969). The data were converted from volumetric units to areal units by morphometric profiles of mean oxygen production. An extrapolation of the GPP and respiration data were made to calculate total productivity for the entire water column when the station depth exceeded the sampling depth. These data were then used to calculate seasonal and annual estimates of carbon fixation and the corresponding productivity to respiration ratio. This ratio can be used as an indicator of the change in the eutrophic condition of the lake, possibly the result of the input of thermal effluent from the power plant. Linear regression analyses were run to determine relationships between gross primary productivity and respiration and various nutrient, temperature, light, and suspended solids concentrations.

RESULTS AND DISCUSSION

Gross Primary Productivity

Depth Variation

Vertical profiles of gross primary productivity (GPP) indicate a significant decrease in the rate of carbon assimilation at depths greater than 1.5 m (Figure 3). The river exhibited the lowest productivity rates at all depths over the entire study period. In 1970 the discharge canal served only as an embayment of the lake. The first pumping units came on line in May 1971. During those two years the productivity was highest in the discharge canal, with the lake values being intermediate. In 1972 the pumping rate was doubled (44 m^3/sec) with subsequent units being added in 1973 and 1974. Upon addition of the second and succeeding units, the rate of production in the discharge canal was usually lower than that of the lake.

The waters of the western basin of Lake Erie, because of its extreme shallowness, are stirred thoroughly from top to bottom by wave and seiche action (Verduin, 1964). This results in relatively homogeneous temperature profiles, nutrient concentrations, and biological populations. Cody (1972) was unable to determine the existance of a thermocline in the areas of Niagara Reef and North Bass Island. Similar results were also described by Marcus (1971) and Kreh (1972) for the study area.

The productivity of the water column varied greatly. On numerous occasions, particularly at the lake station, the GPP was higher at the 0.5 m depth than at the surface. This is in agreement with other investigators' results working in similar conditions (Vollenweider and Nauwerck, 1961; Cody, 1972; and Glooschenko et al., 1974). This below

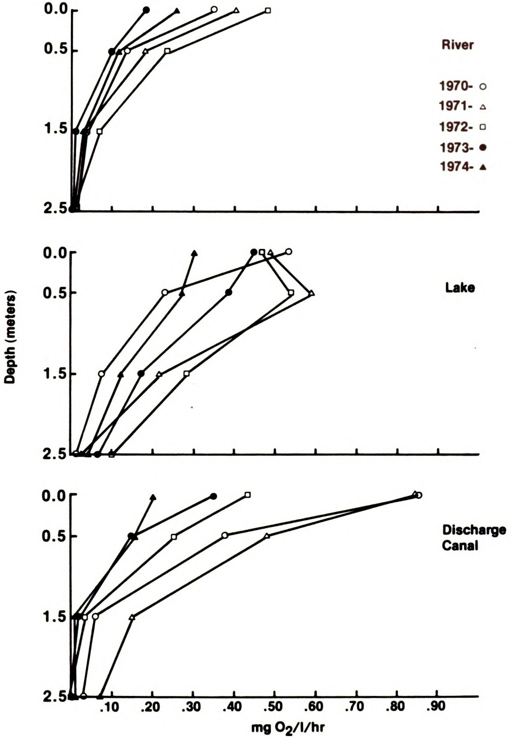


Figure 3. Depth profile of mean annual gross primary productivity at the river, lake, and discharge canal stations, 1970 through 1974.

surface inhibition has been attributed to sensitization to high light levels and photoautoxidation, causing irreversible destruction to some parts of the photosynthetic apparatus (Vollenweider and Nauwerck, 1961).

Yearly averages for the lake (station 3) for 1971 and 1972 exhibited photoautoxidation. This surface depression of GPP did not appear to be seasonal in nature, as it was measured throughout the year. However, this trend was rarely exhibited in the river (station 9) and discharge canal (station 8). Yearly averages of GPP remained almost constant in their rate of decrease with depth in the river and discharge canal. GPP at 2.5 m was nearly 0.00 mg O_2/l/hr in the river at all times. The values at the same depth were similar ($<$ 0.02 mg O_2/l/hr) in the discharge canal during operation, except 1971 and 1972 when the flow of cooling water was slight. The lake station exhibited production at 2.5 m (0.5-1.0 mg O_2/l/hr) on most occasions because of greater light penetration in the water. The discharge canal showed similar results in 1970 and 1971 when it operated as an embayment to the lake.

Diurnal Variation

Diurnal gross primary productivity was measured on four occasions (Figure 4) using a four hour incubation period and on two occasions using incubation periods of 2, 4, 6, 8, and 12 hours (Figure 5). Diurnal GPP rates calculated from the four hour incubation periods resulted in a maximum rate of photosynthesis occurring at midday, seven to eight hours after sunrise in the summer. This corresponds closely with the peak height of the sun in the sky. All three stations showed similar patterns of maximum productivity.

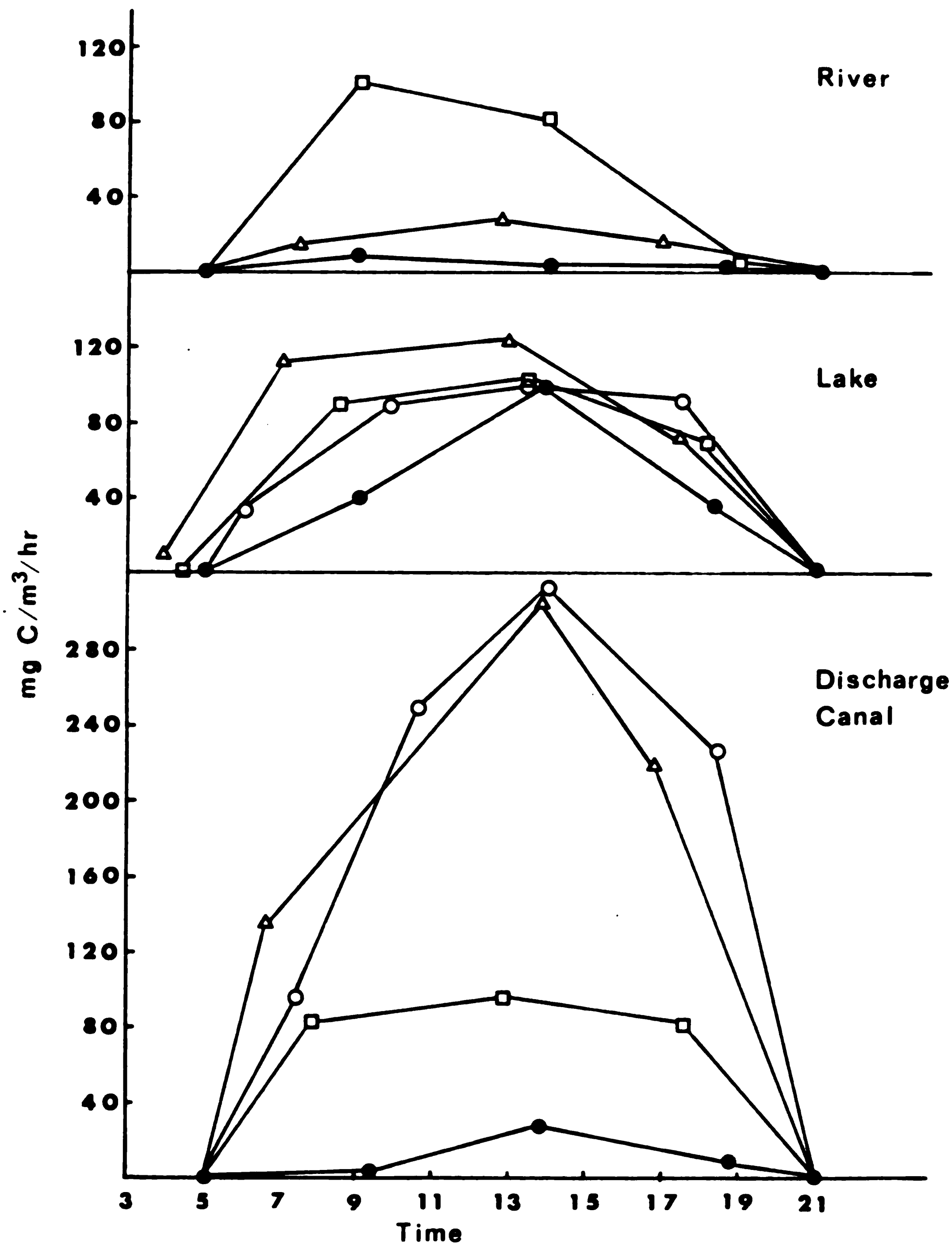


Figure 4. Diurnal mean gross primary productivity at the river, lake, and discharge canal stations on 1 July 1970 (○), 26 August 1971 (△), 1 June 1972 (□), and 18 June 1974 (●).

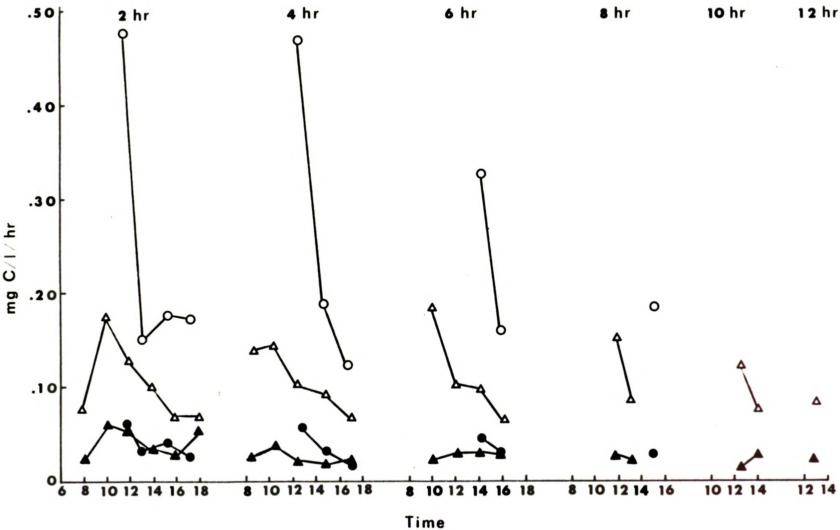


Figure 5. Effect of incubation time on gross primary productivity (26 June 1974 (○) and 22 August 1974 (△)) and respiration (26 June 1974 (●) and 22 August 1974 (▲)) at the lake station.

Lake station diurnal rates remained almost constant over the four sampled dates. The rates were also more equal over the photoperiod, remaining so for an eight to ten hour period. The discharge canal values showed a much higher peak in production in 1970 and 1971 during the midday period, while the values determined in 1972 more closely resembled the lake data. River station values also exhibited the midday peak, although lower than in the lake station.

The results of the mixed incubation times showed the photosynthetic maximum occurring four to five hours after sunrise and then decreasing as the sun approached its maximum height in the sky at midday (Figure 5). The rate of production was not constant over the photoperiod as other data showed, but dropped off much more rapidly once the maximum rate was reached. Other investigations concur with this trend. Vollenweider and Nauwerck (1961) and Munawar et al. (1972) measured maximum rates of photosynthesis occurring in mid to late morning, with a decline in the afternoon and evening. Verduin (1957) reported maximum rates between 0700 and 1000 hours in the morning, a reduced rate between 1000 and 1600, and a negative rate between 1600 and 1900 hours while working in western Lake Erie. This suggests another parameter, besides solar radiation, as the limiting factor of GPP.

One explanation for the maximum productivity rate occurring at midday for the four hour incubations may be a consequence of the chosen time frames for the exposure of the samples. It is possible that the maximum rate of GPP was spread over two sampling periods, thereby causing a decrease in the first value and an increase in the second, skewing the diurnal curves to the right.

Gross primary productivity was measured during the midday time interval (0900-1600 hours) on most occasions. The *in situ* rate of carbon assimilation was lowest in the river on 35 of the 48 dates sampled (Figure 6). The river had the highest production rate on only 3 of 48 occasions. The lake station had the highest GPP levels on 28 of the sampling dates and the discharge canal had the highest rates on 17 dates, 15 of which were in 1970 and 1971 when the canal had no or very low flow through rates. After two units of the power plant came on line, there were only two occasions where GPP rates were the highest. The lake station had the lowest level of production on five dates, four of which were in the 1970 and 1971 period. The discharge canal had the lowest rate of carbon fixation on nine dates, all in 1972 to 1974.

Summary of the GPP data (48 dates sampled)

	River	Lake	Discharge Canal
Highest	3	28	17
Lowest	35	4.5	8.5

The lake station had a maximum GPP of 563 mg $C/m^2/hr$ on 30 August 1972. Maximum rate for the discharge canal was 498 mg $C/m^2/hr$ on 16 July 1971. The river station also had a maximum rate on 30 August 1972 of 294 mg $C/m^2/hr$.

Annual Variation by Season

Daily estimates of gross primary productivity were based upon the proportion of carbon fixation that occurred during the exposure period. The diurnal data were combined to give a proportional estimate of production during the whole photoperiod. This proportion was then used

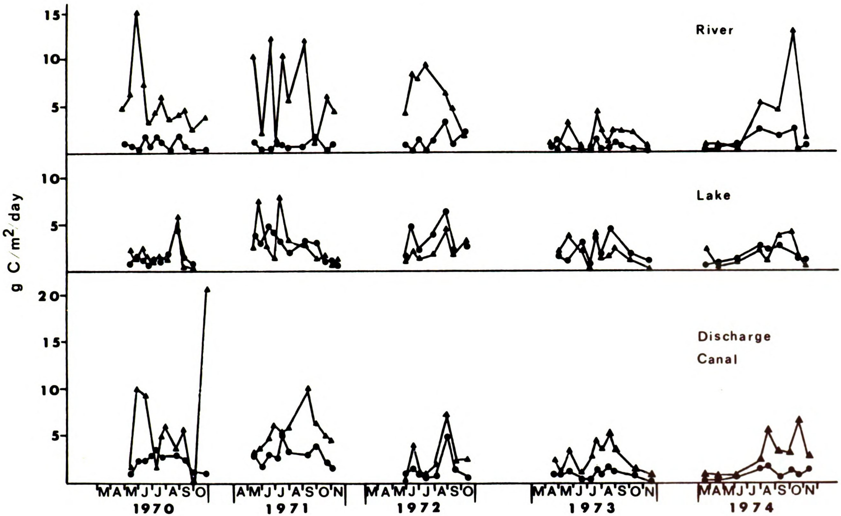


Figure 6. Mean gross primary productivity (●) and mean respiration (▲) at the river, lake, and discharge canal stations, 1970 through 1974.

to determine the percentage of production that occurred during the exposure period and the daily estimate was then calculated. The incubation times were chosen to correspond to periods of maximum production in order to minimize the variability occurring in the diurnal cycle.

Primary productivity was highly variable from one sampling period to the next, even during the same season (Figure 6). This was due mainly to changes in available light, suspended solids in the water effecting the light penetration, algal biomass, and water temperature. Seasonal GPP was also variable (Table 1). The lake station had the highest level of productivity in the summer season during the study period, with the exception of 1971 when the spring season was most productive. Discharge canal productivity maxima also occurred in the summer except for the fall of 1974. The maximum productivity of the river was more variable with the summers of 1970, 1972, and 1974; fall of 1971; and spring of 1973 having highest rates.

Yearly productivity values were more consistant. The lake had the highest GPP for all seasons except in 1970 where the discharge canal values were higher during the time it was not receiving the flow of cooling water. In 1971 the lake and discharge canal values were almost equal. The river had the lowest annual productivity in all years except 1974, when high summer values greatly increased the annual productivity.

Productivity values varied greatly from one year to the next with no apparent relationship. Annual productivity estimates for the lake ranged from 300 g C/m^2 (1970) to 852 g C/m^2 (1972). The discharge canal ranged from a low of 227 g C/m^2 (1974) to a high of 786 g C/m^2 (1971).

Table 1. Daily, seasonal, and annual mean GPP and respiration in g C/m^2 by station for the Detroit Edison sites.

	9 (River)		3 (Lake)		8 (Discharge Canal)	
Spring 1970	GPP	R	GPP	R	GPP	R
Daily	0.8	8.4	0.9	2.0	2.0	7.1
Seasonal	71.0	756.3	78.3	181.1	185.8	647.9
Summer 1970						
Daily	1.5	4.3	1.7	2.4	2.7	4.4
Seasonal	141.2	392.2	159.2	214.8	250.7	404.0
Fall 1970						
Daily	0.7	3.2	0.7	0.3	2.2	10.7
Seasonal	63.7	286.7	62.9	24.6	100.1	933.7
1970 Mean 274 days	275.9	1444.2	300.4	420.4	536.5	1985.6
Spring 1971						
Daily	0.8	8.4	4.0	4.1	2.3	3.7
Seasonal	68.7	764.4	361.0	370.4	212.3	340.3
Summer 1971						
Daily	1.0	7.3	2.9	4.0	3.6	6.7
Seasonal	94.4	668.0	261.6	361.3	323.1	611.5
Fall 1971						
Daily	1.4	4.0	1.5	1.2	2.6	5.2
Seasonal	124.7	362.2	135.7	106.5	239.2	476.8
Winter 1971						
Daily	---	---	0.3	1.3	-0.1	0.7
Seasonal	---	---	30.0	118.3	-6.8	64.6
1971 Mean 365 days	287.8	1794.5	788.3	956.4	767.8	1493.3
Spring 1972						
Daily	0.6	6.3	3.1	1.6	1.2	2.5
Seasonal	50.1	574.2	282.1	149.2	112.2	231.1
Summer 1972						
Daily	1.5	8.0	3.7	2.4	1.9	2.9
Seasonal	139.0	723.5	331.7	220.2	176.1	261.2
Fall 1972						
Daily	0.6	3.6	2.6	2.5	0.9	2.3
Seasonal	54.2	325.8	238.9	225.7	83.7	207.5
1972 Mean 273 days	243.2	1623.4	852.7	595.1	372.0	699.8

Table 1 (Con't.)

	(9) River		(3) Lake		(8) Discharge Canal	
	GPP	R	GPP	R	GPP	R
Spring 1973						
Daily	0.8	1.5	1.6	2.8	1.0	2.4
Seasonal	70.4	134.7	146.2	258.4	89.2	217.5
Summer 1973						
Daily	0.6	1.7	3.2	2.0	1.1	3.5
Seasonal	56.6	155.6	287.7	184.7	101.8	316.7
Fall 1973						
Daily	0.5	1.7	1.3	0.7	0.4	1.2
Seasonal	47.0	156.5	119.2	59.2	36.9	111.0
1973 Mean 273 days	174.0	446.8	553.1	502.3	227.8	645.2
Spring 1974						
Daily	0.4	0.4	0.8	1.2	0.2	0.8
Seasonal	34.3	36.4	69.8	112.0	19.1	76.4
Summer 1974						
Daily	2.3	5.0	2.8	2.4	1.1	3.8
Seasonal	207.9	458.6	253.6	219.3	100.7	348.5
Fall 1974						
Daily	1.0	7.1	2.2	2.2	1.2	4.2
Seasonal	91.9	649.7	151.7	198.4	107.1	385.0
1974 Mean	334.1	1144.8	475.0	529.6	226.9	810.0

River values were more constant, from 174 g C/m^2 (1973) to 334 g C/m^2 (1974).

Temperature Effects

Linear regression analysis yields a significant ($p < 0.05$) relationship between gross primary productivity and temperature in the spring and fall of the year at temperatures less than 20 C at stations 3, 8, and 9 (Figure 7). When all stations were combined the relationship was highly significant ($p < 0.01$). This trend was not evident during the summer periods when temperatures exceeded 20 C. This variability apparently is related to factors other than temperature alone. The lake and discharge canal showed approximately the same variability for the summer season while the river was highly erratic. This may be due to the presence of other factors which have a greater effect on production than temperature.

The mean annual gross primary productivity was usually less in the upper discharge (station 12) than predicted from the mixing of river and lake cooling waters (Table 2 and 3). The productivity of the water at station 12 more closely resembled that of the river (station 9) than of the lake (station 3), even when the lake water was the major contributing component. Mean afternoon productivities averaged 33% less than morning samples. Evening samples showed negligible production, as expected for the dark hours. The inhibition of gross primary production in the upper discharge canal could have resulted from four possible factors, or a combination of them; mechanical damage from passage through the condensers, thermal shocking as a result of a rapid temperature increase during passage, inhibiting factors in the river water from upstream sources, or exposure to chlorine as a result of daily application to keep

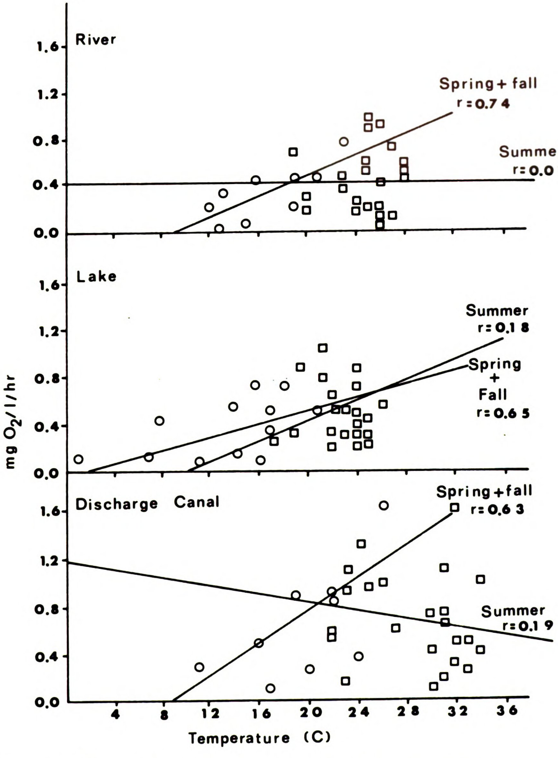


Figure 7. Mean surface gross primary productivity compared to temperature for the combined spring and fall season (O) and summer season (□) at the river, lake, and discharge canal stations, 1970 through 1974.

Table 2. Relative proportion of Raisin River and additional Lake Erie water pumped through the discharge canal.

Season	Mean River Discharge m^3/sec (% of canal flow)		Lake Input m^3/sec (% of canal flow)		Canal Discharge m^3/sec
Spring 1970	15.7				0.0
Summer 1970	11.3				0.0
Fall 1970	6.0				0.0
Spring 1971	8.8	(42)	12.2	(58)	21.0
Summer 1971	1.6	(8)	19.4	(92)	21.0
Fall 1971	2.6	(12)	18.4	(88)	21.0
Winter 1971	9.1	(43)	11.9	(57)	21.0
Spring 1972	12.4	(34)	24.4	(66)	36.8
Summer 1972	4.1	(12)	29.2	(88)	33.3
Fall 1972	33.0	(100)	0.0	(0)	31.5
Spring 1973	36.8	(78)	10.5	(22)	47.3
Summer 1973	11.6	(20)	46.2	(80)	57.8
Fall 1973	5.2	(8)	59.6	(92)	64.8
Spring 1974	33.7	(69)	15.3	(31)	49.0
Summer 1974	4.5	(6)	74.3	(94)	78.8
Fall 1974	4.4	(8)	49.9	(92)	54.3

Table 3. Mean gross primary productivity at the USEPA sites for cool (November-April) and warm (May-October) months of 1973-75 (mg O_2/liter/hour).

Period	Station						
	Lake	River	Upper Canal	Middle Canal	Lower Canal	Thermal plume	
Year-season	3	9	12	8	14	15	16
Morning							
1973-cool	0.03	0.06	0.03	0.00	0.03	0.05	0.01
-warm	0.76	0.39	0.34	0.36	0.42	0.62	0.79
1974-cool	0.04	0.06	0.04	0.01	0.03	0.05	0.00
-warm	0.52	0.22	0.33	0.48	0.50	0.61	0.73
1975-cool	0.08	-0.02	0.08	0.07	0.02	-0.05	0.12
-warm	0.54	0.56	0.58	0.54	0.74	0.64	0.64
Grand mean-cool	0.05	0.03	0.05	0.03	0.03	0.02	0.04
Grand mean-warm	0.61	0.39	0.47	0.46	0.55	0.62	0.72
Grand mean-3 year	0.33	0.21	0.24	0.24	0.29	0.32	0.44
Afternoon							
1973-cool	-0.04	0.01	0.01	0.03	0.05	0.07	0.00
-warm	0.26	0.13	0.21	0.12	0.16	0.31	0.30
1974-cool	0.04	-0.01	0.04	-0.02	0.00	0.00	0.01
-warm	0.43	0.33	0.41	0.40	0.43	0.58	0.43
1975-cool	--	--	--	--	--	--	--
-warm	0.70	0.34	0.33	0.41	0.41	0.95	0.88
Grand mean-cool	0.00	0.00	0.02	0.00	0.02	0.02	0.00
Grand mean-warm	0.46	0.27	0.32	0.31	0.33	0.61	0.54
Grand mean-3 year	0.23	0.13	0.18	0.16	0.18	0.22	0.27
Evening							
1973-cool	0.02	-0.02	0.00	0.00	0.00	0.01	0.00
-warm	0.02	0.02	-0.03	0.00	0.01	-0.06	-0.01
1974-cool	-0.05	0.01	-0.01	0.03	0.01	-0.01	-0.03
-warm	-0.01	0.02	-0.02	-0.08	-0.01	0.00	-0.01
1975-cool	-0.04	-0.04	-0.03	-0.02	-0.04	0.00	-0.01
-warm	0.04	-0.04	-0.05	-0.10	0.07	0.04	0.03
Grand mean-cool	-0.02	-0.02	-0.01	-0.00	-0.01	0.00	-0.01
Grand mean-warm	0.02	0.00	-0.03	-0.06	0.02	-0.01	0.00
Grand mean-3 year	0.00	-0.01	-0.02	-0.03	0.00	0.00	0.00

the condensers free of slime accumulation. However, no chlorination occurred during the afternoon sampling periods so the depression of productivity must have resulted also from other factors.

As water passed through the discharge canal, there was a recovery of the depressed productivity. The three year grand mean for the morning sampling period showed a 21% increase in productivity, almost reaching the predicted values for the system based on the mixing of the water masses (Table 3). The afternoon productivity remained almost constant, slightly below predicted values.

The productivity of the thermal effluent continued to increase as the water moved into the lake. Mid-plume productivities at station 15 usually exceeded those of the lake (station 3) prior to intake. Station 16 values averaged 33% above lake productivities, even though temperatures were only 1 to 2 C above ambient.

Suspended Solids Effects

Suspended solids and algal density are the major factors that influence light penetration into the aquatic system. Due to the heavy agricultural disturbance in the Lake Erie watershed, the levels of suspended solids were high. Concentrations were quite variable over the study period and no apparent annual trends were revealed (Table 4). Levels were generally highest in the spring, corresponding to high run-off rates and flow rates of the river, and lowest in the late summer. The near shore of the western basin of Lake Erie, being very shallow, is subject to remixing of settled bottom materials during periods of high turbulence. The increasing proportion of lake water being taken for

Table 4. Seasonal and annual mean concentrations of suspended solids in mg/l by station for the Detroit Edison sites.

Season	Station		
	9 (River)	3 (Lake)	9 (Discharge Canal)
Spring 1970	42.0	41.6	66.4
Summer 1970	53.0	26.2	43.8
Fall 1970	37.0	17.5	20.7
1970 Mean	45.9	28.9	45.4
Spring 1971	67.5	35.1	61.1
Summer 1971	29.6	21.1	33.2
Fall 1971	45.9	16.0	41.1
1971 Mean	45.9	23.1	43.7
Spring 1972	24.4	16.0	33.0
Summer 1972	23.7	8.8	19.3
Fall 1972	55.7	17.2	27.0
1972 Mean	31.0	13.3	26.3
Spring 1973	24.1	15.9	25.4
Summer 1973	43.1	22.2	46.3
Fall 1973	21.2	17.8	28.9
1973 Mean	33.7	19.8	37.7
Spring 1974	56.8	37.9	73.5
Summer 1974	25.5	13.3	25.0
Fall 1974	66.3	16.5	29.3
1974 Mean	52.6	23.7	44.8

cooling after plant operation began, has resulted in a decrease in the annual concentrations of suspended solids in the discharge canal.

The compensation point, where 1 percent of the surface light is available for photosynthesis, is generally accepted as the maximum depth where net primary production occurs. The compensation point in the river (station 3) averaged 1.7 m and the lake 3.1 m (Table 5). The discharge canal average, during the first two years of the study, was similar to the lake. This occurred before the canal received the flow of cooling water. As pumping units came on line, the discharge canal received the input of river water, resulting in the decreased photic zone.

Upon operation of all pumping units, the volume of intake water usually exceeded the total river flow and resulted in additional lake water being mixed with the river water. This should have resulted in the discharge canal light penetration values being intermediate between the river and lake values, proportionally related to the percentage each contributed to the discharge waters. During 1973 and 1974 the compensation depth of the river and discharge canal were the same (1.7 m). This implies the additional input of material causing a decrease in the light penetration, possibly the erosion of bottom sediments from the discharge canal.

A significant relationship exists between the depth of the compensation point (1% light) and the suspended solids concentration in the river ($p < 0.05$), lake ($p < 0.05$), and the discharge canal ($p < 0.01$) (Figure 8). Because of the relatively high suspended solids levels and a corresponding shallow depth of the euphotic zone, less than 3 m ,

Table 5. Compensation depth (1% light) measured at the Detroit Edison stations, 1973 and 1974.

Date	River		Lake	Discharge Canal	
	Depth (m) 1% light	% of lake 1% light depth	Depth (m) 1% light	Depth (m) 1% light	% of lake 1% light depth
1973					
6-21	1.00	36	2.80	1.40	63
7-7	0.88	54	1.62	0.90	56
7-17	1.78	47	3.80	2.00	53
8-16	2.00	68	2.92	1.72	59
9-10	1.78	75	2.38	--	--
10-9	1.91	59	3.22	1.72	53
1974					
5-22	0.89	49	1.80	1.45	81
7-16	2.00	48	4.18	2.21	53
7-31	--	--	3.45	--	--
9-27	1.27	43	2.93	--	--
10-24	2.92	71	4.12	2.05	50
11-7	2.58	60	4.30	2.00	47
Mean	1.72	55	3.13	1.72	57

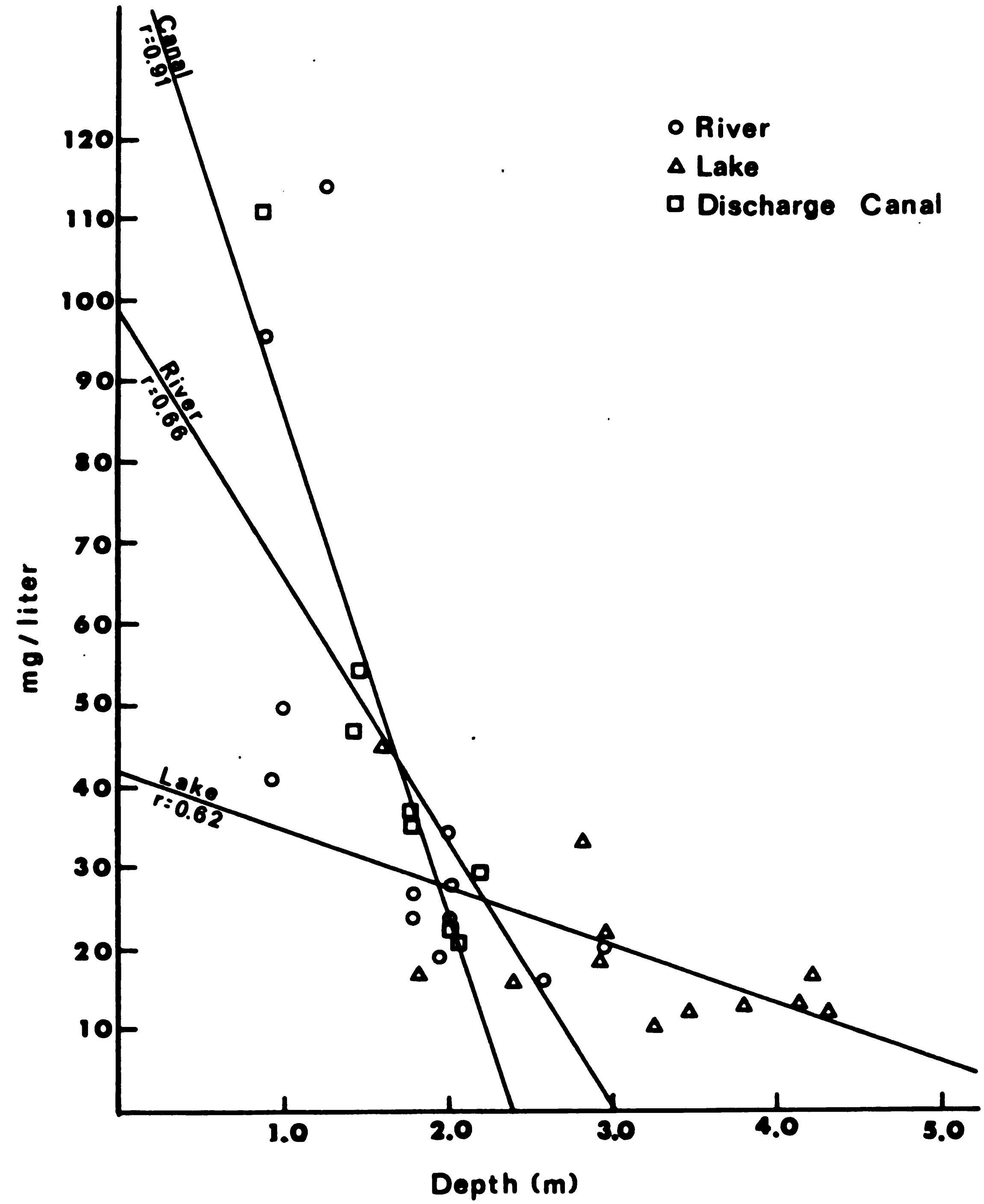


Figure 8. Mean depth of 1% surface light compared to mean suspended solids concentrations at the river, lake, and discharge canal stations, 1973 and 1974.

large portion of the near shore area does not contribute to the productivity of the system.

Suspended solids and GPP were inversely related but highly variable, with no significant ($p<0.05$) relationship for all stations (Figure 9). The lowest productivity rates and highest suspended solids levels were found in the river, while the inverse was true in the lake. The discharge canal showed a decrease in productivity over the study period, while the suspended solids concentrations increased and then slightly decreased.

Nutrient Effects

Productivity does not appear to be related directly to either total nongaseous nitrogen or total soluble phosphorus (Figures 10 and 11). At particular times they may exhibit a dominant role but no positive trends were observed.

Free CO_2 concentrations decreased from maximum spring levels to minimum values in late summer and a gradual increase in the fall (Table 6). River values were consistantly highest, resulting from high respiration rates. On most occasions the concentration of free CO_2 in the river water was above atmospheric saturation (0.70 mg/1), resulting in an export of CO_2 from the water due to supersaturated conditions. Lake values were the lowest, with unsaturated conditions existing, resulting in an import of atmospheric CO_2 into the lake system. Discharge canal values were usually intermediate.

CO_2 concentrations indicate levels low enough to limit productivity occasionally occurred in the lake and discharge canal. Summer and early fall values approached or fell below the 0.31 mg/1 concentration that favors

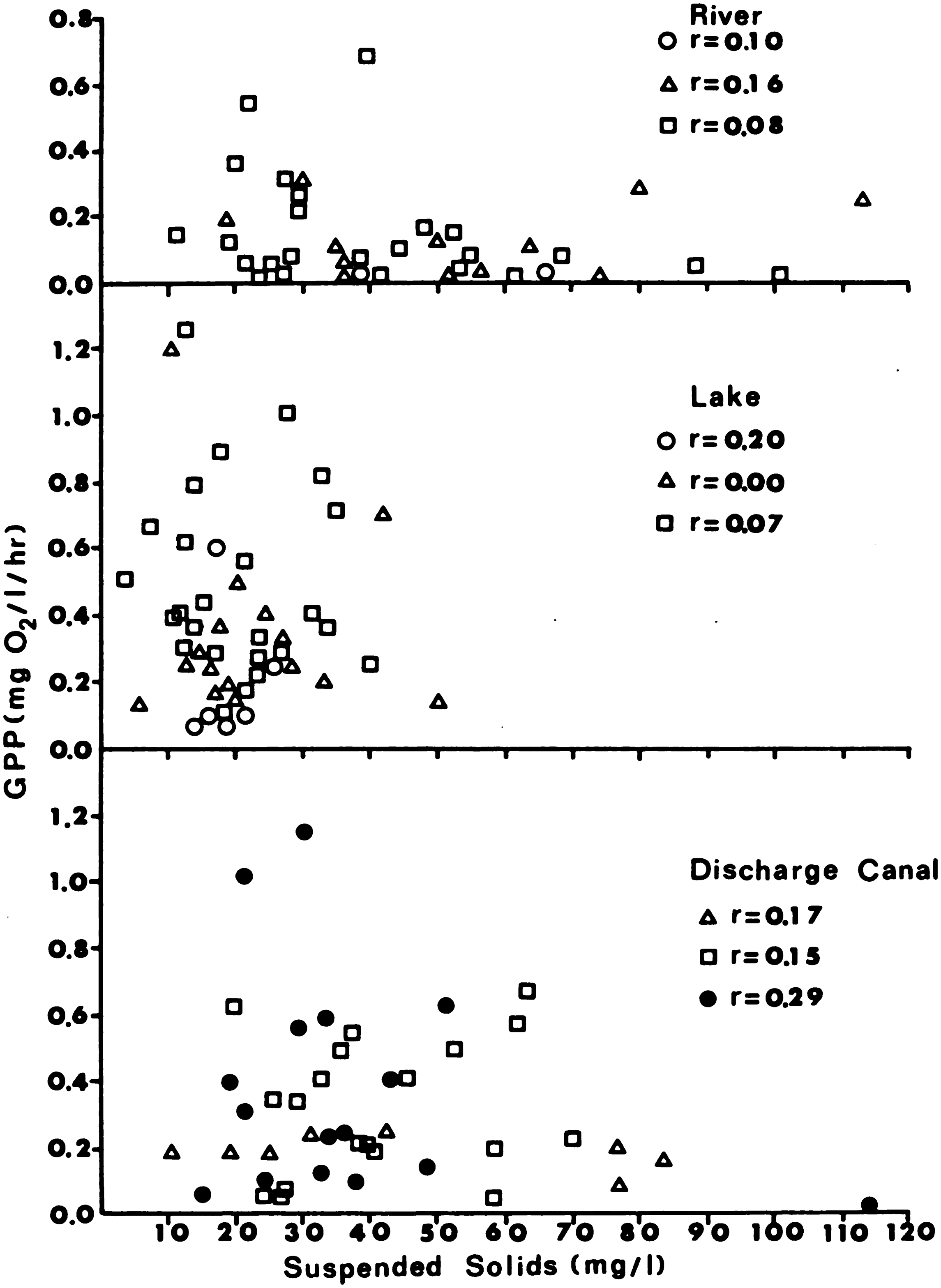


Figure 9. Mean gross primary productivity at 0.5 m compared to mean suspended solids concentrations at temperature intervals 8-13 C (○), 14-20 C (△), 21-27 C (□), and 28-35 C (●) at the river, lake, and discharge canal stations, 1970 through 1974.

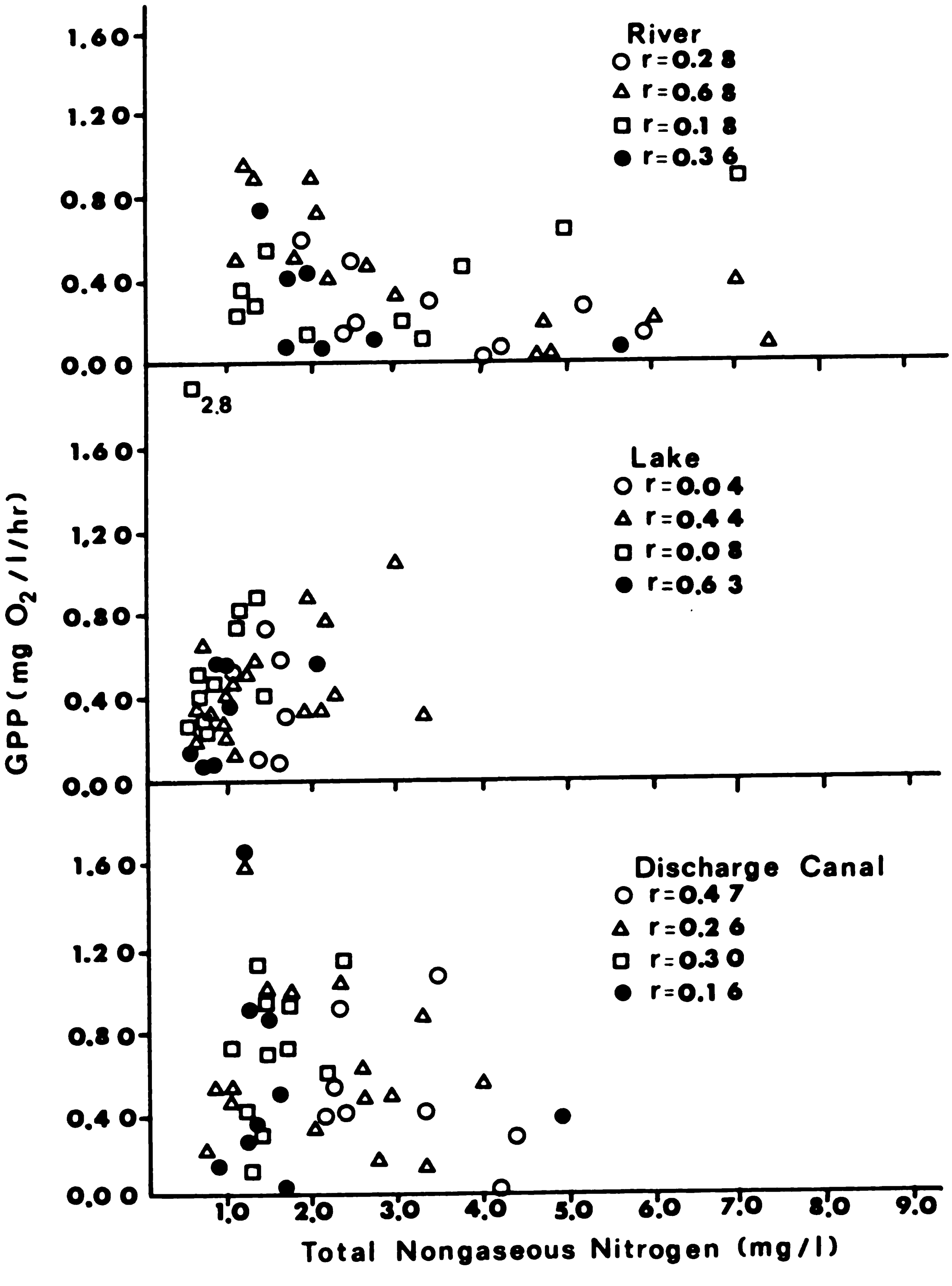


Figure 10. Total nongaseous nitrogen concentrations compared to mean surface gross primary productivity for April-May (○), June-July (△), August-September (□), and October-November (●) at the river, lake, and discharge canal stations, 1970 through 1974.

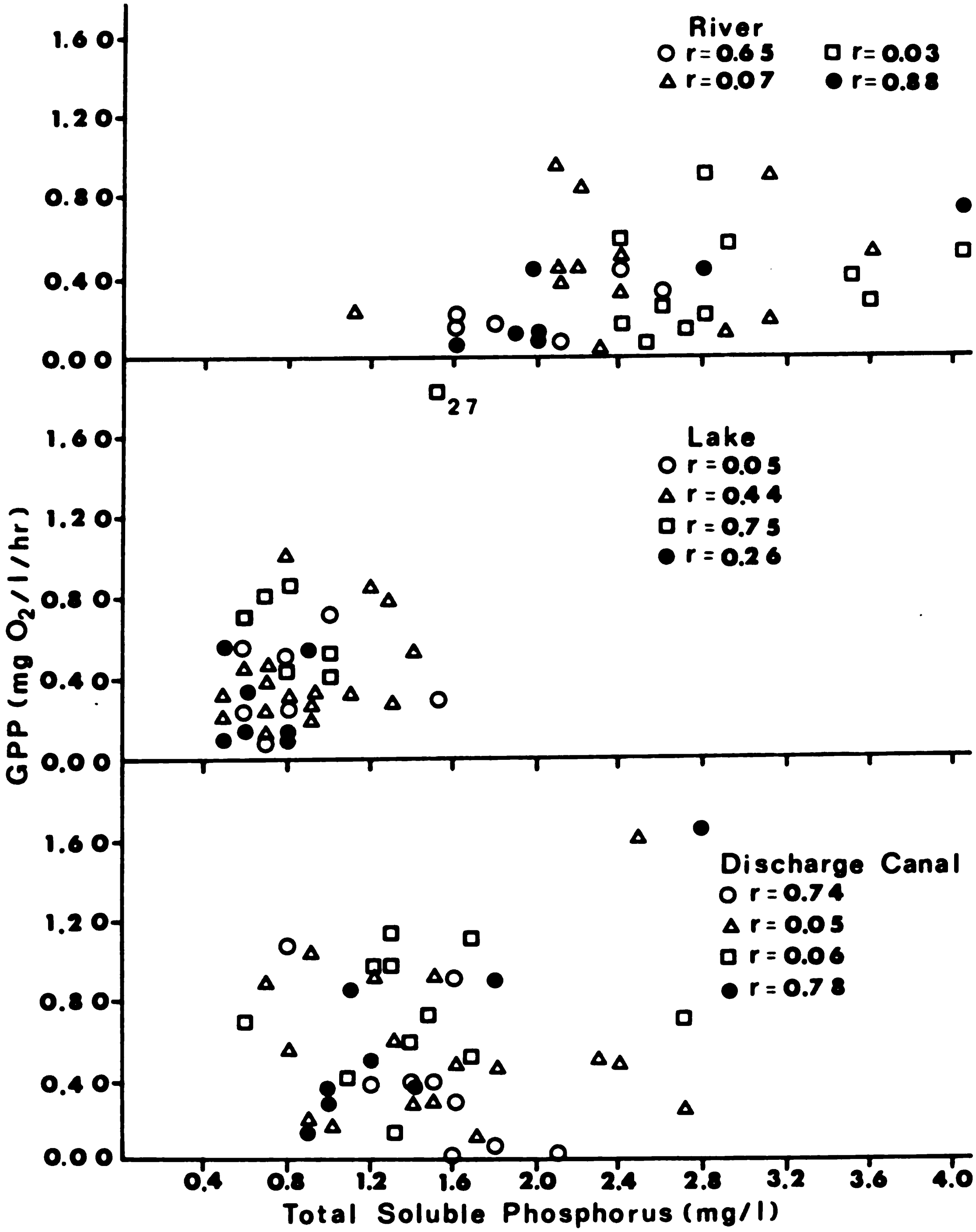


Figure 11. Total soluble phosphorus concentrations compared to mean surface gross primary productivity for April-May (○), June-July (△), August-September (□), and October-November (●) at the river, lake, and discharge canal stations, 1970 through 1974.

Table 6. Alkalinity, pH, and free CO_2 concentrations during 1971 and 1974.

Date		3 (Lake)					8 (Discharge Canal)					9 (River)				
7-15-71 7-16-71	Time	1312	1745	2240	0720	1110	1340	1730	2215	0735	1155	1300	1755	2300	0710	1040
	Alk(mg/l)	108	94	96	102	92	114	104	112	112	112	132	126	130	130	132
	pH	8.6	8.7	8.7	8.8	8.7	8.4	8.2	7.9	8.2	8.1	8.7	8.7	8.7	8.7	8.7
	CO_2 free (mg/l)	0.52	0.36	0.37	0.33	0.35	0.86	1.26	2.73	1.36	1.71	0.50	0.48	0.50	0.50	0.50
9-1-71 9-2-71	Time	1650	2050	0405	0910	1200	1700	2105	0425	0445	1140	1640	2035	0345	0830	1205
	Alk(mg/l)	98	92	90	90	96	114	102	104	106	110	118	122	118	120	116
	pH	8.8	8.4	8.3	8.1	8.6	8.2	7.6	7.7	7.8	7.9	8.2	7.2	7.3	7.2	7.8
	CO_2 free (mg/l)	0.32	0.78	0.97	1.55	0.51	1.43	4.99	4.03	3.26	2.68	1.48	15.5	11.9	15.2	3.69
10-15-71 10-16-71	Time	1615	2115	0445	0920	1235	1620	2130	0500	0945	1300	1610	2100	0430	0855	1210
	Alk(mg/l)	90	98	112	104	114	116	126	118	112	120	122	120	134	134	134
	pH	8.6	8.4	8.6	8.4	8.6	7.6	7.7	7.6	7.5	7.8	7.4	6.9	7.5	7.5	7.5
	CO_2 free (mg/l)	0.51	0.89	0.64	0.95	0.65	5.87	5.06	6.49	7.77	4.16	11.3	35.4	9.92	9.92	9.92
11-12-71 11-13-71	Time	1615	2115	0605	0915	1345	1635	2130	0600	0930	1330	1600	2100	0545	0900	1315
	Alk(mg/l)	116	108	108	110	106	136	128	---	130	132	150	152	114	116	120
	pH	8.2	8.6	8.7	8.7	8.7	7.9	8.2	---	7.9	8.1	7.8	8.3	8.5	8.4	8.2
	CO_2 free (mg/l)	2.12	0.77	0.61	0.62	0.60	3.99	1.87	---	3.81	2.43	6.12	2.12	0.91	1.17	1.99

Table 6. (Con't.)

Date		3 (Lake)					8 (Discharge Canal)					9 (River)				
4-16-74 4-17-74	Time	1600	2000	2400	0800	1200	1600	2000	2400	0800	1200	1600	2000	2400	0800	1200
	Alk(mg/l)	98	102	102	114	120	166	170	184	168	192	192	200	194	194	200
	pH	8.1	8.0	8.2	8.3	8.0	8.1	8.1	8.2	8.2	8.0	7.8	8.1	7.9	8.3	8.0
	CO_2 free (mg/l)	1.99	2.62	1.69	1.46	3.08	2.86	2.94	2.52	2.30	4.18	7.10	3.69	5.69	2.48	5.14
6-17-74 6-18-74	Time	1600	2000	2400	0600	1030	1600	2000	2400	0600	1030	1600	2000	2400	0600	1030
	Alk(mg/l)	104	104	110	110	110	128	140	140	130	130	192	154	195	176	148
	pH	8.2	8.4	8.3	8.4	8.1	7.9	8.2	8.0	8.2	8.1	8.0	7.6	8.0	8.0	8.8
	CO_2 free (mg/l)	1.42	0.89	1.19	0.94	1.90	3.12	1.70	2.80	1.63	2.18	4.18	8.48	4.25	3.84	0.49
8-27-74 8-28-74	Time	1600	2000	2400	0600	1000	1600	2000	2400	0600	1000	1600	2000	2400	0600	1000
	Alk(mg/l)	90	96	96	102	108	98	98	108	112	106	116	126	114	148	118
	pH	8.7	8.8	8.4	8.3	8.7	8.4	8.3	8.4	8.5	8.6	8.6	8.0	8.2	8.8	8.4
	CO_2 free (mg/l)	0.34	0.29	0.75	1.01	0.41	0.74	0.94	0.82	0.67	0.50	0.54	2.43	1.38	0.44	0.92
9-26-74 9-27-74	Time	1600	2000	2400	0700	1100	1600	2000	2400	0700	1100	1600	2000	2400	0700	1100
	Alk(mg/l)	108	95	92	102	96	114	110	110	114	110	172	108	130	150	128
	pH	9.0	9.1	9.0	8.8	9.0	9.0	8.8	8.8	8.9	8.8	8.3	8.8	8.5	8.2	8.6
	CO_2 free (mg/l)	0.23	0.15	0.20	0.36	0.21	0.21	0.33	0.33	0.27	0.33	1.86	0.35	0.88	2.05	0.68

blue-green algal production (King, 1970). Diurnal curves revealed the expected increase in CO_2 during the dark hours. Levels decreased in the morning hours but did not peak before maximum productivity occurred, indicating that CO_2 was not limiting.

Respiration

Depth Variation

Vertical profiles indicated a decrease in the rate of respiration with increasing depth (Figure 12). All three stations; lake (3), discharge canal (8), and river (9), exhibited approximately a 40% decrease in respiration at 2.5 m relative to surface values. This decline is attributed primarily to the decreasing rate of photosynthesis, discussed below.

Diurnal Variation

Diurnal respiration rates generally paralleled the diurnal curves for productivity, although the changes were not as pronounced (Figures 5 and 13). Maximum rates corresponded very closely to the midday peaks in GPP. Lowest respiration occurred in the evening hours when agal productivity ceased (Table 7). The evening rates of respiration were found to be about 40% below the daytime rates. All stations exhibited similar trends. The decrease in respiration was slightly greater during water temperatures less than 10 C.

Annual Variation by Season

Daily respiration rates were variable over the study period for all stations (Figure 6). Mean seasonal values were generally highest in the summer (Table 1). Spring and fall values were similarly lower.

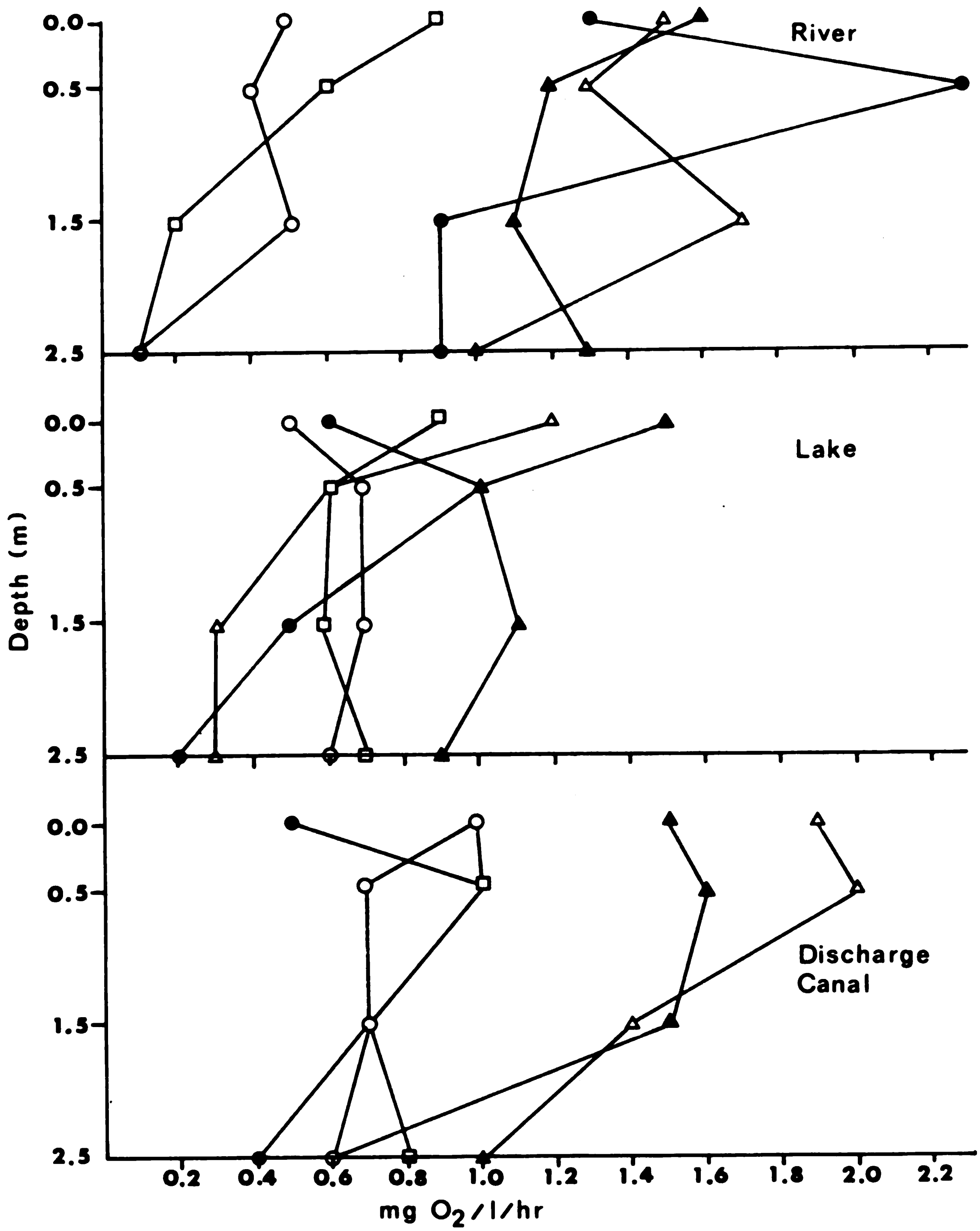


Figure 12. Depth profiles of mean annual respiration at the river, lake and discharge canal stations, 1970 through 1974.

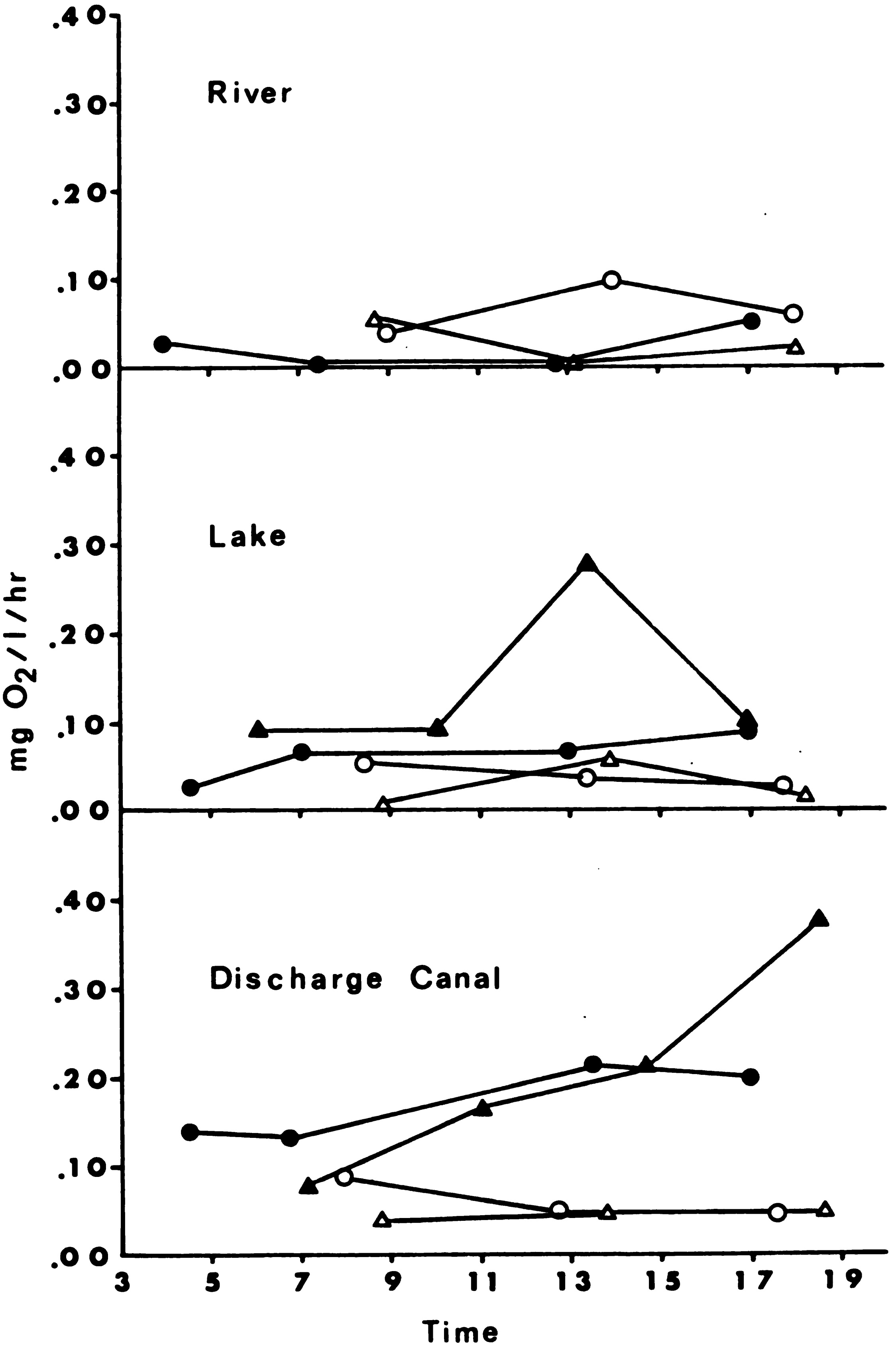


Figure 13. Diurnal mean respiration at the river, lake, and discharge canal stations on 1 July 1970 (▲), 26 August 1971 (●), 1 June 1972 (○), and 18 June 1974 (△).

Table 7. Mean respiration rate for the USEPA study sites for cool (November-April) and warm (May-October) months of 1973-75 (mg O_2/liter/hour).

Period Year-season	Lake 3	River 9	Upper Canal 12	Middle Canal 8	Lower Canal 14	Thermal 15	plume 16
Morning							
1973-cool	0.00	0.05	0.01	0.02	0.05	0.02	-0.01
-warm	0.08	0.07	0.05	0.08	0.08	0.09	0.10
1974-cool	0.04	0.03	0.05	0.03	0.03	0.02	0.02
-warm	0.10	0.05	0.08	0.08	0.09	0.09	0.09
1975-cool	0.00	0.06	0.10	0.12	0.06	0.02	0.00
-warm	0.10	0.06	0.14	0.13	0.10	0.03	0.05
Grand mean-cool	0.01	0.05	0.05	0.06	0.05	0.02	0.01
Grand mean-warm	0.09	0.06	0.09	0.10	0.09	0.07	0.09
Grand mean-3 year	0.05	0.05	0.07	0.08	0.06	0.05	0.05
Afternoon							
1973-cool	0.10	0.05	0.07	0.11	0.12	-0.02	0.00
-warm	0.09	0.16	0.12	0.05	0.08	0.11	0.08
1974-cool	0.02	-0.01	0.05	0.03	0.02	-0.02	0.00
-warm	0.03	0.04	0.13	0.14	0.13	0.13	0.12
1975-cool	--	--	--	--	--	--	--
-warm	0.09	-0.02	0.10	0.13	0.11	0.12	0.17
Grand mean-cool	0.06	0.02	0.06	0.07	0.07	-0.02	0.00
Grand mean-warm	0.07	0.06	0.12	0.11	0.11	0.12	0.12
Grand mean-3 year	0.06	0.04	0.09	0.09	0.09	0.05	0.06
Evening							
1973-cool	-0.02	-0.05	0.03	0.03	0.06	0.02	0.00
-warm	0.03	0.09	0.09	0.07	0.04	0.04	-0.04
1974-cool	-0.01	-0.04	0.05	0.05	0.09	-0.02	-0.04
-warm	0.06	0.04	0.07	0.11	0.05	0.09	0.04
1975-cool	-0.06	0.00	0.08	0.06	0.05	0.01	0.04
-warm	0.02	0.05	0.09	-0.05	0.09	0.08	0.09
Grand mean-cool	-0.03	-0.03	0.05	0.05	0.07	0.00	0.00
Grand mean-warm	0.04	0.06	0.08	0.04	0.06	0.07	0.03
Grand mean-3 year	0.01	0.02	0.07	0.04	0.06	0.04	0.01

However, the maximum respiration rates during the study period occurred in the spring and fall at stations 3, 8, and 9: lake, spring 1971, 370 g C/m^2; discharge canal, fall 1970, 933 g C/m^2; and the river, spring 1971, 764 g C/m^2, respectively. Winter data from the Monroe demonstration sites were limited, but the USEPA entrainment data indicated winter respiration rates were the lowest of all seasons (Table 7).

Mean annual river respiration remained constant from 1970 through 1972 and then significantly decreased in 1973 and 1974. These lower values coincided with improvements to the Monroe Sewage Treatment Plant and subsequent decrease in industrial and municipal sewage entering the Raisin River. Mean annual concentrations of organic carbon followed similar decreases during the same period (Table 8). Mean annual GPP values over the study period remained constant from 1970 through 1972, decreased in 1973, and reached their maximum in 1974 (Table 1). Mean annual oxygen values for the river more than doubled in 1973 and 1974 from the three preceding years (Table 9). The decrease in respiration, due to decreased organic loading, along with relatively constant GPP rates, has resulted in significantly higher oxygen concentrations in the Raisin River during the last two years of the study period.

Mean annual respiration for the lake station (3) remained almost constant, except 1971, which was almost double the average rate. The discharge canal exhibited its highest respiration rate during 1970, before it received thermal effluent from the power plant. The rate of carbon release greatly decreased as additional cooling water was pumped through the discharge canal. This led to the greater incorporation of lake water into the canal as water demands exceeded the volume

Table 8. Seasonal and annual mean concentrations of total organic carbon in mg/l by station for the Detroit Edison sites.

Season	Station		
	9 (River)	3 (Lake)	9 (Discharge Canal)
Spring 1970	21.3	13.4	14.0
Summer 1970	13.9	6.5	16.4
Fall 1970	16.3	7.4	10.5
1970 Mean	16.7	9.0	14.6
Spring 1971	16.3	6.5	15.3
Summer 1971	13.7	9.6	13.2
Fall 1971	22.4	12.1	17.4
1971 Mean	17.1	9.7	15.3
Spring 1972	12.2	4.9	9.8
Summer 1972	10.7	4.0	6.3
Fall 1972	9.9	5.4	7.1
1972 Mean	10.9	4.6	7.7
Spring 1973	10.8	5.9	9.3
Summer 1973	9.8	6.4	7.2
Fall 1973	7.5	4.8	5.7
1973 Mean	9.4	5.9	7.2
Spring 1974	10.4	5.5	10.0
Summer 1974	10.7	5.0	5.5
Fall 1974	9.2	5.3	8.2
1974 Mean	10.0	5.3	8.2

Table 9. Seasonal and annual mean oxygen concentrations in mg/l by station and depth for the Detroit Edison sites.

Station	3 (Lake)		8 (Discharge Canal)		9 (River)	
	0.5m	2.5m	0.5m	2.5m	0.5m	2.5m
Spring 1970	9.6	8.5	9.5	8.1	4.5	4.4
Summer 1970	7.8	7.3	7.8	6.0	2.3	2.3
Fall 1970	8.8	8.4	9.7	9.2	4.2	4.2
1970 Mean	8.7	8.0	9.0	7.8	3.7	3.6
Spring 1971	11.6	10.5	5.8	5.0	3.8	4.1
Summer 1971	9.8	8.1	4.8	4.1	0.3	0.1
Fall 1971	11.4	10.8	4.4	---	2.9	---
1971 Mean	10.9	9.8	5.0	4.6	2.3	2.1
Spring 1972	11.3	10.3	8.1	8.1	2.0	0.8
Summer 1972	12.0	10.6	7.9	6.7	4.9	3.5
Fall 1972	14.1	13.9	7.5	6.7	3.0	2.1
1972 Mean	12.5	11.6	7.8	7.2	3.3	2.1
Spring 1973	11.2	11.0	8.8	8.7	7.5	7.5
Summer 1973	8.4	8.0	6.2	6.0	5.8	5.6
Fall 1973	10.2	10.2	10.2	10.2	8.1	8.0
1973 Mean	10.0	9.7	8.4	8.3	7.1	7.0
Spring 1974	11.4	11.4	9.6	9.8	10.0	10.0
Summer 1974	8.2	8.1	6.8	6.7	6.0	5.3
Fall 1974	9.9	9.8	8.7	8.3	8.2	7.6
1974 Mean	9.8	9.8	8.4	8.3	8.1	7.6

supplied by the river. Respiration rates of the canal fell predictably, resulting from the combined effects of the lower respiratory demand of the lake water and the decreasing organic carbon concentration of the river water.

Temperature Effects

Respiration was related to temperature seasonally, with significant ($p<0.05$) relationships occurring only in the river during August and September and in the discharge canal during June and July (Figure 14). Temperatures appeared to contribute more strongly during the cool seasons, than in the warm summer months. The lake showed the least variability when all seasons were combined and the discharge canal the greatest.

The entrainment of the water mass through the power plant resulted in an elevation of the rate of respiration (Table 7). Mean annual water temperature elevation across the condensers averaged 7 to 8 C while the mean annual respiration rate in the upper discharge canal (station 12) almost doubled. This is in close agreement with the Q_{10} temperature increase. The stimulation of respiration was greatest, although variable, during the cool months, November through April. Mean annual rates for May through October increased about 50%. Diurnal comparisons indicated the greatest increase in respiration after entrainment occurred during the evening hours. Lesser increases were observed for the morning and afternoon sampling periods.

A 12% summertime and a 16% wintertime heat loss were accompanied by a 25% decrease in mean annual respiration, regardless of season, as the water moved through the discharge canal. The respiration of the

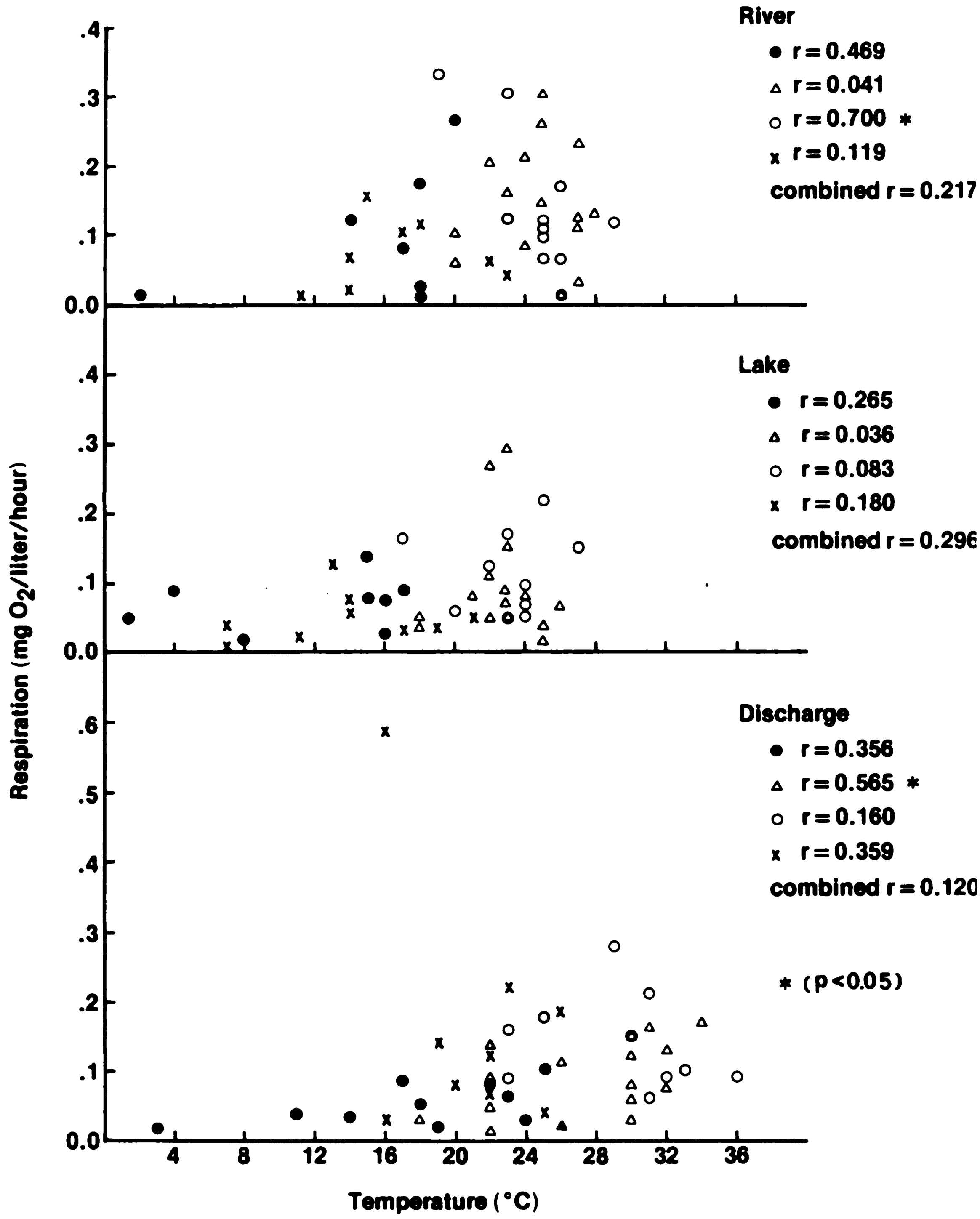


Figure 14. Mean respiration compared to mean temperature for March-May (●), June-July (△), August-September (○), and October-November (x) at the river, lake, and discharge canal stations, 1970 through 1974.

thermal plume, upon entering the lake, continued to decline as the temperature of the water decreased. Upon reaching station 16 (1-2 C over ambient) the mean respiration rate had recovered to its initial rate before thermal stiumulation. This recovery was independent of seasonal temperature variation or diurnal changes in the productivity of the system.

Gross Primary Productivity Effects

Respiration rates were clearly related to gross primary productivity (Figure 15). Highly significant ($p<0.01$) relationships existed in the lake and discharge canal at temperatures above 20 C. Neither station exhibited a positive relationship at temeperatures less than 20 C, but with temperatures combined, a highly significant ($p<0.01$) relationship existed. In the river just the opposite was true, respiration being related to GPP at temperatures below 20 C ($p<0.01$) and unrelated above 20 C. The decomposition of allochthonous organic material may have been a major contributor to respiration at the higher temperatures, thereby confounding the relationship, but at lower temperatures its impact may have been minimal. Gross primary productivity emerged as the main contributor.

Gross Primary Productivity/Respiration

Season GPP/R ratios were based on mean seasonal averages of daily GPP and respiration (Table 10). Highest river ratios occurred in the springs of 1973 and 1974, the result of greatly reduced respiration due to decreased sewage input. In three of the five years, highest ratios for the lake occurred in the fall. Autotrophic conditions (GPP/R>1).

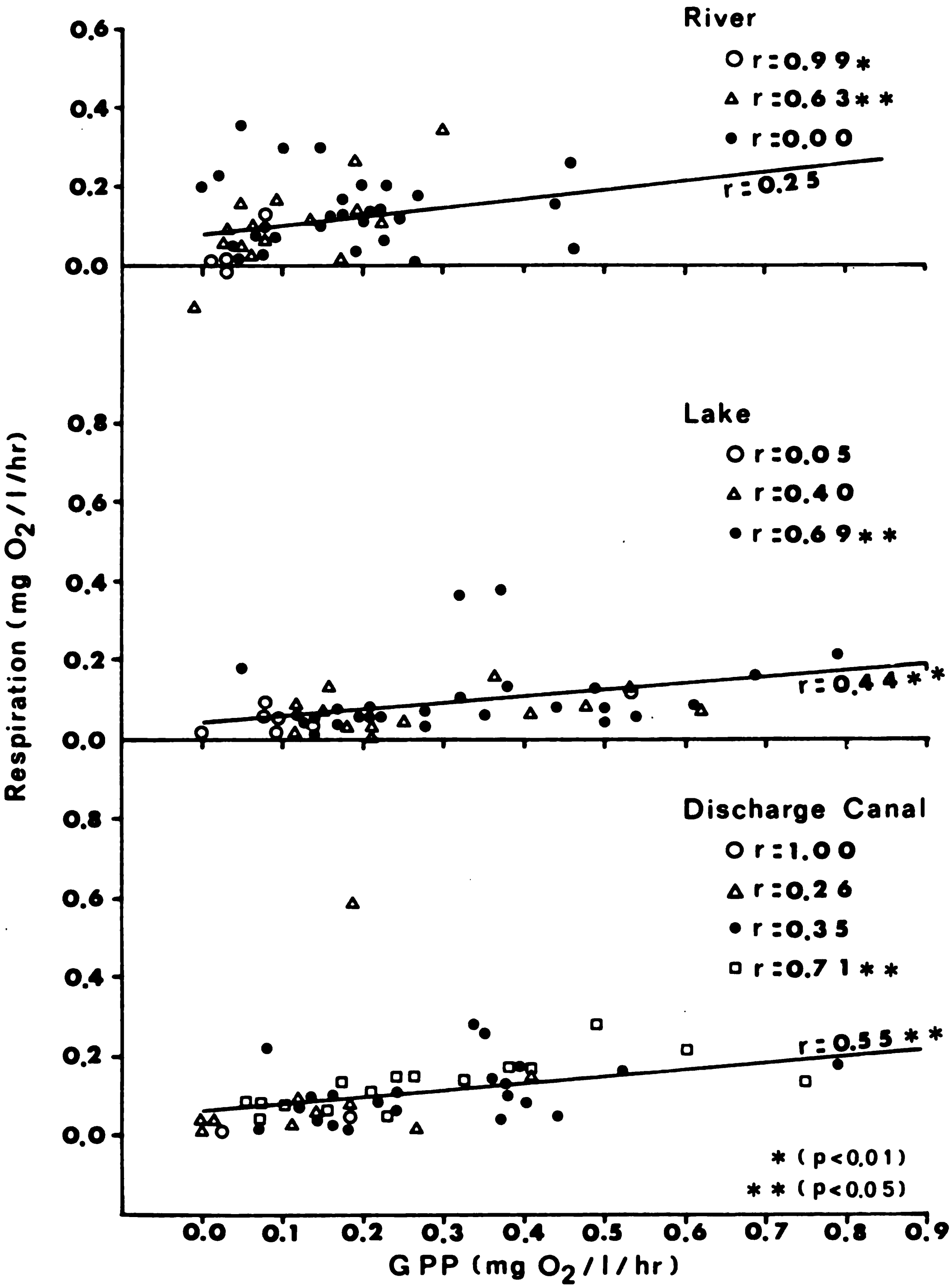


Figure 15. Mean respiration compared to mean gross primary productivity at temperature intervals 8-13 C (o), 14-20 C (Δ), 21-27 C (•), and 28-35 C (□) at the river, lake, and discharge canal stations, 1970 through 1974.

Table 10. Seasonal and annual GPP/R ratios by station for the Detroit Edison sites.

	9 (River)	3 (Lake)	8 (Discharge Canal)
Spring 1970	0.09	0.43	0.29
Summer 1970	0.36	0.74	0.62
Fall 1970	0.22	2.56	0.11
1970 Mean	0.19	0.71	0.27
Spring 1971	0.09	0.97	0.62
Summer 1971	0.14	0.72	0.53
Fall 1971	0.34	1.27	0.50
Winter 1971	--	0.25	--
1971 Mean	0.16	0.82	0.51
Spring 1972	0.09	1.89	0.49
Summer 1972	0.19	1.51	0.67
Fall 1972	0.17	1.06	0.40
1972 Mean	0.15	1.43	0.53
Spring 1973	0.52	0.57	0.41
Summer 1973	0.36	1.56	0.32
Fall 1973	0.30	2.02	0.33
1973 Mean	0.39	1.10	0.35
Spring 1974	0.94	0.62	0.25
Summer 1974	0.45	1.16	0.29
Fall 1974	0.14	0.76	0.28
1974 Mean	0.29	0.90	0.28

occurring in eight of the sixteen seasons sampled, were found only in the lake. Discharge canal values were intermediate but more closely resembled those of the river. Maximum ratios occurred in the spring and summer.

Annual GPP/R, calculated from mean annual GPP and respiration values, indicate heterotrophic (GPP/R<1) conditions existed for all stations except the lake in 1972 and 1973. Due to very limited winter data, annual ratios may have overestimated actual conditions. River values remained almost constant from 1970 through 1972, more than doubled in 1973 following increased sewage treatment, and slightly decreased in 1974. Lake and discharge canal ratios followed similar trends, although peaking in 1972 and decreasing the last two years. As successive generating units came on line and approached normal operating conditions in 1973 and 1974, discharge canal ratios fell below those of the river due to higher temperatures elevating respiration while algal productivity decreased.

GPP/R ratios were calculated for the discharge canal and thermal plume stations using hourly GPP and respiration data from the upper photic zone. While greatly overestimating daily ratios, comparative analysis can be made as the water moved through the discharge system. Ratios in the upper discharge were usually less than expected from the mixing of the water masses, again the result of temperature elevated respiration and depressed algal production (Table 11). Ratios slightly increased with movement through the discharge canal and, near ambient temperatures, recovered to approach those of the original lake water as the respiration rates fell and productivity recovered.

Table 11. GPP/R ratios for the USEPA study sites for cool (November-April) and warm (May-October) months of 1973-75.

Period Year-season	Lake 3	River 9	Upper Canal 12	Middle Canal 8	Lower Canal 14	Thermal 15	Plume 16
Morning							
1973-cool		1.20	3.00	0.00	0.60	2.50	-1.00
-warm	9.50	5.57	6.80	4.50	5.25	6.89	7.90
1974-cool	1.00	2.00	0.80	0.33	1.00	2.50	0.00
-warm	5.20	4.40	4.12	6.00	5.56	6.78	8.11
1975-cool		-0.33	0.80	0.58	0.33	-2.50	
-warm	5.40	9.33	4.14	4.15	7.40	21.33	8.00
Grand mean-cool	5.00	0.60	1.00	0.50	0.60	1.00	
Grand mean-warm	6.78	6.50	4.67	4.60	6.11	8.86	8.00
Grand mean-3 year	6.66	4.20	3.43	3.00	4.83	6.40	8.80
Afternoon							
1973-cool	-0.40	0.20	0.14	0.27	0.42	-3.50	0.00
-warm	2.89	0.81	1.75	2.40	2.00	2.82	3.75
1974-cool	2.00	1.00	0.80	-0.67	0.00	0.00	
-warm	14.33	8.25	3.15	2.86	3.31	19.33	3.58
1975-cool	--	--	--	--	--	--	--
-warm	7.78	-17.00	3.30	3.15	9.09	7.92	5.18
Grand mean-cool	0.00	0.00	0.50	0.00	0.29	-2.00	0.00
Grand mean-warm	6.57	4.50	2.67	2.82	3.00	6.78	4.50
Grand mean-3 year	3.83	4.00	1.85	1.78	2.00	5.50	4.50

CONCLUSIONS

Primary production in the lake was highly variable over the study period. High levels of suspended solids, contributed by the Raisin River and resuspended by turbulence in the shallow depths, usually limited productivity to a depth less than 2.5 m in the nearshore areas. Maximum production usually occurred in the summer months, with spring and fall values equally lower. Temperature was significantly related to productivity only in the spring and fall. Concentrations of total soluble phosphorus and total nongaseous nitrogen showed no individual relationship to productivity. Peak daily production occurred in the late morning hours, before maximum levels of solar radiation were encountered. Highest annual rates of production occurred in 1971 and 1972, returning to preoperational levels in 1973 and 1974, probably resulting from sewage clean up of Raisin River water.

The Raisin River usually exhibited the lowest productivity rates of all stations measured. Annual variability was also lowest and showed no trends over the study period. Highest levels of suspended solids usually limited production to a depth less than 1.5 m. Maximum seasonal rates occurred in the summer, corresponding to trends exhibited by the lake. The river water was subjected to high levels of industrial and municipal sewage, along with nutrient rich runoff. Productivity rates were not noticeably effected by the completion of improvements to an upstream sewage treatment plant in 1972. As power generation increased, larger amounts of river water were diverted through the discharge canal, thereby moving the river's flow southward into the lake, except during times of high discharge.

Respiration was clearly related to gross primary production, with maximum daily rates occurring at nearly the same time as maximum productivity. Seasonal maximums of respiration and production occurred during the summer. Rates of respiration decreased about 40% at depths below the compensation point. Nighttime respiration showed a similar decrease from daytime values, implying that the rate of respiration remained almost constant for that portion of the aquatic community not engaged in photosynthesis. Respiration rates in the lake remained fairly constant over the study period. However, with the completion of the sewage treatment plant, and the corresponding decrease in organic carbon, the river respiration rates fell. Respiration was related to gross primary productivity at temperatures greater than 20 C in the lake but not in the river. At cooler temperatures (less than 20 C), there is a relationship to temperature in the river, possibly resulting from decreased decomposition of allochthonous material, which may have confounded the relationship in warm temperatures.

The entrainment of the water mass through the power plant usually resulted in a depression of the productivity in the upper discharge canal waters. The resulting productivity rates of the water closely resembled those of the river water. This inhibition of productivity could have resulted from mechanical damage due to condenser passage, thermal shocking resulting from increased temperature, or the presence of inhibitors, possibly in the river water. As the water mass moved through the discharge canal, the depressed productivity recovered partially. Movement of the thermal plume into the lake resulted in the stimulation of productivity, exceeding the lake values slightly.

Respiration rates in the upper discharge canal almost doubled after passing through the power plant, as predicted by temperature elevations. The respiration rates decreased as water moved through the canal, until a recovery to pre-exposure rates was observed near the end of the thermal plume, as ambient temperatures were approached. The increase in respiration, along with a corresponding decrease in productivity, indicated the existance of a decomposing environment in the discharge canal waters. This precludes the possibility of photosynthetic carbon biomass export into the receiving waters under existing conditions, a major concern of power plant designers utilizing once-through cooling.

Measurements of photosynthesis in western Lake Erie, first performed by Verduin (1962) and Saunders (1964), were limited to single stations and covered only certain seasons. Recent studies by Cody (1972) in the vicinity of the Bass Islands and the Canadian Centre for Inland Waters (Glooschenko, 1974) lake wide have shown a general increase in the rate of productivity occurring in the western basin (Table 12).

Preoperational productivity in the near shore vicinity of the power plant was approximately double that found in the open lake by Glooschenko. Nutrient enrichment from the Raisin River could have been responsible for this increased productivity, as the completion of new sewage treatment facilities was followed by declining productivity of the near shore area. Total soluble phosphorus concentrations were similar, 0.1-0.2 mg/l (Gachter et al., 1974 and Annett, 1977), for the near shore and open lake. However, inorganic nitrogen concentrations

Table 12. Comparison of productivity measurements in Western Lake Erie, 1962-1974.

Method	g C/m^2/day	g C/m^2/year	Data source
pH-CO_2-O_2	0.51	---	Verduin (1962)
^{14}C	0.008-0.031	---	Saunders (1964)
^{14}C	0.83	304	Cody (1972)
O_2	0.54	197	Cody (1972)
^{14}C	1.13	310 (274 days)	Glooschenko (1974)
O_2	2.20	594 (274 days)	Warner

for the study area, 0.7-2.3 mg/l (Ecker, 1976) were significantly higher than in the open lake, 0.2-0.4 mg/l (Gachter et al., 1974).

Much has been said about the advance of eutrophication in Lake Erie in recent years. Gross primary productivity/respiration ratios of 1.0 (Verduin, 1962) and 1.8 (Cody, 1972) indicate that the rate of production is increasing faster than respiration, a sign of increased lake enrichment. GPP/R ratios for the study area were almost 1.0 in the lake stations, reflecting a possible return to less eutrophic conditions or increased respiration from allochthonous inputs.

As demand for cooling water increases in Lake Erie, the possibility exists for a negative impact from the thermal effluent upon the apparent recovery of the western basin. The Detroit Edison Power Plant, located near the mouth of the Raisin River, had little if any measurable impact upon the productivity of the receiving waters. The depressed productivity and increased respiration of the light limited system have resulted in water of slighlty higher quality being released back into the lake. However, continued monitoring of the productivity should be maintained at all power plants using once-through cooling to measure changing conditions that may lead to the thermal stimulation of algal production. Any changes resulting in the export of organic biomass into the aquatic system may adversely effect the present recovery of Lake Erie as a viable natural resource.

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APPENDICES

Table A1. Sampling dates for the Detroit Edison study sites, 1970 through 1974.

Year	Seasons		
	Spring	Summer	Fall
1970	5-1	6-23	9-29
	5-15	7-7	10-27
	5-27	7-21	
	6-10	8-4	
		8-24	
		9-1	
1971	4-15	6-30	10-2
	5-21	7-16	10-16
	6-3	7-29	10-30
	6-18	9-15	11-13
1972	5-12	6-28	9-13
	6-1	7-12	10-13
	6-14	7-25	
		8-30	
1973	4-27	6-21	9-10
	5-11	7-7	10-9
	5-23	7-17	11-13
		8-1	
		8-16	
		8-29	
1974	3-15	7-16	9-27
	4-17	7-31	10-7
	5-22	8-27	10-24

Table A2. Sampling dates for the USEPA Study sites, 1972 through 1975.

Date	Morning	Afternoon	Evening
November 1972	11-9	11-10	11-9
January 1973	1-26	1-25	1-18
March/April 1973	4-6	4-5	3-30
June 1973	6-13	6-12	6-11
August 1973	8-10	8-9	8-8
September/October 1973	10-1	9-29	9-28
December 1973	12-14	12-13	12-12
January/February 1974	2-2	2-1	1-31
April 1974	4-12	4-11	4-10
June 1974	6-13	6-12	6-11
August 1974	8-16	8-15	8-14
October 1974	10-21	10-20	10-19
January 1975	1-25	1-25	1-24
March 1975	3-17	3-16	3-15
May 1975	5-18	5-17	5-16
July 1975	7-29	7-28	7-27
September 1975	9-17	9-16	9-15

Table A3. Mean Gross Primary productivity and respiration in mg O_2/l/hr by station and date for the Detroit Edison study sites.

Date	Station	Surface (0.0m)		0.5m		1.5m		2.5m	
		GPP	R	GPP	R	GPP	R	GPP	R
5-1-1970	9	0.33	0.13	0.05	0.05	0.04	0.34	-0.10	0.04
	3	--	--	--	--	--	--	--	--
	8	--	--	--	--	--	--	--	--
5-15-1970	9	0.16	0.18	0.13	0.16	0.06	0.15	0.02	0.16
	3	0.30	0.12	0.16	0.13	0.04	0.06	-0.01	0.02
	8	0.39	0.12	0.15	0.12	0.00	0.03	0.02	-0.07
5-27-70	9	0.15	0.45	0.04	0.37	0.01	0.41	0.00	0.24
	3	0.25	0.04	0.01	0.12	0.14	0.10	0.06	0.08
	8	1.08	0.31	0.23	0.36	0.03	0.23	0.02	0.21
6-10-1970	9	0.89	0.28	0.32	0.20	0.01	0.16	-0.08	0.09
	3	0.39	0.10	0.23	0.12	0.02	0.05	0.03	0.06
	8	1.02	0.43	0.26	0.29	0.06	0.18	0.05	0.12
6-23-1970	9	0.23	0.13	0.06	0.06	0.03	0.05	0.05	0.07
	3	0.32	0.07	0.20	0.06	0.04	0.05	0.08	0.15
	8	0.87	0.04	0.52	0.03	0.10	0.07	-0.01	-0.29
7-7-1970	9	0.49	0.07	0.38	0.12	0.08	0.16	0.03	0.08
	3	0.25	0.13	0.17	0.01	0.09	0.03	0.05	-0.01
	8	0.92	0.08	0.68	0.05	0.18	0.07	-0.04	0.01
7-21-1970	9	0.43	0.18	0.08	0.09	0.05	0.14	0.10	0.19
	3	0.20	0.12	0.22	0.03	0.08	0.03	0.03	0.03
	8	0.93	0.23	0.40	0.21	0.07	0.04	0.02	0.07
8-4-1970	9	0.15	0.00	0.11	0.14	0.05	0.19	-0.01	0.01
	3	0.27	0.10	0.37	0.05	0.16	0.07	0.09	0.07
	8	0.96	0.14	0.49	0.25	0.05	0.09	0.07	0.18
8-24-1970	9	0.55	0.09	0.17	0.11	0.12	0.11	0.07	0.08
	3	2.75	0.53	0.28	0.07	0.15	0.13	0.02	0.14
	8	0.96	0.05	0.48	0.07	0.05	0.14	0.04	0.12

Table A3 (Con't.)

Date	Station	Surface (0.0m)		0.5m		1.5m		2.5m	
		GPP	R	GPP	R	GPP	R	GPP	R
9-1-1970	9	0.38	0.05	0.12	0.18	0.06	0.10	0.02	0.11
	3	0.40	0.00	0.29	0.04	0.11	0.07	-0.02	0.12
	8	1.10	0.15	0.44	0.16	0.02	0.18	--	--
9-29-1970	9	0.28	0.15	0.06	0.03	-0.06	0.03	0.03	0.02
	3	0.26	0.00	0.18	0.09	-0.01	-0.04	0.05	-0.01
	8	0.70	-0.02	0.19	0.01	0.06	0.02	0.08	0.00
10-27-1970	9	0.09	0.10	0.03	0.08	0.07	0.14	0.04	0.09
	3	--	--	--	--	--	--	--	--
	8	0.50	0.52	0.18	0.70	0.00	0.46	0.07	0.67
4-15-1971	9	0.21	-0.18	0.08	-0.09	-0.05	-0.05	0.00	0.10
	3	0.43	0.20	0.98	0.05	0.00	-0.72	-0.20	-0.47
	8	0.28	0.22	-0.08	-0.04	0.13	0.03	0.37	-0.05
5-21-1971	9	0.45	0.23	0.29	0.22	0.00	0.21	0.01	0.38
	3	0.73	0.10	0.70	0.10	0.39	0.10	0.08	0.05
	8	0.91	0.17	0.56	0.02	0.13	0.12	0.01	-0.01
6-3-1971	9	0.21	0.11	0.04	0.08	-0.03	0.00	-0.01	0.02
	3	0.64	0.47	0.39	0.16	0.19	0.14	0.07	0.29
	8	0.55	0.08	0.24	0.15	0.12	0.10	-0.02	0.04
6-18-1971	9	0.19	0.35	0.15	0.32	0.08	0.27	-0.04	0.24
	3	0.86	0.12	1.05	0.08	0.43	0.12	0.10	0.05
	8	0.49	0.02	0.64	0.16	0.11	0.23	0.05	0.14
6-30-1971	9	0.71	0.03	0.03	0.04	0.00	0.02	0.00	0.02
	3	0.56	0.05	0.54	0.06	0.03	0.12	0.00	0.05
	8	0.98	0.17	0.41	0.12	0.07	0.16	0.07	0.21
7-16-1971	9	0.90	0.41	--	--	--	--	0.01	0.11
	3	0.54	0.21	0.72	0.40	0.25	0.40	0.04	0.13
	8	1.59	0.17	1.13	0.17	0.23	0.17	0.06	0.05
7-29-1971	9	0.53	0.36	0.14	0.13	0.00	0.05	0.00	0.02
	3	0.32	0.23	0.41	0.07	0.41	0.04	0.14	0.11
	8	0.49	0.02	0.59	0.27	0.53	0.32	0.04	0.02

Table A3 (Con't.)

Date	Station	Surface (0.0m)		0.5m		1.5m		2.5m	
		GPP	R	GPP	R	GPP	R	GPP	R
9-15-1971	9	0.26	0.36	0.15	0.29	0.04	0.24	--	--
	3	0.52	0.12	0.76	0.16	0.18	0.07	--	--
	8	0.71	0.28	0.60	0.30	0.17	0.25	--	--
10-2-1971	9	0.74	0.04	0.58	0.03	0.07	0.10	--	--
	3	0.54	0.08	0.66	0.05	0.31	0.03	--	--
	8	1.64	0.19	0.64	0.21	0.08	0.14	--	--
10-16-1971	9	0.43	0.19	0.06	0.15	0.05	0.12	--	--
	3	0.13	0.06	0.20	0.02	0.08	0.10	--	--
	8	0.90	0.16	0.27	0.16	0.07	0.09	--	--
10-30-1971	9	0.45	0.17	0.14	0.05	0.08	0.12	--	--
	3	0.35	0.05	0.42	0.02	0.16	0.07	0.07	-0.03
	8	0.86	0.16	0.22	0.14	0.05	0.09		
11-13-1971	9	--	--	--	--	--	--	--	--
	3	0.11	0.08	0.11	0.00	0.11	0.03	0.03	0.05
	8	--	--	--	--	--	--	--	--
2-29-1972	9	--	--	--	--	--	--	--	--
	3	0.10	0.10	0.09	0.14	0.07	0.03	0.05	0.10
	8	0.00	0.04	-0.04	-0.05	0.00	0.03	-0.02	0.04
5-12-1972	9	--	--	--	--	--	--	--	--
	3	--	--	--	--	--	--	--	--
	8	0.09	0.08	0.26	0.14	0.09	0.06	0.02	0.06
6-1-1972	9	0.33	0.06	0.20	0.09	0.04	0.15	-0.01	0.11
	3	0.34	0.04	0.30	0.06	0.07	0.06	0.01	0.00
	8	0.48	0.05	0.23	0.03	0.02	0.04	-0.01	-0.10
6-14-1972	9	0.00	0.20	0.00	0.43	0.00	0.00	0.00	0.20
	3	1.02	0.09	1.20	0.10	0.16	0.04	0.11	0.07
	8	0.61	0.16	0.35	0.16	0.00	0.10	0.00	0.03
6-28-1972	9	0.40	0.08	0.37	0.53	0.01	0.10	0.00	0.10
	3	0.20	0.06	0.14	0.03	0.23	0.09	0.16	0.00
	8	0.17	-0.06	0.18	0.05	0.06	0.05	0.04	0.08

Table A3 (Con't.)

Date	Station	Surface (0.0m)		0.5m		1.5m		2.5m	
		GPP	R	GPP	R	GPP	R	GPP	R
7-12-1972	9	0.00	0.21	0.00	0.33	0.00	0.18	0.08	0.20
	3	0.11	-0.11	0.29	-0.08	0.14	0.04	0.13	-0.07
	8	0.30	-0.05	0.36	0.11	0.04	0.02	-0.03	0.01
7-25-1972	9	0.95	0.00	0.08	0.00	0.00	0.00	0.00	0.00
	3	0.31	0.04	0.52	-0.01	0.34	0.03	0.22	0.17
	8	0.44	0.07	0.05	0.17	-0.04	-0.07	--	--
8-30-1972	9	0.90	0.18	0.70	0.18	0.11	0.13	0.04	0.13
	3	0.71	0.26	1.26	0.26	0.62	0.11	0.16	0.00
	8	1.12	0.16	1.02	0.26	0.10	0.26	0.15	0.17
9-13-1972	9	0.48	0.25	0.06	0.09	0.12	0.14	-0.02	0.00
	3	0.80	0.04	0.37	0.11	0.07	0.02	--	--
	8	0.58	0.01	0.00	0.07	0.11	0.10	--	--
10-13-1972	9	0.11	0.03	-0.10	0.15	0.04	0.03	0.05	0.03
	3	0.55	0.08	0.60	0.31	0.85	0.05	0.15	0.08
	8	0.39	0.08	0.09	0.06	--	--	--	--
4-27-1973	9	0.08	0.09	0.11	--	0.02	0.01	0.04	-0.05
	3	0.55	0.22	0.08	0.07	0.13	0.09	0.09	0.08
	8	0.40	0.18	0.07	0.09	0.00	0.06	0.00	0.06
5-11-1973	9	0.21	0.00	0.16	-0.02	0.34	0.05	-0.02	0.00
	3	0.09	0.02	0.20	0.08	0.32	0.08	-0.02	0.08
	8	0.37	0.13	0.05	-0.04	0.11	0.04	-0.03	0.02
5-23-1973	9	0.13	0.11	0.00	0.07	-0.02	0.06	0.02	0.07
	3	0.30	0.13	0.29	0.22	0.03	0.10	0.02	0.10
	8	0.35	0.05	0.09	0.15	0.18	0.09	0.00	0.09
6-21-1973	9	0.05	-0.05	0.07	0.04	-0.08	-0.03	0.07	0.07
	3	0.79	0.07	0.82	0.10	0.34	0.06	0.05	0.09
	8	0.13	0.03	0.16	0.03	-0.03	0.03	0.00	0.01
7-7-1973	9	0.11	0.00	0.00	0.01	0.02	0.01	-0.02	0.03
	3	0.29	0.01	0.25	0.03	-0.01	0.01	-0.02	0.00
	8	0.26	0.08	0.01	0.06	0.02	0.08	0.00	0.09

Table A3 (Con't.)

Date	Station	Surface (0.0m)		0.5m		1.5m		2.5m	
		GPP	R	GPP	R	GPP	R	GPP	R
7-17-1973	9	0.46	0.15	0.33	0.13	0.09	0.15	-0.10	0.01
	3	0.46	0.14	0.42	0.10	0.25	0.11	0.40	0.24
	8	0.31	0.13	0.26	0.11	0.10	0.13	0.02	0.15
8-1-1973	9	0.06	0.05	0.07	0.08	0.02	0.07	0.00	0.05
	3	0.42	0.05	0.37	0.05	0.08	0.06	-0.02	0.06
	8	0.51	0.11	0.11	0.08	0.01	0.08	-0.01	0.08
8-16-1973	9	0.21	0.07	0.04	0.00	0.03	0.03	-0.01	-0.01
	3	0.84	0.08	0.87	0.00	0.29	0.09	0.15	0.07
	8	0.72	0.19	0.26	0.15	0.05	0.16	0.01	0.08
8-29-1973	9	0.57	0.05	0.30	0.06	0.03	0.27	0.01	-0.08
	3	0.45	0.09	0.63	0.09	0.51	0.06	0.17	0.12
	8	0.40	0.09	0.33	0.12	0.07	0.12	0.05	0.07
9-10-1973	9	0.14	0.08	0.06	0.03	0.05	0.05	-0.01	0.08
	3	0.30	--	0.15	-0.02	0.07	0.10	-0.01	-0.02
	8	--	--	--	--	--	--	--	--
10-9-1973	9	0.13	0.03	0.09	0.08	0.00	0.14	-0.01	-0.01
	3	0.55	0.08	0.26	0.04	0.04	0.02	0.00	0.00
	8	0.35	0.07	0.24	0.04	-0.03	0.03	-0.01	0.03
11-13-1973	9	0.05	-0.01	-0.01	0.00	0.01	0.04	0.01	0.00
	3	--	--	0.23	0.03	0.05	0.01	-0.01	0.00
	8	0.03	0.06	0.00	0.02	-0.01	0.03	0.03	0.01
3-15-1974	9	0.00	0.02	0.06	0.05	-0.02	-0.02	0.00	-0.03
	3	0.13	0.10	0.11	0.02	0.03	0.06	0.03	0.19
	8	-0.03	0.04	0.09	0.04	-0.03	0.02	-0.06	0.03
4-17-1974	9	0.02	-0.01	0.02	-0.01	0.01	-0.01	0.01	-0.02
	3	-0.01	0.02	-0.02	0.01	0.00	0.01	0.02	0.05
	8	0.01	0.02	-0.01	0.04	-0.02	0.02	-0.01	0.01
5-22-1974	9	0.29	-0.07	-0.05	-0.20	-0.05	-0.21	-0.01	-0.16
	3	0.51	0.04	0.25	0.02	0.06	0.05	0.02	0.00
	8	0.29	0.12	0.02	-0.01	0.02	0.04	-0.05	0.02

Table A3 (Con't.)

Date	Station	Surface (0.0m)		0.5m		1.5m		2.5m	
		GPP	R	GPP	R	GPP	R	GPP	R
7-16-1974	9	0.52	0.09	0.24	0.21	0.05	0.12	0.03	0.10
	3	0.29	0.10	0.29	0.10	0.19	0.07	0.05	0.04
	8	0.20	0.14	0.13	0.06	0.02	0.05	0.05	0.08
7-31-1974	9	--	--	--	--	--	--	--	--
	3	0.45	0.06	0.39	0.00	0.19	0.03	0.10	0.06
	8	0.54	0.15	0.40	0.16	0.02	0.14	0.01	0.14
8-27-1974	9	0.50	0.19	0.31	0.09	0.07	0.10	0.01	0.10
	3	0.90	0.20	0.53	0.17	0.07	0.10	0.00	0.11
	8	0.23	0.10	0.09	0.13	0.14	0.02	0.02	0.10
9-27-1974	9	0.65	0.43	0.26	0.37	0.20	0.28	0.08	0.24
	3	0.24	0.20	0.47	0.17	0.24	0.15	0.05	0.10
	8	0.12	0.04	0.10	0.06	0.17	0.11	0.14	0.15
10-7-1974	9	0.07	-0.02	-0.03	-0.09	-0.06	-0.12	-0.05	-0.17
	3	0.13	0.08	0.29	0.05	0.12	0.05	0.04	0.08
	8	0.15	0.25	0.12	0.31	0.03	0.20	0.03	0.11
10-27-1974	9	0.05	0.07	0.09	0.03	0.05	-0.01	0.05	0.03
	3	0.09	0.02	0.14	0.02	0.18	0.01	0.13	0.02
	8	0.28	0.09	0.27	0.10	0.09	0.07	0.06	0.07

Table A4. Mean suspended solids, total nongaseous nitrogen, total soluble phorphorus, and total organic carbon concentrations in mg/l by station for the Detroit Edison study sites.

Date	Station	Suspended Solids	Total Nongaseous Nitrogen	Total Soluble Phosphorus	Total Organic Carbon
5-1-1970	3	54.7	3.73	0.19	11.0
	8	63.3	3.71	0.15	12.7
	9	38.3	3.74	0.26	18.7
5-15-1970	3	50.3	1.63	0.15	15.3
	8	84.7	2.37	0.15	13.7
	9	49.7	2.44	0.18	29.7
5-27-1970	3	33.7	0.89	0.06	16.0
	8	75.7	3.47	0.08	19.3
	9	51.0	5.95	0.16	22.8
6-10-1970	3	27.7	2.25	0.07	11.5
	8	42.0	2.34	0.09	10.3
	9	29.0	2.08	0.22	14.0
6-23-1970	3	21.0	1.93	0.05	6.2
	8	35.7	3.28	0.07	9.7
	9	51.8	6.08	0.11	13.0
7-7-1970	3	25.7	0.88	0.07	5.5
	8	62.8	1.77	0.12	15.5
	9	66.7	1.89	0.24	5.8
7-21-1970	3	25.0	0.71	0.09	5.3
	8	45.3	1.46	0.15	16.0
	9	38.0	2.24	0.22	13.0
8-4-1970	3	33.7	0.75	0.08	6.2
	8	52.0	1.83	0.12	17.3
	9	68.3	1.91	0.24	17.2
8-24-1970	3	26.7	0.58	0.15	6.2
	8	34.7	1.45	0.13	20.2
	9	49.0	1.52	0.29	17.5
9-1-1970	3	25.0	0.71	0.10	9.8
	8	32.3	1.39	0.17	19.7
	9	44.0	1.27	0.35	16.7
9-29-1970	3	20.0	0.55	0.07	8.2
	8	24.7	1.51	0.06	10.7
	9	37.0	1.33	0.26	16.5
10-27-1970	3	16.3	0.99	0.08	6.5
	8	18.7	1.61	0.12	10.3
	9	37.0	1.69	0.20	16.0
5-21-1971	3	45.7	1.46	0.10	8.0
	8	61.2	2.30	0.16	17.2
	9	77.7	2.50	0.24	18.2
6-3-1971	3	31.7	0.74	--	6.7
	8	71.5	3.90	--	18.3
	9	73.5	4.74	--	20.2

Table A4 (Con't)

Date	Station	Suspended Solids	Total Nitrogen	Total Phosphorus	Total Organic Carbon
6-18-1971	3	27.8	1.97	0.12	4.8
	8	50.7	2.65	0.23	10.3
	9	51.3	2.54	0.31	10.5
6-30-1971	3	22.7	1.33	--	8.2
	8	43.5	1.48	--	12.8
	9	40.7	2.13	--	15.5
7-16-1971	3	35.2	1.25	0.14	8.2
	8	28.0	1.20	0.25	10.3
	9	29.7	1.34	0.31	9.8
7-29-1971	3	12.3	0.77	0.09	--
	8	28.7	0.88	0.24	10.8
	9	27.7	1.19	0.36	12.5
9-15-1971	3	14.3	0.66	0.10	12.5
	8	32.5	1.06	0.27	18.7
	9	20.3	1.25	0.36	16.8
10-2-1971	3	8.0	0.98	0.09	13.8
	8	20.5	1.20	0.28	22.5
	9	20.8	1.45	0.41	19.0
10-16-1971	3	13.8	0.70	0.08	14.3
	8	30.2	1.25	0.18	17.5
	9	54.3	1.73	0.28	22.0
10-30-1971	3	26.3	1.00	0.06	11.5
	8	58.3	1.43	0.11	15.5
	9	62.7	1.96	0.20	26.2
11-13-1971	3	16.0	0.81	0.08	8.7
	8	55.2	1.74	0.26	14.2
	9	--	--	--	--
2-29-1972	3	9.7	1.40	0.06	2.2
	8	24.0	2.89	0.23	7.8
	9	--	--	--	--
5-12-1972	3	14.3	0.60	0.06	3.5
	8	42.2	9.01	0.18	12.3
	9	31.7	8.40	0.19	15.3
6-1-1972	3	27.2	2.04	0.11	4.8
	8	40.5	2.28	0.16	9.5
	9	19.5	3.03	0.24	10.0
6-14-1972	3	12.5	3.00	0.08	6.5
	8	25.3	2.63	0.13	7.7
	9	22.0	4.70	0.22	11.2
6-28-1972	3	5.7	0.64	0.05	4.0
	8	11.2	2.76	0.10	4.7
	9	19.8	7.00	0.21	11.2
7-12-1972	3	11.7	1.10	0.07	4.3
	8	28.3	1.34	0.14	8.5
	9	22.2	1.89	0.28	12.3

Table A4 (Con't.)

Date	Station	Suspended Solids	Total Nitrogen	Total Phosphorus	Total Organic Carbon
7-25-1972	3	4.8	0.69	0.08	2.8
	8	15.5	1.04	0.18	4.3
	9	13.8	1.27	0.21	5.7
8-30-1972	3	13.0	1.08	0.06	4.8
	8	22.3	2.34	0.13	7.7
	9	38.8	7.00	0.28	13.7
9-13-1972	3	16.7	1.12	0.07	5.2
	8	26.8	2.21	0.14	5.0
	9	87.5	3.83	0.41	10.5
10-13-1972	3	17.8	2.08	0.09	5.5
	8	27.2	4.86	0.14	9.2
	9	23.8	5.67	0.19	9.3
4-27-1973	3	12.3	1.62	0.06	6.2
	8	27.0	3.30	0.14	10.8
	9	36.0	4.20	0.21	14.5
5-11-1973	3	19.5	1.55	0.07	5.5
	8	23.8	2.15	0.12	7.7
	9	12.2	2.54	0.16	7.0
6-21-1973	3	32.8	2.17	0.13	8.0
	8	48.3	3.36	0.17	8.5
	9	52.8	4.87	0.23	11.3
7-7-1973	3	39.7	3.33	0.13	5.3
	8	114.7	7.35	0.27	10.0
	9	101.7	7.38	0.29	10.0
7-17-1973	3	15.7	0.97	0.07	8.2
	8	34.0	2.01	0.15	6.8
	9	27.2	2.70	0.21	9.5
8-1-1973	3	13.5	1.39	0.08	6.8
	8	24.0	2.26	0.17	7.3
	9	24.7	4.09	0.25	10.0
8-16-1973	3	19.0	1.31	0.08	5.3
	8	35.5	1.73	0.15	7.2
	9	23.8	3.09	0.28	10.2
8-29-1973	3	12.3	0.88	0.06	4.5
	8	21.2	1.25	0.11	3.3
	9	28.5	1.89	0.24	8.0
9-10-1973	3	16.0	0.86	0.08	6.0
	8	23.0	1.51	0.11	5.0
	9	27.0	3.31	0.27	10.8
10-9-1973	3	11.7	0.86	0.05	4.2
	8	37.2	1.35	0.10	5.3
	9	21.0	2.79	0.20	6.5
11-13-1973	3	25.7	0.88	0.08	4.3
	8	26.5	1.69	0.16	6.7
	9	15.7	2.12	0.16	5.2

Table A4 (Con't.)

Date	Station	Suspended Solids	Total Nitrogen	Total Phosphorus	Total Organic Carbon
3-15-1974	3	21.8	--	0.11	5.3
	8	76.5	--	0.22	12.3
	9	66.2	--	0.18	11.2
4-17-1974	3	76.2	2.09	0.15	5.0
	8	91.2	4.15	0.21	8.0
	9	60.8	4.04	0.22	9.8
5-22-1974	3	15.7	1.07	0.08	6.3
	8	52.8	4.36	0.16	9.8
	9	43.5	5.25	0.16	10.2
7-16-1974	3	15.3	0.62	0.09	4.5
	8	31.0	0.74	0.09	5.0
	9	28.7	1.85	0.09	8.3
7-31-1974	3	11.3	0.91	0.06	5.5
	8	19.0	1.07	0.08	6.0
	9	22.3	2.48	0.21	13.0
9-27-1974	3	22.0	0.79	0.09	6.2
	8	37.0	1.25	0.13	8.0
	9	113.5	4.93	0.42	12.7
10-7-1974	3	14.5	0.56	0.06	4.3
	8	27.3	0.86	0.09	6.2
	9	67.8	2.17	0.20	6.8
10-24-1974	3	13.0	0.72	0.05	5.3
	8	23.5	1.24	0.10	10.3
	9	18.5	2.12	0.14	8.0

Table A5. Mean temperature (C) by station for the Detroit Edison study sites.

Date	Station	DEPTH 0.0m	0.5m	1.5m	2.5m
5-1-1970	3	--	--	--	--
	8	--	--	--	--
	9	13.8	13.8	13.9	13.9
5-15-1970	3	15.0	15.0	15.0	15.0
	8	18.0	18.0	17.5	17.5
	9	18.0	18.0	18.0	17.5
7-7-1970	3	25.0	24.8	24.0	22.0
	8	26.2	26.2	26.0	26.0
	9	27.5	27.0	26.5	25.5
7-21-1970	3	22.1	21.5	21.5	21.0
	8	22.7	22.7	22.4	22.1
	9	22.5	22.5	22.0	21.0
8-4-1970	3	23.8	23.5	23.5	23.5
	8	24.9	24.5	24.5	24.0
	9	25.0	25.0	24.5	24.0
8-24-1970	3	25.0	25.0	25.0	25.0
	8	25.0	25.0	25.0	25.0
	9	25.0	25.0	25.0	25.0
9-1-1970	3	24.0	24.0	23.5	23.0
	8	23.2	23.0	23.0	22.8
	9	25.3	25.0	24.5	24.5
10-27-1970	3	16.0	16.2	16.2	16.2
	8	15.8	16.2	16.2	16.2
	9	16.5	17.0	17.2	17.2
4-15-1971	3	8.0	7.5	7.5	7.5
	8	11.0	11.0	11.0	11.0
	9	12.5	12.5	12.0	12.0
5-21-1971	3	17.5	17.5	17.5	17.5
	8	22.0	22.0	22.0	21.5
	9	20.5	20.5	20.0	20.0
6-3-1971	3	22.0	21.5	20.0	19.0
	8	22.0	21.5	20.5	19.5
	9	20.0	20.0	19.5	19.0

Table A5 (Con't.)

Date	Station	DEPTH 0.0m	0.5m	1.5m	2.5m
6-18-1971	3	23.5	23.5	23.5	22.5
	8	32.5	32.5	32.5	31.0
	9	25.0	24.5	24.0	24.0
6-30-1971	3	26.5	26.5	26.0	25.0
	8	34.0	34.0	34.0	33.0
	9	27.5	27.5	27.0	26.5
7-16-1971	3	23.0	23.0	23.0	23.0
	8	32.0	32.0	31.5	30.0
	9	25.0	24.5	24.0	24.0
7-29-1971	3	22.0	22.0	22.0	22.0
	8	31.5	31.5	31.5	30.5
	9	25.0	25.0	24.0	23.5
9-15-1971	3	22.0	22.0	22.0	22.0
	8	29.5	29.5	29.5	29.5
	9	23.5	23.0	23.0	23.0
10-2-1971	3	21.5	21.5	20.5	20.0
	8	26.0	26.0	26.0	25.0
	9	23.0	22.5	22.0	21.5
10-16-1971	3	14.5	14.5	14.5	14.5
	8	19.5	19.5	19.0	19.0
	9	15.5	15.0	15.0	15.0
10-30-1971	3	17.0	16.5	16.5	16.5
	8	22.0	22.0	20.0	19.0
	9	18.5	18.0	18.0	17.5
11-13-1971	3	7.0	7.0	7.0	7.0
	8	14.0	14.0	14.0	14.0
	9	7.0	7.0	7.0	6.5
2-29-1972	3	1.0	1.0	1.0	1.0
	8	3.0	2.5	2.0	1.5
	9	--	--	--	--
5-12-1972	3	--	--	--	--
	8	17.0	17.0	17.0	17.0
	9	--	--	--	--
6-1-1972	3	18.5	18.0	18.0	18.0
	8	22.0	22.0	22.0	22.0
	9	20.0	20.0	20.0	19.5

Table A5 (Con't.)

Date	Station	DEPTH 0.0m	0.5m	1.5m	2.5m
6-14-1972	3	21.0	20.5	20.0	19.5
	8	26.5	26.5	26.5	26.5
	9	24.0	23.5	23.0	22.0
6-28-1972	3	18.0	18.0	18.0	18.0
	8	18.5	18.5	18.5	18.5
	9	23.0	22.0	21.0	20.0
7-12-1972	3	22.0	22.0	22.0	21.5
	8	26.5	26.0	26.0	26.0
	9	27.0	27.0	22.0	21.5
7-25-1972	3	23.0	23.0	23.0	23.0
	8	30.0	30.0	30.0	30.0
	9	25.0	25.0	24.5	24.0
8-30-1972	3	23.5	23.0	23.0	23.0
	8	31.0	31.0	31.0	31.0
	9	26.0	26.0	25.5	25.0
9-13-1972	3	20.5	20.5	20.5	20.5
	8	31.0	31.0	28.5	27.0
	9	23.0	23.0	22.0	22.0
10-13-1972	3	13.5	13.5	13.5	13.5
	8	22.0	22.0	21.5	20.0
	9	14.0	14.0	14.0	13.5
4-27-1973	3	13.0	13.0	12.5	12.5
	8	23.0	23.5	23.5	23.5
	9	18.5	18.0	16.0	16.0
5-11-1973	3	16.0	16.0	16.0	16.0
	8	24.0	24.0	24.0	24.0
	9	18.5	18.5	18.5	18.5
5-23-1973	3	15.0	15.0	15.0	15.0
	8	25.0	25.0	25.0	25.0
	9	17.0	17.0	16.5	16.5
6-21-1973	3	23.0	23.0	23.0	22.5
	8	30.0	30.0	30.0	30.0
	9	26.0	25.5	25.0	24.0
7-7-1973	3	25.0	25.0	24.0	23.0
	8	32.5	32.5	32.0	32.0
	9	26.5	26.5	25.5	24.5

Table A5 (Con't.)

Date	Station	DEPTH 0.0m	0.5m	1.5m	2.5m
7-17-1973	3	23.5	23.5	23.5	23.5
	8	31.5	31.5	31.5	31.5
	9	27.5	27.0	27.0	26.0
8-1-1973	3	23.0	23.5	23.5	23.5
	8	32.0	32.0	32.0	32.0
	9	25.0	25.0	24.5	24.0
8-16-1973	3	24.0	24.0	24.0	24.0
	8	30.5	31.0	31.0	31.0
	9	26.0	26.0	26.0	25.5
8-29-1973	3	24.5	24.0	24.0	23.0
	8	33.5	33.5	33.5	33.5
	9	24.5	24.5	24.0	23.5
9-10-1973	3	23.5	23.5	23.5	23.5
	8	--	--	--	--
	9	26.0	25.5	25.0	24.5
10-9-1973	3	19.0	19.0	19.0	19.0
	8	25.0	26.0	26.0	26.0
	9	22.5	22.5	22.0	21.0
11-13-1973	3	7.0	7.0	7.0	6.5
	8	16.5	16.5	17.0	17.0
	9	11.0	11.0	10.0	9.0
3-15-1974	3	4.0	4.0	4.0	4.0
	8	13.8	14.0	14.0	14.0
	9	4.0	4.0	4.0	4.0
4-17-1974	3	8.0	8.0	8.0	8.0
	8	19.0	19.0	19.5	19.5
	9	13.5	13.0	12.5	12.0
5-22-1974	3	16.5	16.5	16.0	15.0
	8	26.0	26.0	26.0	26.0
	9	19.0	19.0	18.5	18.5
7-16-1974	3	24.5	24.5	24.5	24.5
	8	31.0	30.0	30.0	30.0
	9	28.0	27.5	27.0	27.0
7-31-1974	3	25.0	25.0	24.5	24.5
	8	30.5	30.5	30.5	30.5
	9	--	--	--	--

Table A5 (Con't.)

Date	Station	DEPTH 0.0m	0.5m	1.5m	2.5m
8-27-1974	3	27.0	27.0	27.0	27.0
	8	36.0	36.0	36.0	36.0
	9	29.0	29.0	29.0	27.0
9-27-1974	3	17.0	17.0	17.0	17.0
	8	23.0	22.5	22.5	22.5
	9	19.0	18.5	18.5	18.5
10-7-1974	3	14.0	14.0	14.0	14.0
	8	23.0	23.5	23.5	23.0
	9	16.5	16.5	16.0	15.5
10-24-1974	3	11.0	11.0	11.0	11.0
	8	20.0	20.5	20.5	20.5
	9	14.5	15.0	14.5	13.5

Table A6. Mean gross primary productivity and respiration in mg O_2/l/hr and temperature (C) by station and date in the cooling system for the USEPA study sites.

Date	Station	Morning			Afternoon			Evening		
		Temp.	GPP	R	Temp.	GPP	R	Temp.	GPP	R
11/9-10/1972	3	9.0	0.06	0.00	8.0	-0.03	0.15	9.0	0.03	0.00
	9	9.0	0.12	0.09	9.0	0.03	0.03	9.0	0.00	0.00
	12	14.0	0.06	0.00	14.5	0.03	0.03	22.5	0.00	0.06
	8	13.0	0.00	0.00	14.5	0.15	0.00	19.0	0.00	0.06
	14	13.5	0.01	0.00	14.0	0.01	0.24	14.0	0.00	0.03
	15	11.2	0.03	0.00	11.0	0.21	0.21	9.0	--	--
	16	10.5	-0.06	0.00	9.0	--	--	10.0	--	--
1/18-19 & 25/1973	3	3.0	0.00	0.00	3.0	-0.03	0.06	4.0	0.00	0.03
	9	5.0	0.00	0.06	3.0	0.00	0.21	9.0	-0.03	0.00
	12	8.0	0.03	0.12	8.0	0.00	0.18	15.0	0.00	0.03
	8	8.0	0.00	0.06	5.7	-0.03	0.15	13.0	0.00	0.00
	14	8.0	0.06	0.09	6.0	0.03	0.09	13.0	0.03	0.06
	15	4.0	0.00	0.00	5.0	0.00	0.00	8.0	0.03	0.03
	16	3.0	0.00	0.00	3.0	0.00	0.03	4.0	0.00	0.00
3/30 & 4/5/1973	3	10.0	0.03	0.00	8.0	0.00	0.00	10.0	--	--
	9	11.1	0.00	0.00	9.7	0.00	0.00	9.0	--	--
	12	16.0	0.00	0.03	17.0	0.00	0.03	16.0	-0.03	0.00
	8	16.0	--	--	17.0	0.00	0.06	16.0	0.03	0.03
	14	16.0	0.00	0.03	17.0	0.00	0.00	15.7	0.03	0.02
	15	13.0	0.03	0.06	13.0	0.00	0.00	13.0	--	--
	16	11.5	0.09	0.03	11.0	0.03	0.06	10.0	--	--

Table A6 (Con't.)

Date	Station	Morning			Afternoon			Evening		
		Temp.	GPP	R	Temp.	GPP	R	Temp.	GPP	R
6/11-13/1973	3	22.0	0.36	0.09	23.5	0.06	0.06	23.5	0.06	0.00
	9	24.5	0.45	0.06	26.0	0.15	0.15	25.0	0.03	0.06
	12	25.0	0.09	0.03	26.0	0.06	0.06	27.0	0.03	0.03
	8	26.0	0.24	0.03	26.0	0.03	0.03	27.0	0.03	0.03
	14	25.5	0.21	0.00	26.0	0.09	0.03	26.5	0.03	0.09
	15	22.5	0.48	0.06	22.0	0.21	0.06	24.0	-0.06	0.18
	16	21.5	0.72	0.09	21.5	0.18	0.03	21.0	0.03	0.00
8/8-10/1973	3	26.0	1.62	0.75	26.5	0.33	0.12	25.0	0.03	-0.03
	9	27.0	0.51	1.41	27.5	0.09	0.09	27.0	0.03	0.09
	12	29.0	0.66	0.84	30.0	0.48	0.18	31.0	0.21	0.18
	8	29.0	0.60	1.50	31.0	0.24	0.09	31.0	0.12	0.12
	14	29.0	0.72	1.50	31.5	0.27	0.12	31.0	0.06	0.06
	15	28.0	0.78	1.86	30.0	0.48	0.15	27.0	0.03	-0.03
	16	26.0	1.35	1.86	27.5	0.45	0.15	26.0	0.03	-0.01
9/29-10/1/1973	3	18.0	0.12	0.06	18.5	0.36	0.06	18.5	0.06	0.15
	9	19.7	0.12	0.98	22.0	0.03	0.12	22.0	0.09	0.12
	12	21.0	0.18	0.03	26.7	0.03	0.09	25.3	0.12	0.03
	8	21.5	0.21	0.06	26.0	0.06	0.03	25.7	0.03	0.03
	14	21.0	0.21	0.06	25.7	0.12	0.03	25.3	0.03	0.03
	15	19.3	0.18	0.03	22.0	0.18	0.09	21.5	0.06	-0.03
	16	18.5	0.18	0.00	20.0	0.24	0.06	20.5	-0.03	0.00
12/12-14/1973	3	2.0	0.12	0.03	3.5	0.00	0.03	2.0	-0.03	0.06
	9	3.3	0.15	0.06	4.5	-0.03	-0.03	9.5	-0.06	-0.09
	12	16.0	0.09	0.12	16.7	0.33	0.12	18.0	-0.03	0.06
	8	15.3	0.03	0.03	16.3	-0.03	0.03	17.7	-0.06	0.09
	14	15.0	0.03	0.03	16.0	0.03	0.06	17.0	-0.09	0.09
	15	9.0	0.09	-0.06	--	--	--	9.5	-0.03	-0.03
	16	3.5	--	--	--	--	--	4.0	-0.03	-0.03

Table A6 (Con't.)

Date	Station	Morning			Afternoon			Evening		
		Temp.	GPP	R	Temp.	GPP	R	Temp.	GPP	R
1/31-2/2/1974	3	4.0	0.00	0.03	6.0	0.09	0.06	4.0	0.18	-0.12
	9	1.0	-0.03	-0.03	1.5	0.03	-0.03	2.5	-0.06	0.03
	12	18.0	0.03	0.03	18.5	-0.03	-0.03	13.0	0.06	0.03
	8	12.2	-0.03	0.03	12.5	-0.03	0.03	11.5	-0.06	0.03
	14	11.5	0.03	0.03	11.0	0.03	0.03	4.0	0.06	0.03
	15	--	--	--	--	--	--	--	--	--
	16	--	-	--	--	--	--	--	--	--
4/10-13/1974	3	8.0	0.03	0.03	11.0	0.00	0.00	9.5	0.03	0.03
	9	15.0	--	--	11.6	-0.03	-0.01	16.5	-0.03	-0.03
	12	15.5	0.03	0.03	14.3	0.06	0.06	18.3	0.06	0.06
	8	15.0	0.06	0.06	14.0	0.06	0.06	16.5	-0.06	0.06
	14	14.0	-0.03	-0.03	14.5	-0.03	-0.03	15.0	0.12	0.04
	15	10.0	0.06	0.06	11.5	-0.03	-0.03	11.0	0.03	-0.03
	16	8.0	0.00	0.00	9.0	-0.03	-0.03	9.0	0.03	-0.03
6/11-13/1974	3	21.5	0.36	0.03	23.0	0.33	0.03	21.5	0.06	0.03
	9	23.5	0.09	0.03	25.0	0.24	0.03	23.5	0.06	0.03
	12	28.7	0.24	0.06	29.3	0.36	0.09	29.3	0.06	0.03
	8	28.7	0.36	0.06	29.5	0.30	0.09	28.7	0.09	0.06
	14	28.3	0.39	0.09	29.0	0.24	0.09	28.7	0.06	0.06
	15	24.7	0.57	0.12	25.0	0.69	0.09	24.0	0.03	0.06
	16	22.7	0.96	0.12	23.5	0.33	0.06	22.0	0.06	0.03
8/14-16/1974	3	26.0	0.72	0.15	26.0	0.75	0.09	25.2	0.12	0.12
	9	27.0	0.48	0.12	29.2	0.66	0.00	27.0	0.06	0.09
	12	31.5	0.30	0.12	34.0	0.51	0.18	35.2	0.15	0.15
	8	30.7	0.42	0.12	34.0	0.45	0.24	34.5	0.12	0.15
	14	30.0	0.54	0.09	33.5	0.66	0.24	34.0	0.09	0.12
	15	27.0	0.51	0.18	29.0	0.72	0.00	29.5	0.18	0.12
	16	25.7	0.81	0.12	27.0	0.63	0.24	27.0	0.09	0.12

Table A6 (Con't.)

Date	Station	Morning			Afternoon			Evening		
		Temp.	GPP	R	Temp.	GPP	R	Temp.	GPP	R
10/19-21/1974	3	12.0	0.40	0.13	10.2	0.12	0.00	12.0	0.01	0.03
	9	12.5	0.02	0.04	13.5	0.02	0.02	12.5	-0.06	-0.01
	12	21.2	0.41	0.06	21.0	0.30	0.11	21.2	--	--
	8	20.2	0.60	0.04	20.0	0.40	0.08	20.2	-0.27	0.08
	14	19.5	0.53	0.05	19.0	0.32	0.07	19.5	-0.02	-0.03
	15	15.5	0.45	0.04	15.0	0.24	0.02	15.5	0.02	0.07
	16	13.0	0.27	0.06	12.0	0.28	0.06	13.0	-0.02	-0.04
1/24-25/1975	3	6.0	0.12	0.00	6.5	--	--	1.7	-0.07	-0.10
	9	13.2	-0.02	0.06	12.0	--	--	11.0	-0.04	-0.01
	12	14.5	0.11	0.10	15.2	--	--	15.5	-0.06	0.11
	8	12.7	0.02	0.05	14.0	--	--	13.2	-0.02	0.08
	14	12.2	0.02	0.02	13.0	--	--	12.5	-0.09	-0.03
	15	7.5	--	--	8.2	--	--	9.2	-0.03	0.00
	16	3.7	0.05	-0.03	4.0	--	--	8.7	-0.04	0.04
3/15-17/1975	3	2.2	0.02	-0.01	2.2	--	--	2.5	0.00	-0.02
	9	15.7	-0.03	0.07	12.5	--	--	14.2	-0.03	0.00
	12	19.0	0.04	0.10	16.2	--	--	20.0	0.00	0.05
	8	17.5	0.14	0.18	16.0	--	--	18.2	-0.01	0.03
	14	16.7	0.03	0.10	15.2	--	--	17.5	0.01	0.06
	15	11.0	-0.05	0.02	7.7	--	--	11.7	0.02	0.02
	16	7.0	0.20	0.02	5.0	--	--	7.0	0.02	0.03
5/15-18/1975	3	18.2	0.11	0.16	17.0	0.44	0.04	15.0	0.02	0.00
	9	20.7	0.66	0.00	20.0	0.34	0.05	--	0.02	0.00
	12	28.2	0.33	0.19	28.0	0.30	0.06	28.1	-0.06	0.01
	8	27.2	0.44	0.13	27.0	0.26	0.07	26.2	0.00	-0.16
	14	26.7	0.54	0.09	27.0	0.27	0.07	25.0	-0.03	0.04
	15	22.3	0.44	0.04	22.0	0.54	0.06	21.2	0.06	0.10
	16	20.2	0.41	0.16	20.0	0.40	0.10	17.0	0.11	0.17

Table A6 (Con't.)

Date	Station	Morning			Afternoon			Evening		
		Temp.	GPP	R	Temp.	GPP	R	Temp.	GPP	R
7/27-29/1975	3	26.7	0.86	0.03	26.7	0.86	0.14	24.4	0.02	0.00
	9	25.6	0.47	0.12	26.7	--	0.08	23.9	0.06	0.14
	12	33.9	0.74	0.10	35.0	0.31	0.18	33.3	-0.06	0.08
	8	33.3	0.65	0.13	34.4	0.41	0.12	33.3	0.01	0.06
	14	32.8	0.94	0.10	35.0	0.43	0.15	31.7	0.01	-0.03
	15	28.3	0.85	0.02	30.6	0.81	0.19	28.3	0.03	0.05
	16	25.6	0.88	0.00	28.9	0.94	0.19	24.4	-0.03	0.01
9/15-17/1975	3	17.0	--	--	18.2	0.81	0.10	17.0	0.09	-0.01
	9	19.0	--	--	19.0	0.26	-0.18	17.0	-0.19	0.00
	12	26.0	--	--	25.5	0.37	0.06	26.2	-0.04	0.18
	8	25.0	--	--	25.5	0.56	0.21	26.0	-0.30	-0.05
	14	25.0	--	--	25.5	0.66	0.11	24.7	0.02	0.26
	15	22.0	--	--	21.5	1.49	0.12	21.5	--	--
	16	18.5	--	--	19.0	1.30	0.23	19.0	--	--