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Effect of Reservoir Function on Water Quality and Phytoplankton in Lake Taylorville, Christian County, Illinois

Scott Warren Phipps

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EFFECT OF RESERVOIR FUNCTION ON WATER QUALITY AND PHYTOPLANKTON IN LAKE TAYLORVILLE, CHRISTIAN COUNTY,ILLINOIS

by

SCOTT WARREN PHIPPS

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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CHARLESTON, ILLINOIS

1994

I HEREBY RECOMMEND THIS THESIS BE ACCEPTED AS FULFILLING
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ABSTRACT

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Effect of Reservoir Function on Water Quality
and Phytoplankton in Lake Taylorville,
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As is true for most reservoirs in agricultural areas, Lake Taylorville is currently impacted by excess sedimentation. A system of floodplain wetlands, holding ponds, and sediment basins is being constructed on the tributaries to the reservoir in effort to reduce sediment and nutrient loads. A comprehensive twelve-month assessment of water quality has been conducted to provide a baseline for evaluating the success of this restoration project and to allow predictions regarding future management strategies.

In reservoirs, a continuum of longitudinal gradients result in the establishment of three distinct zones possessing unique physical, chemical and biological properties. The function of these zones (termed the riverine zone, transitional zone and the lacustrine zone) can be used to characterize the ecosystem of a reservoir. In

Lake Taylorville, only the riverine and transitional zones were found. The elimination of the lacustrine zone in Lake Taylorville is consistent with the large watershed to surface area ratio found there. Lake Taylorville can be characterized as a high flow reservoir that is more river like than lake like in function.

Light penetration in Lake Taylorville was usually limited to less than a meter at the surface by high suspended solids concentrations and although nutrient concentrations were high, phytoplankton density, primary productivity and chlorophyll a concentrations were lower than expected. Carlson Trophic State Index (TSI) calculated for total phosphorus and Secchi depth suggest hypereutrophy while those calculated from chlorophyll a data indicate a lower trophic state. Algae may be unable to maximize utilization of available nutrients as a result of low light availability. Because algal bioassays and nitrogen : phosphorus ratios indicate phosphorus limitation of primary productivity, productivity and phytoplankton standing crop may increase if light regimes are improved by sediment reduction resulting from wetland creation. Wetlands have been found to be effective at denitrification as well as sediment reduction. The combination of

reduced sediments and nitrates coupled with high in-lake phosphate levels could cause a shift in algal community structure from a currently Chlorophycean dominated community to a community dominated by Cyanophyceae. Future reservoir management may need to address the possibility of frequent blue-green algal blooms and perhaps target phosphorus reduction.

ACKNOWLEDGMENTS

I would like to thank the Taylorville City Council and the City of Taylorville for providing the funding for this research. I would also like to thank the Lake Taylorville Resource Planning Committee, the Christian County Soil Conservation Service, the Lake Department and the forward thinking citizens of Taylorville for their assistance in many aspects of this study.

I am grateful to Eastern Illinois University, Graduate Department of Biological Sciences, faculty and students; for providing a fertile environment for my education.

I greatly appreciate the help my committee, Dr. Kipp Kruse and Mr. Hank Nilsen, for their help and advice in the preparation of this paper.

Dr. Charles Pederson, the director of this study and my adviser, has spent a great deal of time and effort for the last two years helping in every aspect of my graduate education in more ways than I can begin to explain in this short space. I am truly grateful.

Without the help of my friends - Sanhita Datta, Tony Hall and especially John H. Ensign Jr. - this research would have been much more difficult and much less enjoyable.

I would not have pursued higher education had it not been for the unfailing support and encouragement of my parents, Don and Inez Phipps.

This paper and all else I do henceforth is dedicated to Marla Faver.

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INTRODUCTION

The Nature of Reservoirs

Reservoirs are typically created by damming rivers or streams to create a more static water supply. This creates a "sort of hybrid" (Thornton, Kimmel and Payne, 1990) water supply with characteristics somewhere between those of a river and a lake. Reservoirs have less surface area in comparison to watershed (Fig. 1) resulting in greater flow, higher suspended solids concentration and nutrient enrichment. Classical limnology cannot always be used to understand reservoir ecosystems due to the differences between lakes and reservoirs.

Kimmel and Groener (1984) assert that, in reservoirs, a continuum on the longitudinal axis of a reservoir results in the establishment of three distinct zones possessing unique physical, chemical and biological properties. These zones are the riverine zone, transitional zone and lacustrine zone (Fig. 2). The riverine zone (river like) is characterized by high flow rate and shallow depth, resulting in higher concentrations of suspended solids and nutrients but low productivity due to light limitation. The transitional zone exhibits decreased flow which allows sediments to settle out, thereby increasing light penetration. This, coupled

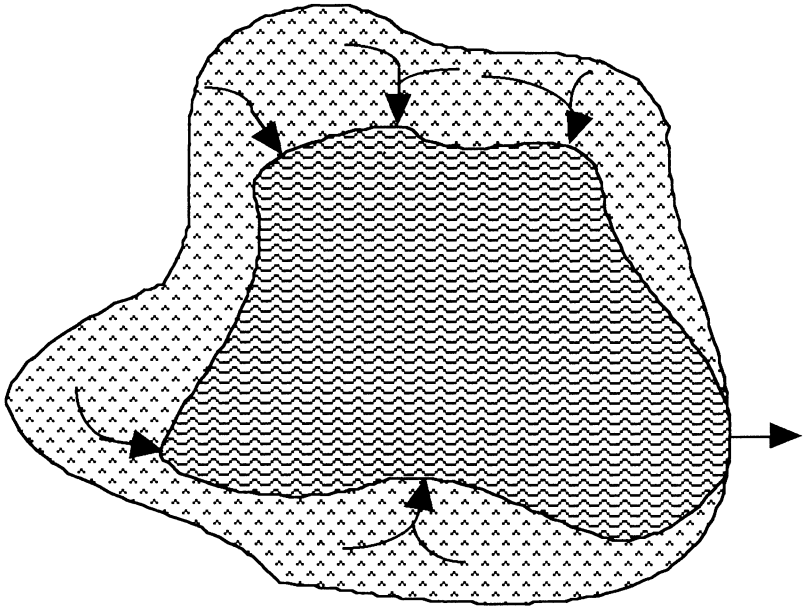
Figure 1. The relationship between surface area and drainage area in reservoirs and natural lakes.

LAKE/RESERVOIR AREA

DRAINAGE AREA

STREAM

TYPICAL LAKE



TYPICAL RESERVOIR

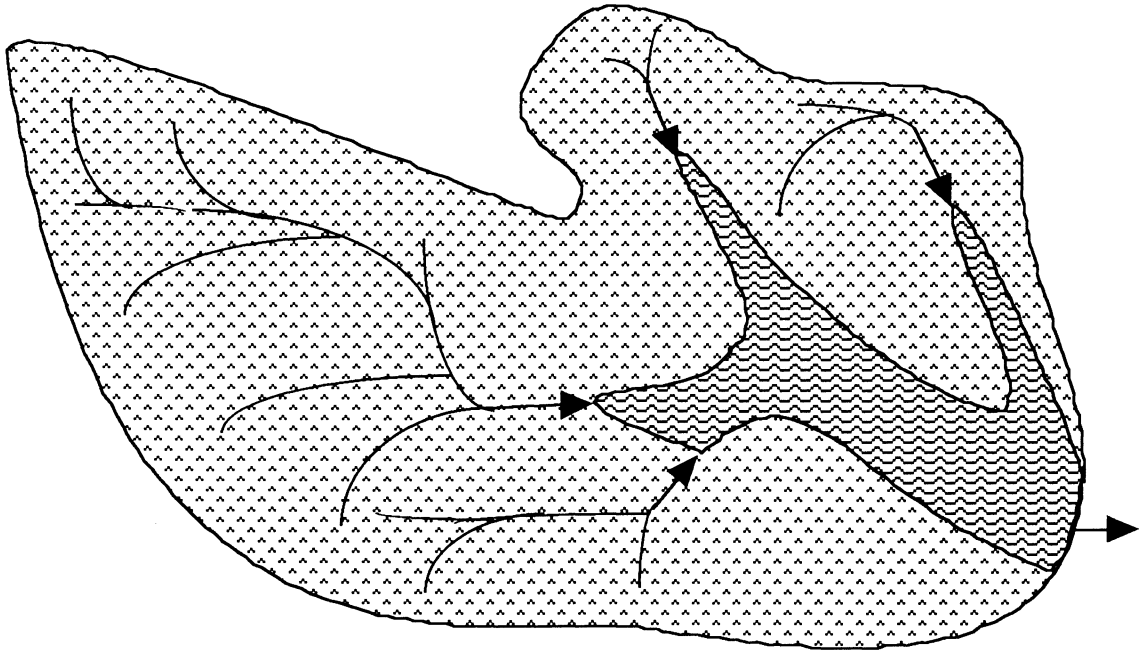
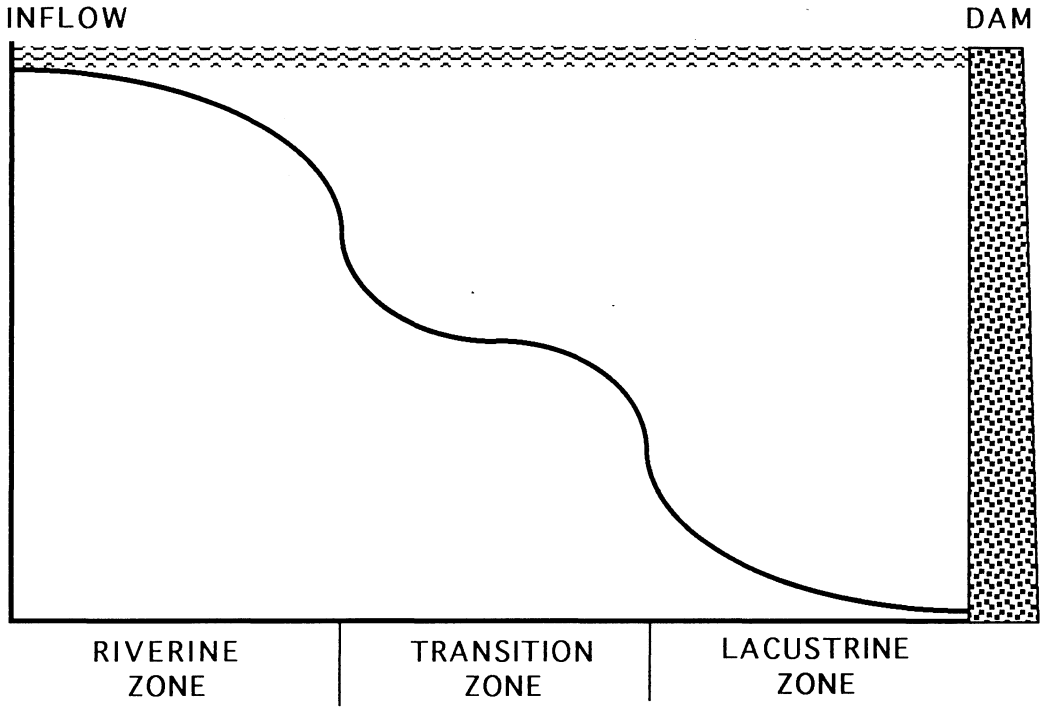
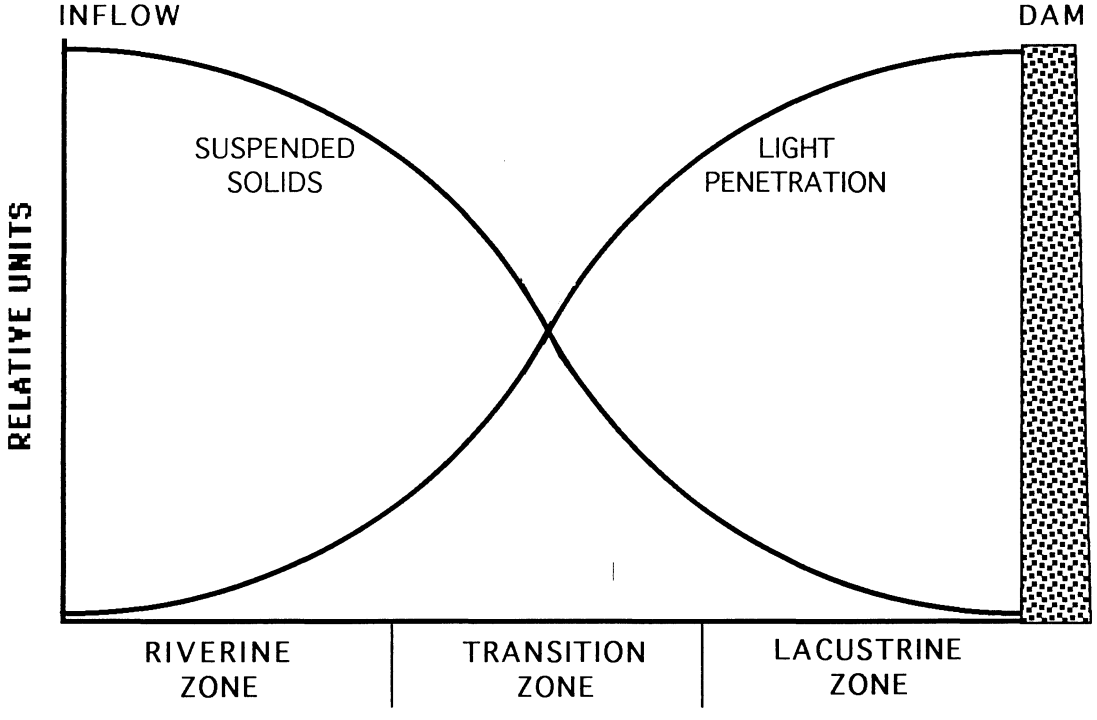


Figure 2. The longitudinal gradient of reservoir classification showing, i) three zones and their relationship to reservoir morphometry (top), ii) function of suspended particles and light penetration within the three zones (bottom) (modified from Thorton Kimmel and Payne, 1990).

RESERVOIR ZONES



TYPICAL RESERVOIR



with the high nutrient concentration, causes productivity to rise. The lacustrine zone (lake like) is characterized by low flow and greater depth which leads to thermal stratification, decreased suspended solids, greater light penetration and lower productivity due to lower nutrient concentration.

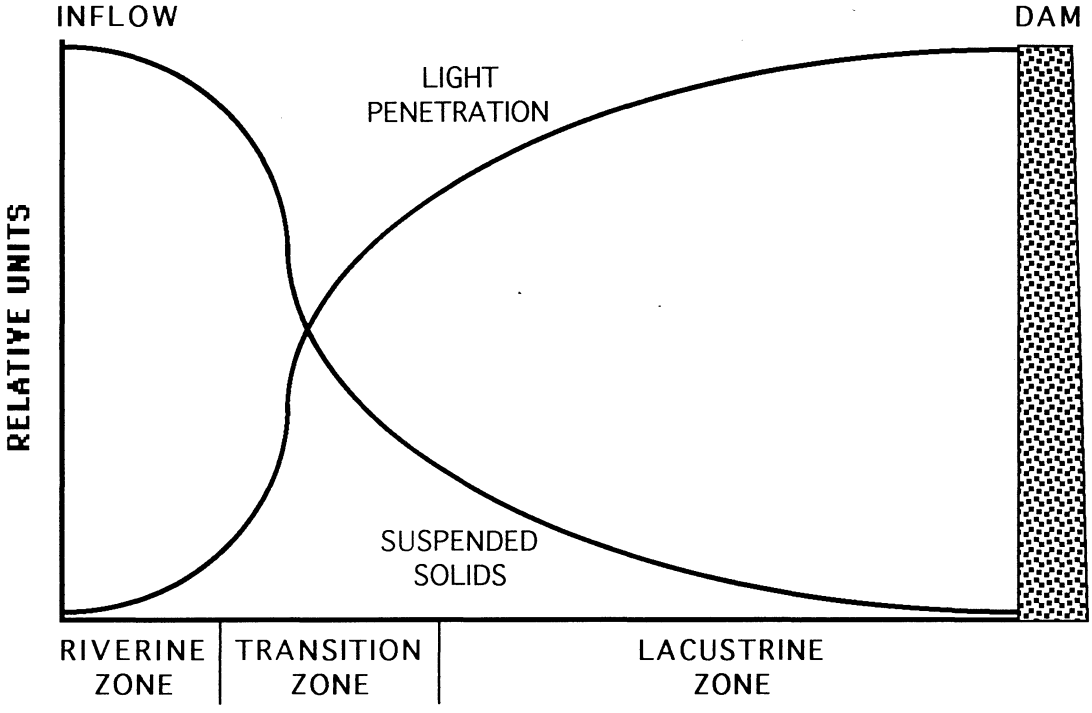
Fluctuations in rate of flow can change the boundaries of the zones. Decreased flow causes sediments to fall out faster, increasing the light penetration and allowing increased phytoplankton productivity and uptake of available nutrients. This results in a decrease in the extent of the riverine zone and transitional zone and a corresponding expansion of the lacustrine zone. Increasing flow can cause the opposite to occur to the point of the elimination of a lacustrine zone (Fig. 3).

Reservoir Restoration

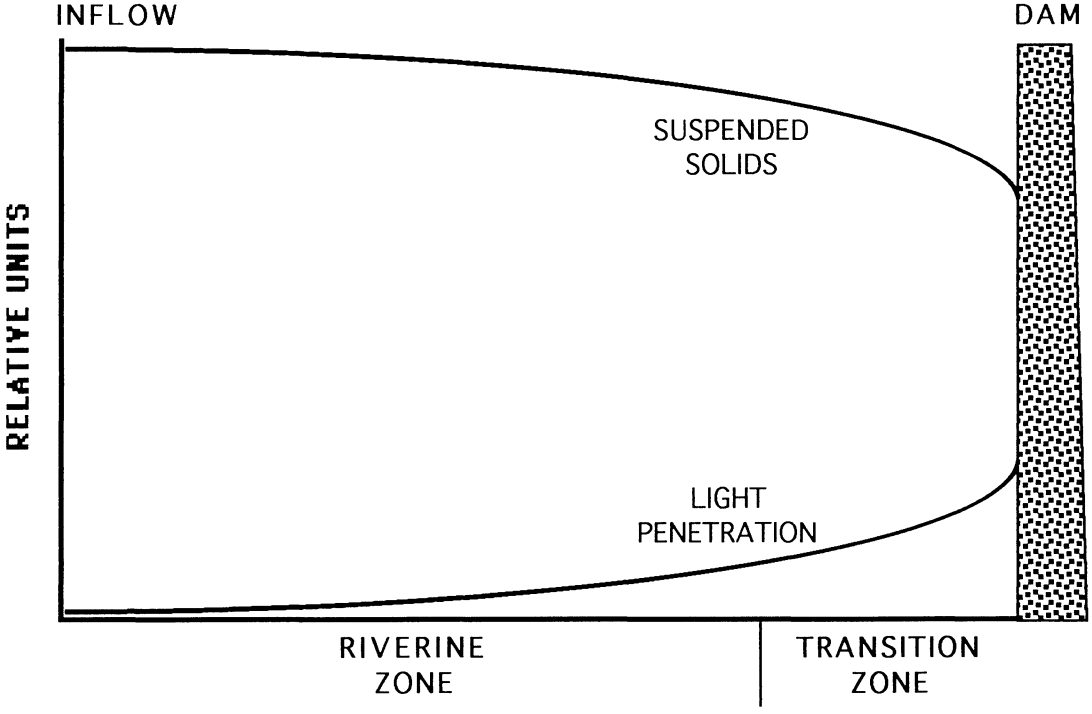
Eutrophication is a natural process in glacial lakes that results from accumulation in the lake of sediments and nutrients derived from the watershed (Wetzel, 1975). In glacial lakes, this process can take thousands of years but may occur in a few decades in a reservoir. In reservoirs, eutrophication is greatly accelerated

Figure 3. Function of suspended particles and light penetration within the three zones of reservoir classification in a low flow reservoir (top) and a high flow reservoir (bottom) (modified from Thornton, Kimmel and Payne, 1990).

LOW FLOW



HIGH FLOW



due to the much larger watershed to surface area ratio (Thornton, Kimmel and Payne, 1990). As eutrophication proceeds there is a corresponding decline in general water quality both for water supply and for recreation as well as a loss of water capacity due to the rapid accumulation of sediments. Thus, the builders of a reservoir face the rapid eutrophication of that reservoir as well as the loss of capacity since the reservoir acts as a trap for the sediments carried by the stream (U.S. EPA, 1988). Reservoir restoration typically focuses on slowing the accumulation of sediments and nutrients and/or removing already accumulated sediments in effort to restore water supply, water quality, and recreation opportunity.

There are several options available to lake managers wishing to restore a reservoir. The optimal solution depends upon key characteristics of that reservoir - morphometry, watershed geography and hydrology, water chemistry, pollution sources, and purpose of the reservoir. Watershed management is the key to successful reservoir restoration but may not be feasible due to expense and the difficulty in enforcement of aims among the many owners of the watershed (U.S.D.A., 1991). Sediments can be removed by dredging or by lowering the pool and excavating. This method can

be very effective in the short term but it is expensive and can only be termed temporary in the absence of successful watershed management (U.S.D.A., 1991). Nutrients may be inactivated by the addition of salts (Funk and Gibbons, 1978; and U.S.EPA, 1982). Hypolimnetic withdrawal is effective in deep water reservoirs with extensive lacustrine zones that are stratified much of the year (Kortmann, et al., 1982). Construction of silt dams and wetlands at the inflow areas of a reservoir (U.S. EPA, 1993; Hammer, 1992) can be effective at sediment reduction as well as the reduction of nutrients. Silt dams can be constructed so as to be easily renewable and wetlands can increase the wildlife and fish populations and aesthetics of the reservoir as well as the water quality and quantity. Wetlands can be expected to provide some degree of improvement even without successful watershed management (Hammer, 1992).

Site Description

Lake Taylorville is an impoundment on the South Fork Sangamon River in Christian county of central Illinois (Water Resource Council Basin #07130007, sub basin code 020)

(U.S.D.A., 1994). The dam was constructed in 1961 and began impounding water in 1962. Lake Taylorville is the primary water supply for the city of Taylorville, as well as Hewittville, Langleyville, Owaneco and the Bertinetti addition, serving approximately 15,000 people (U.S.D.A., 1991). Lake Taylorville also serves as an important recreation facility for the surrounding community. The reservoir is heavily utilized for boating, fishing, swimming, and water skiing (U.S.D.A.,1991). In 1993, it was estimated that $3.50 was spent by each visitor to the reservoir and there were 149,000 visitors, constituting a major income source for the city of Taylorville (U.S.D.A., 1994).

Like many reservoirs, and especially reservoirs in agricultural areas, Lake Taylorville is impacted heavily by sedimentation and nutrient enrichment. The Christian County Soil and Water Conservation District (U.S.D.A.,1991) estimated that 97,500 tons of sediments are deposited in the reservoir each year and since impoundment the reservoir has lost about 1500 acre-feet of capacity (9406 acre-feet in 1962 to 6829 acre-feet in 1988). The watershed is approximately 84,000 acres, primarily agricultural and quite large in relation to the 1,100 acre surface area of the

reservoir. This 76:1 watershed to surface area ratio results in a high flow reservoir that is being rapidly degraded by excess sedimentation and nutrient enrichment from agricultural runoff, leading to eutrophication, water quality degradation, and loss of reservoir capacity due to rapid accumulation of sediments. Dredging operations have removed 230,000 cubic yards of sediments to date at a cost of 2$ per yard (U.S.D.A., 1991). Recently, the city of Taylorville spent over 1 million dollars to upgrade their water treatment plant (U.S.D.A., 1991). As Lake Taylorville fills with sediments, decreased shoreline and shallower conditions may also impair the fishery and diminish recreational opportunities.

Lake Taylorville is part of the Illinois Environmental Protection Agency's (IEPA) Ambient Lakes Monitoring Program and the IEPA's Volunteer Lakes Monitoring Program. In 1988, (I.E.P.A., 1979) the IEPA characterized the lake as hypereutrophic, moderately impaired for water supply and highly impaired for primary contact, recreation, and fish and wildlife (I.E.P.A., 1979). Agricultural non point source and in place contaminants were rated high.

In 1989, the Taylorville City Council appointed a Lake Taylorville Resource Planning Committee (LTRPC) to develop a plan in conjunction with the Christian County Soil and Water Conservation District to improve the conditions in their reservoir (U.S.D.A., 1991). The goals of the committee are to improve the overall water quality, assure retention of an adequate supply and improve recreation and wildlife habitat. To achieve these goals, a system of floodplain wetlands, riverine wetlands, holding ponds and sediment basins is being constructed on the tributaries to the reservoir in effort to reduce sediment and nutrient loads. This project is unique in that more than 85% of the watershed can be routed through these structures.

Baseline Study

Construction of the wetlands and sediment basins began in the summer of 1993. The LTRPC and the Taylorville City Council recognized the need for the commencement of a baseline study prior to the construction of these structures. A baseline study was deemed necessary in order to adequately assess the success of the restoration project. Additionally, a baseline study in conjunction

with post wetland construction studies can aid in the planning of future management strategies. Pursuant to these needs, the City of Taylorville contracted Dr. Charles L. Pederson, of Eastern Illinois University, to direct a comprehensive baseline study of water quality in Lake Taylorville. The study began 5 February 1993 and continued through 31 May, 1994. The phase of the project that I worked on ended 11 February, 1994. The focus of my study was the interaction of chemical and physical water quality parameters with the phytoplankton community in the context of overall reservoir function.

MATERIALS AND METHODS

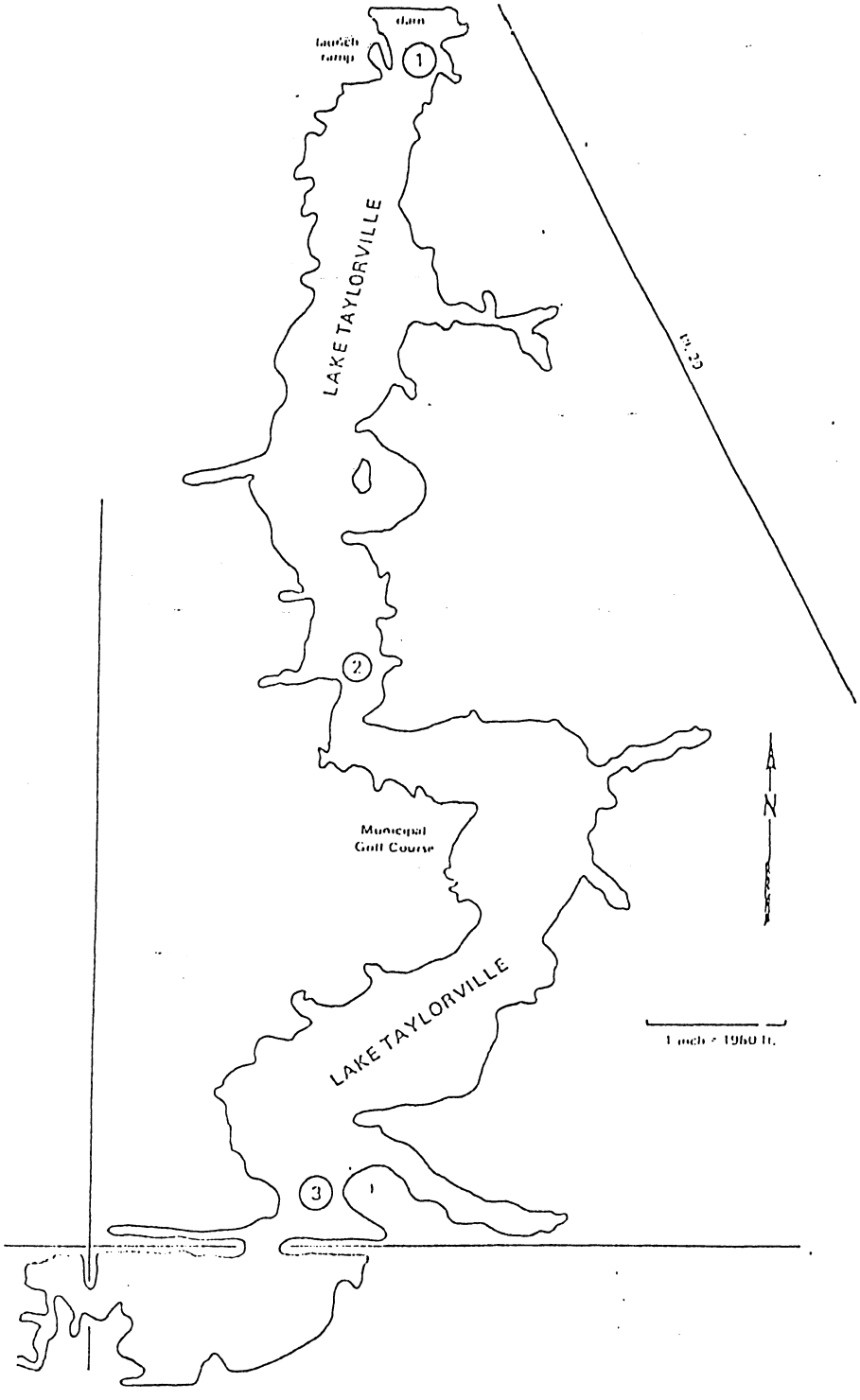
Sample Site Selection

Three sample sites were chosen on Lake Taylorville (Fig. 4). The DAM site is near the dam directly between the water plant intake and the aerator/mixer. The MIDLAKE site is directly in the old stream channel off Vaughn Point just north of the "dogleg" of the lake. The INFLOW site is situated approximately 200 meters north of the Owaneco blacktop aligned with the water underpass and a dock on the west shore of the reservoir. These sites were chosen for ease of identification, to provide a gradient from shallow to deep along the length of the reservoir, to provide sample stations within the three apparent physical zones represented in the trizonal system of reservoir classification (INFLOW = riverine, MIDLAKE = transitional, DAM = lacustrine), and because the IEPA had previously sampled from approximately the same sites (I.E.P.A., 1979).

Sampling Protocol

Sampling was conducted bimonthly from April to September and monthly the remainder of the year. Eighteen sample dates were recorded from 5 February, 1993 to 11 February, 1994. Sampling

Figure 4. Map of Lake Taylorville showing approximate locations of sample collection sites used in this study. Marker 1 is the location of the DAM site, marker 2 is the location of the MIDLAKE site and marker 3 is the location of the INFLOW site (modified from IEPA, 1980).


dam
launch ramp
1
LAKE TAYLORVILLE
2
Municipal
Golf Course
N
LAKE TAYLORVILLE
1 inch = 1960 ft.
3

proceeded as planned regardless of weather except when unsafe conditions existed (high winds, high waves, or ice too thin to walk on but too thick to boat through). In general, sampling commenced at 0900 at the DAM site and was completed by 1400 at the INFLOW site. Sample collection, storage and determination were according to Standard Methods (APHA, 1985) (Tables 1 and 2).

Field Measurements

Light Regime

Secchi depth was determined by lowering a six inch Secchi disk into the water until it could not be seen, then lowering further and raising it until it could be seen again and averaging the two depths (Lind, 1979). Photosynthetically Active Radiation (PAR; that portion of the electromagnetic spectrum used by plants in the process of photosynthesis) was measured with a Li-Cor model LI-185-A quantum sensor equipped with a submarine photometer. Because light is extinguished as it passes through a column of water (Wetzel, 1975), light intensity at a given depth can be calculated as:

$$I_z = I_o e^{-N Z}$$

Table 1. Methods of handling and analysis of chemical and physical samples.

Parameter	Sample Container & Preservation	Method Citation	Analysis	Units	Detection Limits	Time Limit	Sample Size
Temperature		212	In Situ	^{o}C	0.1^{o}		
Dissolved Oxygen		421 F	In Situ or	mg L^{-1} O_2	0.1		
		421 B	Laboratory	mg L^{-1} O_2	0.1	24hrs	201mL
PAR			In Situ	mole photons m^{-2} s^{-1}	0.1		
Photic Zone		Lind, 1979	In Situ	cm	1.0		
Conductivity		205	In Situ	umho's cm^{-1}	10.0		
pH		423	In Situ	pH units	0.1		
Solids							
Total	1-L Poly,4 ^{o}C	209 A	Laboratory	mg L^{-1}	0.1	48hrs	40mL
Suspended	1-L Poly,4 ^{o}C	209 C	Laboratory	mg L^{-1}	0.1	48hrs	100mL
Dissolved	1-L Poly, 4 ^{o}C	209 B	Laboratory	mg L^{-1}	0.1	48hrs	

Table 1. Continued

Parameter	Sample Container & PreservationMethod	Method Citation	Analysis	Units	Detection Limits	Time Limit	Sample Size
Alkalinity	1-L Poly, 4 ^{o}C	403	Laboratory	mg L^{-1}	0.1	6hrs	100mL
Ammonia	1-L Poly,4 ^{o}C	417 C, E	Laboratory	mg L^{-1}	0.1 (>0.8)	6hrs	100mL
Nitrate-N	1-L Poly,4 ^{o}C	418 C	Laboratory	mg L^{-1}	0.01	5 days	25mL
Total Phosphate	300-mL glass,-10 ^{o}C	424 C iii 424 F	Laboratory	mg L^{-1}	0.01	7 days	50mL
Diss. Phosphate	300-mL glass,-10 ^{o}C	424 C iii 424 F	Laboratory	mg L^{-1}	0.01	7 days	50mL

Table 2. Methods of handling and analysis of biological samples.

Parameter	Sample Container & Preservation	Method	Analysis Citation	Units	Detection Limits	Time Limit	Sample Size
Primary Productivity	glass BOD-bottle 4 °C	1002 I O_2 method	In Situ	mg O_2 m^{-2} per hour	0.1	4hrs	300mL
Chlorophyll	1-L Poly, -10 °C	1002 G	Laboratory	mg m^{-3}	0.1	2mths	var.
Phytoplankton	1-L Poly, 4%formalin	1002 F.2b	Laboratory	Natural Unit	1	12mths	40mL

where:

N = extinction coefficient
Z = change in depth
e = base of the natural log
I = light energy in mole photons m^{-2} s^{-1}
I_o = mole photons m^{-2} s^{-1} at surface
I_z = mole photons m^{-2} s^{-1} at given depth

Therefore, light extinction coefficient was determined using the following formula:

$$N = \frac{\ln I_o - \ln I_z}{Z}$$

Temperature and Dissolved Oxygen

Temperature, dissolved oxygen were measured at discrete depths (surface, 0.5 meter, 1.0 meter, 1.5 meters, 2.0 meters and successive 1.0 meter increments to the bottom) in situ using a Yellow Springs Instruments (YSI) Model 54 dissolved oxygen meter with a submersible probe. Samples were collected without the introduction of atmospheric oxygen in glass BOD bottles using a Van Dorn water sampler. These samples were treated immediately on

site with manganous sulfate solution and alkali-iodide-azide reagent and then acidified with concentrated sulfuric acid as per the azide modification of the Winkler method (APHA, 1985). These samples were titrated with sodium thiosulfate to determine oxygen concentration upon returning to the laboratory.

Conductivity and pH

Samples were collected at each discrete depth with the Van Dorn and placed in a 3-L polypropylene beaker for the immediate determination of pH with a Fisher model 107 digital field pH meter or a Cole-Parmer pHtestor field pH meter and the immediate determination of conductivity with a Markson model 10 portable conductivity meter or a Cole-Parmer TDStestor 2 field conductivity meter.

Laboratory Determinations

Water chemistry analyses were performed on samples taken from surface (0.3 meter) and bottom (0.3 meter from sediments). Samples taken for phosphorus determination were stored in acid washed borosilicate glass containers while all other samples were stored in 1-L polypropylene containers.

Available Nutrients

Available nitrogen as ammonia was determined using either the phenate method (APHA, 1985) or the selective electrode method with an Orion Research Ionalyzer, model 407-A. Available oxidized nitrogen (NO_2^-, NO_3^-) was determined by passing a 25 mL sample (or a sample diluted to 25 mL) through a cadmium reduction column in the presence of a base where all nitrates are reduced to nitrites. Nitrites can then be diazotized with sulfanilamide and coupled with N-(1-naphthyl)-ethylenediamine to form a pink azo dye that can be determined colorimetrically (APHA, 1985).

Phosphorus samples were split immediately upon return to the laboratory and one half was filtered through a 0.45 um pore size cellulose acetate filter. Both halves were then either immediately digested using the persulfate method to convert all forms of phosphate to orthophosphate (PO_4^{-3}) or frozen until digestion could be performed. Total phosphate (unfiltered portion) and total dissolved phosphate (filtered portion) was determined by the ascorbic acid method (APHA, 1985).

Concentrations of phosphate and nitrite/nitrate were determined spectrophotometrically using a Bausch and Lomb Spectronic 20 or a Perkin-Elmer Lambda 3B spectrophotometer. A standard curve was plotted for each set of samples using a known concentration and concentrations were determined using the Beer-Lambert Laws and linear correlation.

Total alkalinity (an index of available carbon) was measured by titration of a 100 mL sample with 0.02 N hydrochloric acid to an end point of pH 4.5. Approximately 1 mL bromcresol green solution was added to the sample to provide a colorimetric pH indicator (APHA, 1985). Alkalinity was then calculated using the formula:

$$CaCO_3\ (mg\ L^{-1}) = \frac{A \times N \times 50{,}000}{mL\ sample}$$

where:

A = mL titrant used
N = normality of titrant

Solids

Total solids (TS) was determined by evaporating 40 mL of sample in a tared crucible at 103-105 ^{o}C for 24 hours and then weighing the remaining solids. Total suspended solids (SS) was determined by filtering a 100 mL sample through a tared glass fiber filter, pore size 0.45 um, drying that filter at 103-105 ^{o}C and determining the mass of the filtrate. Total dissolved solids (DS) was determined by finding the difference between TS and SS (APHA, 1985).

Biological Constituents

Metabolic Rate

Metabolic rate of biological constituents was measured at the DAM site using the light - dark bottle method of primary productivity (APHA, 1985). Productivity is defined as the amount of inorganic carbon converted to organic carbon by the process of photosynthesis over a period of time. Since oxygen is a by-product of photosynthesis and, theoretically, one mole of diatomic oxygen is produced for each mole of carbon fixed ($CO_2 + H_2O = [CH_2O]_x + O_2$), measurements of oxygen concentration in light and dark bottles over

time can indicate gross and net productivity as well as respiration. Three 300-mL BOD bottles were filled from a single sample taken at discrete depths to 4.0 m. One of the bottles, designated the "initial" was fixed immediately for later determination of dissolved oxygen. The "dark" bottles (painted and covered with aluminum foil to exclude all light) and the "light" bottles were then suspended at their respective depths from an anchored float for four hours (usually deployed at 1000 and retrieved at 1400). After retrieval, light and dark bottles were also fixed. Dissolved oxygen was determined in initial, light and dark bottles using the azide modification of the Winkler method. Light bottle dissolved oxygen (LBDO) - dark bottle dissolved oxygen (DBDO) = gross photosynthesis; LBDO - initial DO = net photosynthesis; initial DO - DBDO = respiration. Productivity can be calculated using the following formula:

$$\text{mg C fixed } m^{-3} = \text{mg } O_2 \text{ released } L^{-1} \times 12/32 \times 1000L\ m^{-3}$$

The factor 12/32 is used to convert 1 mole of diatomic oxygen released (32g) to 1 mole of carbon fixed (12g).

Chlorophyll

Chlorophyll concentrations can be used as an index of phytoplankton standing crop. Different classes of algae have different ratios of chlorophyll a, b and c. Determination and differentiation of these types of chlorophyll can be used to infer community structure. Samples for chlorophyll determination were taken from surface and bottom and placed in polypropylene containers on ice to return to the laboratory. Care was taken to exclude light from the samples at all steps in the sampling, extraction and determination procedures because light degrades chlorophyll.

Samples were immediately filtered through 0.45 um pore size cellulose acetate filters. Saturated magnesium carbonate solution was added while filtering at a rate of about 1 mL per 100 mL sample to neutralize any acid in the sample or on the glassware that could degrade the chlorophyll. Sample size was limited by the amount of suspended solids in the water. Filters were frozen for storage or extracted immediately. Filters were extracted by placement in 10 mL of a 1:4 mixture of DMSO (Shoaf and Lium, 1976) to 90% acetone, agitated by hand for 1 minute and then stored at 4 ^{o}C for 24

to 48 hours (cellulose acetate filters dissolve in 90% acetone). DMSO facilitates the extraction of chlorophyll from the cells without the use of a tissue grinder and does not change the photoresponse of the 90% acetone (Shoaf and Lium, 1976). After extraction, samples were centrifuged at 1,776 g for 10 minutes to separate the solids from the extract. A 3 mL portion of the supernate was placed in a Perkin-Elmer Lambda 3B spectrophotometer and absorbance read against a solvent blank at 750 nm (turbidity blank), 665 nm, 664 nm, 647 nm, and 630 nm. The extract was then acidified with 3 drops of 0.1N hydrochloric acid, agitated to mix thoroughly and allowed to sit for 90 seconds (acid converts all chlorophyll to phaeophytin). Absorbance was then read at 750 nm, 664nm and 665 nm. Concentrations of chlorophyll a (uncorrected for phaeophytin), chlorophyll b and chlorophyll c in the extract were calculated with the following trichromatic formulae:

$$C_a = 11.85(OD664) - 1.54(OD647) - 0.08(OD630)$$
$$C_b = 21.03(OD647) - 5.43(OD664) - 2.66(OD630)$$
$$C_c = 24.52(OD630) - 7.60(OD647) - 1.67(OD664)$$

where:

OD = optical density
C_a = extract concentration, chlorophyll a (mg L^{-1})
C_b = extract concentration, chlorophyll b (mg L^{-1})
C_c = extract concentration, chlorophyll c (mg L^{-1})

Subsequently, concentrations in lake water were determined as:

$$C = \frac{C_i \times V_e}{V_s}$$

where:

C = concentration in lake water (mg m^{-3})
C_i = concentration (mg L^{-1}) where i = a, b, c
V_e = volume of extract (L)
V_s = volume of sample (m^3)

Concentrations of chlorophyll a (corrected for phaeophytin a) and phaeophytin a were calculated with the following monochromatic formulae:

$$\text{Chl a, (mg m}^{-3}) = \frac{26.7\,[OD664_a - OD665_b] \times V_1}{V_2 \times L}$$

$$\text{Phaeo a, (mg m}^{-3}) = \frac{26.7\,[1.7(OD665_a) - OD664_b] \times V_1}{V_2 \times L}$$

where:

V_1 = volume of extract (L)
V_2 = volume of sample (m^3)
L = light path of sample cuvette (cm)
$OD664_a$ = optical density after acidification (corrected for turbidity)
$OD665_b$ = optical density before acidification (corrected for turbidity)

Phytoplankton

Phytoplankton composite samples were made by collecting 100 mL samples from each sampling depth and mixing to form a composite for that water column from each site. Composites were preserved in 4% formalin. Samples were concentrated by allowing 40 mL of the composite to settle for 5 d and aspirating 35 mL of supernate. Samples were agitated to mix thoroughly and then 0.1 mL was placed in a Palmer-Maloney counting chamber using a milk pipette (large bore). Counts were made with a compound microscope at 400X magnification using an ocular micrometer graduated 0 to 100 that spanned 250 um at 400X. Four microtransects (250 um X 17.9 mm) were counted on each slide. A natural unit count (counting unit = one unicellular organism, natural occurring colony

or filament) was performed counting each unit that occurred within the transect. Units that intersected the left margin of the transect were excluded while units that intersected the right margin were counted. The following formula was used to ensure that the sample size was sufficient to approximate the true mean units per scan to within 10% (modified from Sokal and Rohlf, 1981):

$$n = \frac{(Z^2)\,(S^2)}{(d\bar{X})^2}$$

where:

n = number scans necessary to approximate 10% of mean
$Z^2 = (z)^2 = (z_{.05}) = (1.96)^2$
S^2 = variance of the means
d = desired degree of precision (10% or 0.1)
$\bar{X}$ = mean units per scan

When the number of scans exceeded n, or when the number of scans reached 30, counting was concluded on that sample. Mean algal units mL^{-1} were calculated using the following formula (APHA, 1985):

$$\#\ \text{algal units}\ (mL^{-1}) = \frac{U_t \times 1000mm^3}{(A_t)(D_t)(N_t)(CF)}$$

where:

Ut = units per transect
At = area of a transect (17.9 mm X 0.25 mm)
Dt = depth of a transect (mm)
Nt = number of transects
CF = correction factor (8) for concentration of sample

Phytoplankters were identified to class level and a partial list of genera was constructed. Identification was facilitated by the keys of Smith (1950) Tiffany and Britton (1952) and Taft and Taft (1971).

Algal Assay Procedure - Bottle Test

Nutrient limitation of primary productivity was investigated by the Algal Assay Procedure - Bottle Test (AAP-BT) developed through the National Eutrophication Research Program, United States Environmental Protection Agency (U.S.EPA, 1971). A sample containing Selenastrum capricornutum Prinz. was obtained from D. Vaultonburg and a unialgal culture was produced using the spray plate procedure (Wiedeman, Walne and Trainor, 1964). The unialgal cultures were transferred to 100 mL sterile Bristol's medium (Lylis and Trainor, 1973) in 500-mL Erlenmeyer flasks and placed on

a rotary shaker at 100 rpm. Continuous cool-white florescent lighting was provided at a constant intensity of 400 to 440 ft-c. Temperature was maintained between 22 and 26 ^{o}C. Inoculum from stock cultures was transferred to new Bristol's medium once a week for at least 3 weeks to ensure that the cultures consisted of young, rapidly reproducing cells prior to the assay procedure.

Cells for the inoculum were prepared for the assay procedure by placing them in a 0.2% sodium bicarbonate solution and centrifugation, discarding supernate, resuspending cells in 0.2% sodium bicarbonate. This procedure was repeated at least 3 times to insure that all of the Bristol's medium had been discarded. A cell count was performed using a Petroff-Hauser counting chamber and serial dilutions were made to produce a cell suspension in which 1 mL inoculum would contain approximately 44,000 cells.

Assay flasks were prepared using 250-mL Erlenmeyer flasks containing 59 mL treatment sample and 1 mL inoculum. Six flasks contained filtered (0.2 um pore size cellulose acetate) Lake Taylorville water (LW), 5 contained filtered Lake Taylorville water plus 1 mL of a nitrate spike (LW+N), 5 contained filtered Lake Taylorville water plus 1 mL of a phosphate spike (LW+P), and 3

contained AAP-BT growth media (M) (U.S.EPA, 1971). Nitrogen and phosphorus concentrations as well as N : P ratios were determined for each treatment. All treatments were incubated for 5 days under the same conditions as the stock cultures. The flasks were repositioned randomly on the shaker each day to ensure even light exposure. After 5 days, counts were made of each flask with a Petroff Hauser counting chamber and mean cell counts (mL^{-1}) were determined for each treatment. Specific growth rates were determined using the following formula (U.S.EPA, 1971):

$$u = \frac{\ln (X_2/X_1)}{T_2 - T_1} \text{ days}^{-1}$$

where:

u = specific growth rate
X_2 = cell concentration at beginning of time period
X_1 = cell concentration at end of time period
$T_2 - T_1$ = elapsed time (in days) between time periods

Trophic State

Traditional trophic classification divides lakes and reservoirs into three classes (oligotrophic, mesotrophic and eutrophic) without any clear delineation. Carlson's Trophic State Index (TSI) (Carlson, 1977) provides a number designation from 0 to 100 (0 being the most oligotrophic and 100 the most eutrophic) that is based on specific parameters and can be used to make empirical comparisons. TSI may be determined for three different parameters; i) Secchi depth when light attenuation is due to phytoplankton; ii) total phosphorus when phosphorus is the limiting nutrient; and iii) chlorophyll a. TSI's for Secchi depth, total phosphorus and chlorophyll a were determined using the following formulae:

$$TSI_{sd} = 10 \{ 6 - \frac{\ln sd}{\ln 2} \}$$

$$TSI_{tp} = 10 \{ 6 - \frac{\ln 48/tp}{\ln 2} \}$$

$$TSI_{chl} = 10 \{ 6 - \frac{2.04 - 0.68 \ln chl}{\ln 2} \}$$

where:

sd = Secchi depth (m)
tp = total surface phosphorus (mg m^{-3})
chl = surface chlorophyll a (mg m^{-3})

Statistical Analyses

Two-way analysis of variance (ANOVA) without replication was used to determine significant differences between sites and dates as independent variables (Sokal and Rohlf, 1981). One-way ANOVA was used to determine significant differences between variables for primary productivity comparisons that occurred only at the DAM site. One-way ANOVA also was used to test for differences between treatments for the algal bioassay. In all ANOVA's, Scheffe's multiple-comparisons test was used to identify differences between means (Sokal and Rohlf, 1981). Significant interactions between chemical, physical and biological parameters were determined by Spearman-rank correlation analysis (Sokal and Rohlf, 1981). In all analyses, an alpha value of 0.05 was used to determine significance. Statistical analyses were performed using Data Desk statistics program on a Macintosh Performa 475 (Vellman, 1988).

RESULTS AND DISCUSSION

Nutrient Limitation

A limiting nutrient is that nutrient that is in shortest supply relative to need (Hutchinson, 1961). Plants in general and phytoplankton in particular are composed by weight of a ratio of 40 parts carbon, 7 parts nitrogen and 1 part phosphorus and plants take up these nutrients in relation to this ratio (Redfield, 1958). A measure of the ratios of available carbon, nitrogen and phosphorus in a reservoir can be used to predict the limiting nutrient (Chiaudani and Vighi, 1974).

Carbon

Total alkalinity is a measure of the buffering capacity of water and in lakes with a pH of less than 8.3, alkalinity is due almost entirely to carbonate and bicarbonate buffers. A measure of total alkalinity between the pH units of 8.3 and 4.5 is in effect a measurement of calcium carbonate (APHA, 1985). Carbon available for uptake by plants in water exists in an equilibrium of carbon dioxide, carbonate and bicarbonate (Wetzel, 1975). Alkalinity, therefore, is an index of available carbon. Moyle (1949) found that productivity and carbonate alkalinity were not correlated at $CaCO_3$

concentrations greater than 48 mg $CaCO_3$ L^{-1} indicating carbon was not limiting above this level. Calcium carbonate concentrations in Lake Taylorville did not fall below 48 mg L^{-1} at any time during the year (Fig. 5), and correlation coefficients ($n = 6$, $(r) = 0.78$, $p > 0.05$) did not show any significant interactions between primary productivity and alkalinity leading to the conclusion that carbon was never the limiting factor for phytoplankton productivity.

Nitrogen Phosphorus Ratios

Ratios of available nitrogen (as NO_2^-, NO_3^-, NH_3) and available phosphorus (dissolved PO_4^{-3}) in excess of 10:1 have been found to be phosphorus limiting while ratios of less than 5:1 have been found to be nitrogen limiting (Chiaudani and Vighi, 1974). Ratios of nitrogen to phosphorus dropped below 5:1 only once (930907) during the sample year indicating that the limiting nutrient in Lake Taylorville is phosphorus (Fig. 6).

Figure 5. Alkalinity in mg L^{-1} $CaCO_3$ for all sites, sample dates from 0 to 350 days after the initial sample date. Points above the line at 48 mg L^{-1} $CaCO_3$ indicate carbon is not the limiting factor for primary productivity.

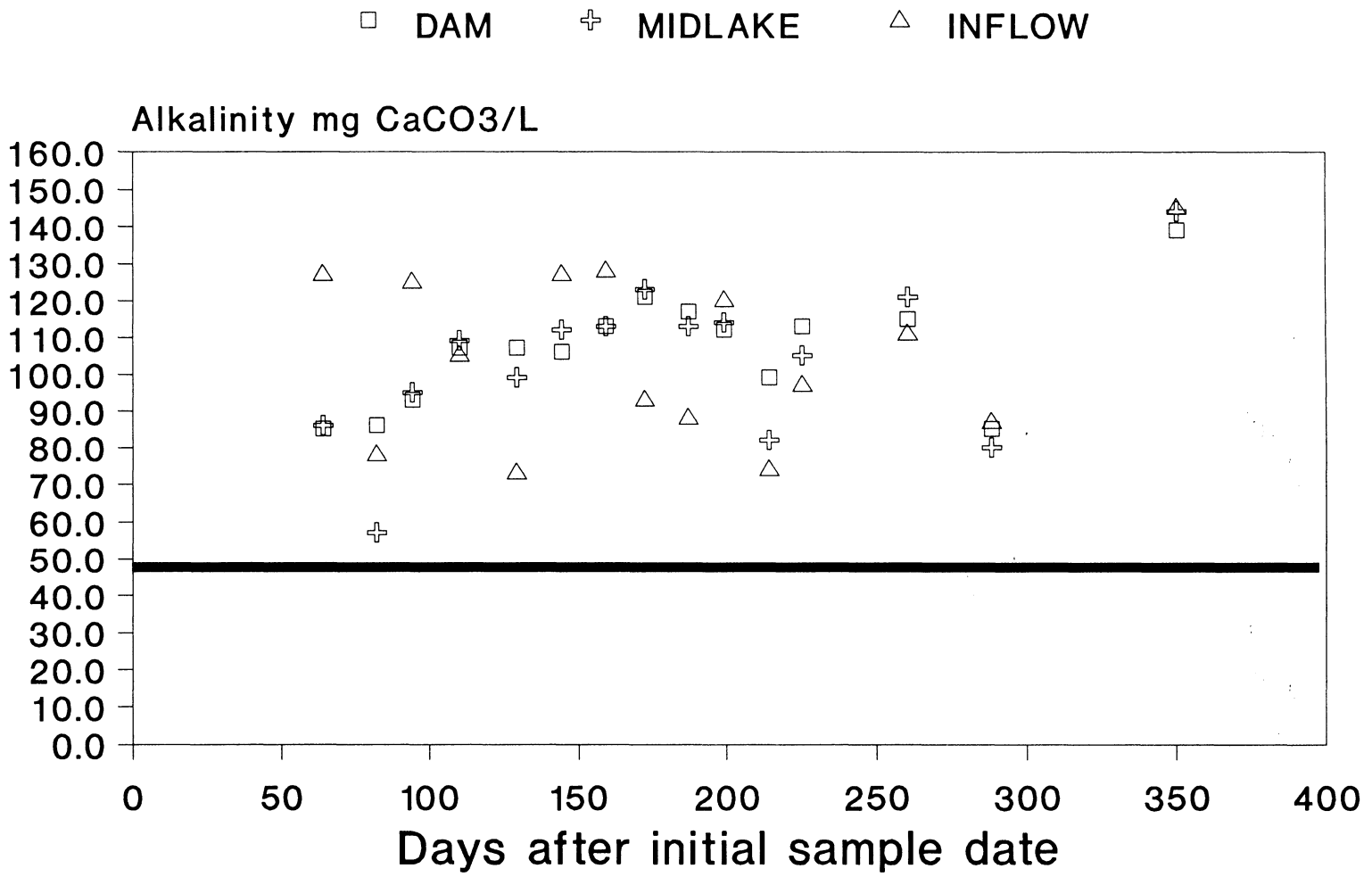
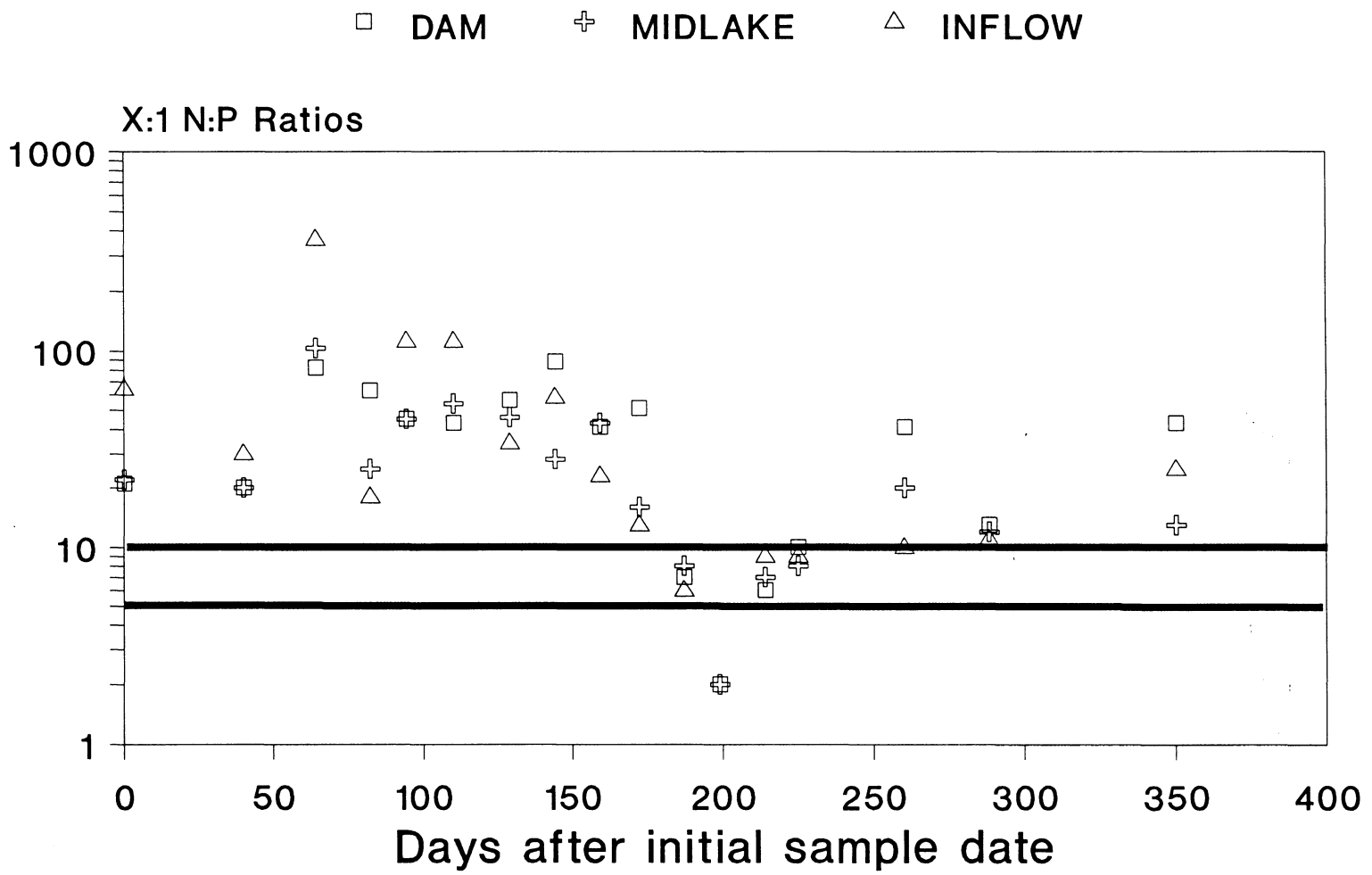

DAM
MIDLAKE
INFLOW
Alkalinity mg CaCO3/L
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
50
100
150
200
250
300
350
400
Days after initial sample date

Figure 6. Logarithmic representation of nitrogen to phosphorus ratios (N:P) for all sites, sample dates from 0 to 350 days after the initial sample date. Points above the line at 10:1 N:P indicate probable phosphorus limitation of primary productivity and points below the line at 5:1 N:P indicate probable nitrogen limitation.


DAM
MIDLAKE
INFLOW
X:1 N:P Ratios
1000
100
10
1
0
50
100
150
200
250
300
350
400
Days after initial sample date

Algal Bioassay

An Algal Assay Procedure - Bottle Test (U.S.EPA, 1971) confirmed that phosphorus was the limiting nutrient in Lake Taylorville. Lake Taylorville water spiked with nitrate (LW+N) did not show any significant difference in growth from Lake Taylorville water unspiked (LW) but Lake Taylorville water spiked with phosphate (LW+P) caused a significantly greater specific growth rate (F_{calc} = 63.04, df = 3, $p < 0.05$) (Table 3) confirming that phosphorus was indeed the limiting nutrient.

When phosphorus concentration was compared with primary productivity, there was no significant relationship (n = 6, (r) = -0.54, $p > 0.05$). In addition, there was no relationship found between phosphorus concentration and chlorophyll a concentrations (n = 14, (r) = -0.02, $p > 0.05$). This lack of relationship suggests that something else is limiting phytoplankton productivity.

Table 3. Algal Assay Procedure - Bottle Test treatments (LW = lake water, LW+N = nitrogen spike, LW+P = phosphorus spike and M = growth medium), concentrations (mg L^{-1}) nitrogen (N) and phosphorus (P), N to P ratios, mean 5-d cell counts (cells mL^{-1}), specific growth rate (u) 5-d, mean 15-d cell counts, mean 15-d chlorophyll *a* concentrations (mg m^{-3}), and 15-d suspended solids (SS) concentrations (mg L^{-1}).

Treatment	N	P	N:P	Count (5d)	u (5d)	Count (15d)	Chl *a*	SS
LW	4.48	0.08	61:1	2.0^6	0.76	14.0^6	140	28
LW+N	11.80	0.08	148:1	2.3^6	0.79	14.0^6	24	29
LW+P	4.84	0.41	11:1	27.6^6	1.29	62.0^6	227	64
M	4.20	0.20	21:1	19.0^6	1.21	73.0^6	158	59

Light

A Secchi disk provides a quick and easy way to measure light attenuation in the water column. Light must travel through the water column to the disk and be reflected to the eye of the observer, therefore, twice Secchi depth provides an estimate of the attenuation point of light usable for photosynthesis (Lind, 1979). Comparison of light extinction coefficients determined with a quantum sensor to Secchi depth measurements correlate in Lake Taylorville ($n = 10$, $(r) = .88$, $p < 0.05$). Therefore, Secchi depth measurements in Lake Taylorville accurately portray the light regime. Mean Secchi depth for all sites, all year in lake Taylorville was 32 cm with a range of 8 cm to 69 cm. Comparison with Ambient Lakes data for other lakes in central Illinois finds Lake Taylorville to have below average light penetration as measured by Secchi depth (IEPA, 1979).

Reservoir Trophic State

Trophic State Index

A discrepancy between TSI indicators suggests that phytoplankton are not maximizing utilization of available nutrients. TSI_{sd} and TSI_{tp} for Lake Taylorville indicate hypereutrophy while TSI_{chl} indicates only mesotrophy to mild eutrophy (Figs. 7, 8, 9). An analysis of variance (ANOVA) ($F_{calc} = 12.4$, $df = 2$) found that TSI_{sd} and TSI_{tp} were not significantly different ($p > 0.05$) but both are greater than TSI_{chl} (TSI_{sd}, $p < 0.05$; TSI_{tp}, $p < 0.05$). Since phosphorus has been found to be the limiting nutrient in Lake Taylorville, it is obvious that another factor, probably light availability, is limiting phytoplankton productivity rather than nutrients. Light attenuation is apparently due to tripton and inorganic suspended solids concentrations rather than phytoplankton population. Therefore, TSI_{chl} can be regarded as the indicator of current trophic state and TSI_{tp} can be regarded as an indicator of potential trophic state.

Figure 7. Carlson's Trophic State Indeces (TSI) for chlorophyll a (CHLa), total phosphorus (TP) and Secchi depth (SD) at DAM site.

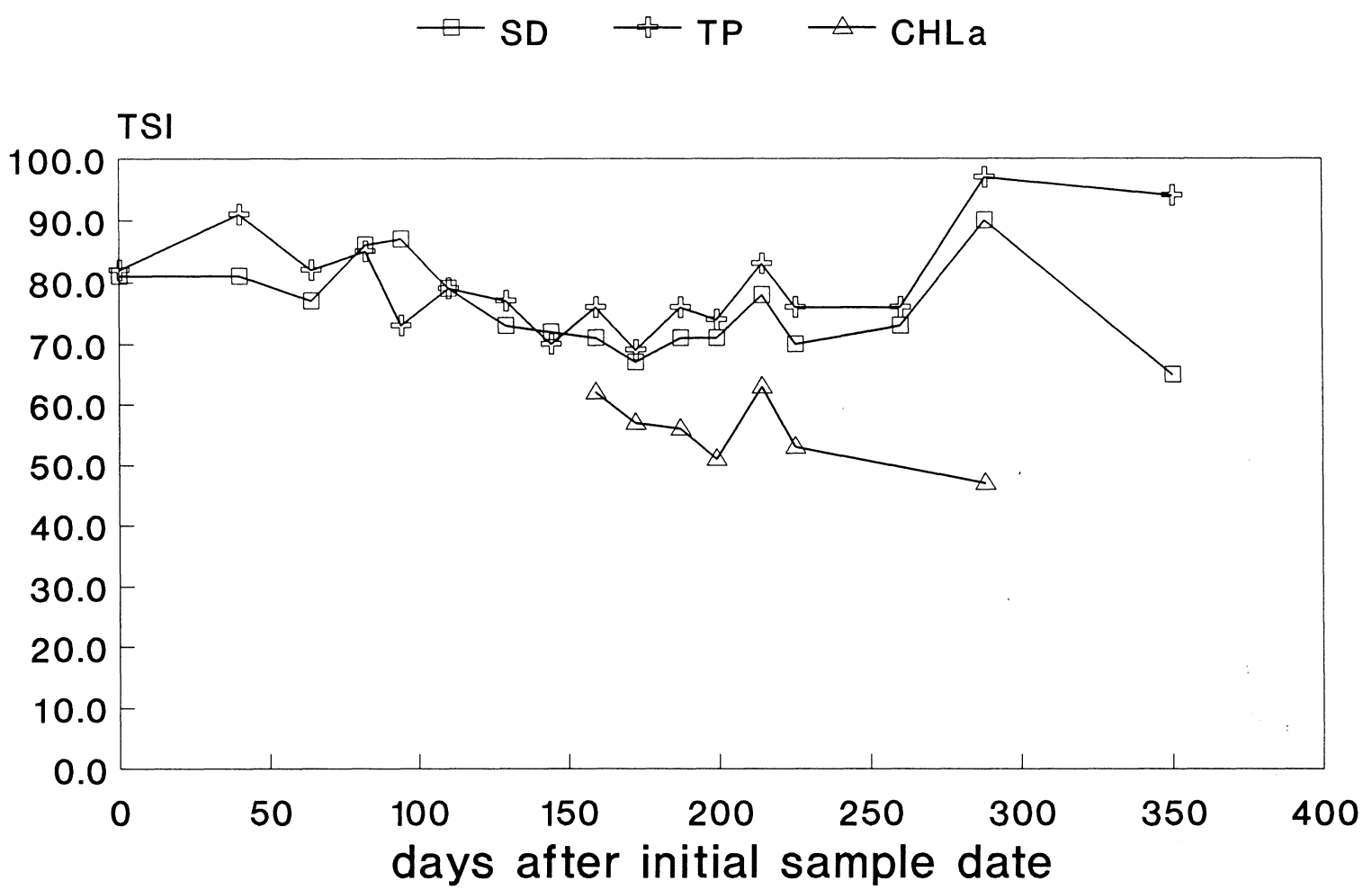

SD
TP
CHLa
TSI
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
50
100
150
200
250
300
350
400
days after initial sample date

Figure 8. Carlson's Trophic State Indeces (TSI) for chlorophyll a (CHLa), total phosphorus (TP) and Secchi depth (SD) at MIDLAKE site.

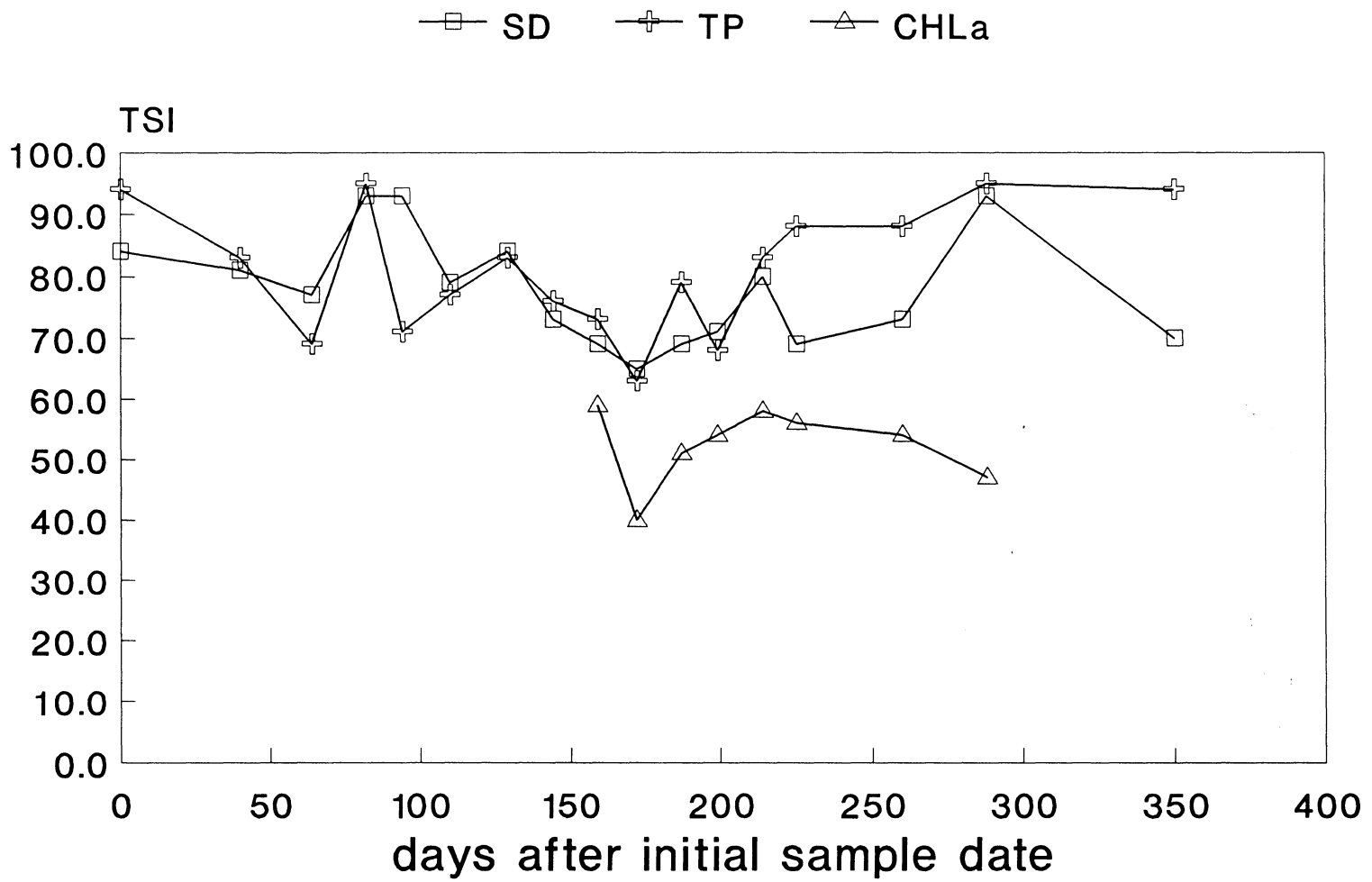
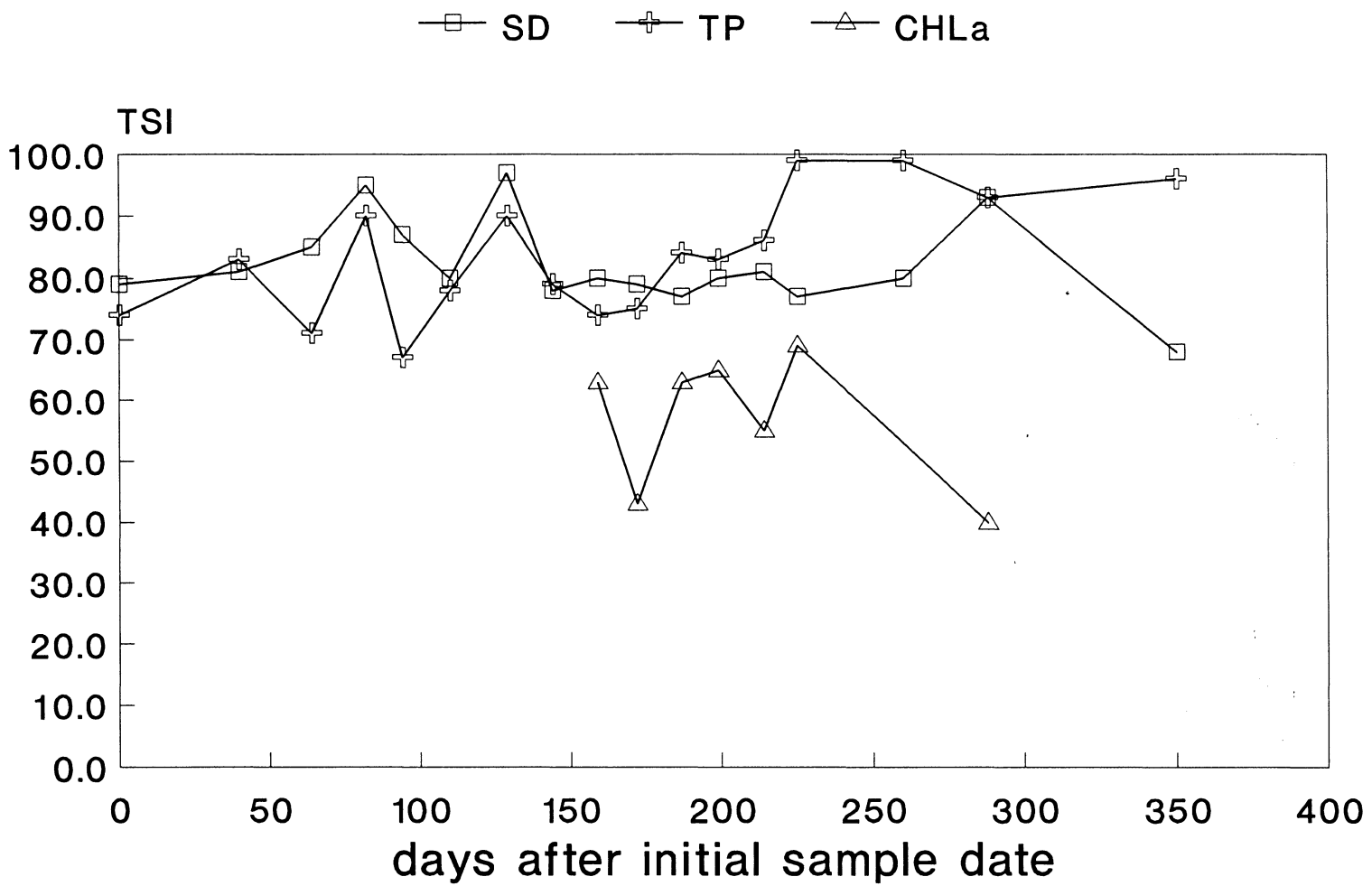

SD
TP
CHLa
TSI
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
50
100
150
200
250
300
350
400
days after initial sample date

Figure 9. Carlson's Trophic State Indeces (TSI) for chlorophyll a (CHLa), total phosphorus (TP) and Secchi depth (SD) at INFLOW site.

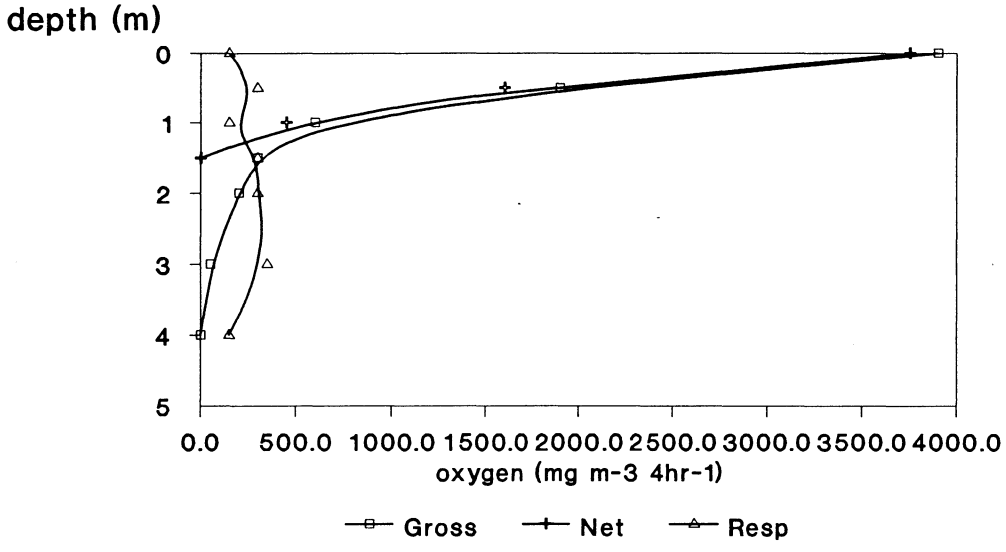

SD
TP
CHLa
TSI
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
50
100
150
200
250
300
350
400
days after initial sample date

Phytoplankton

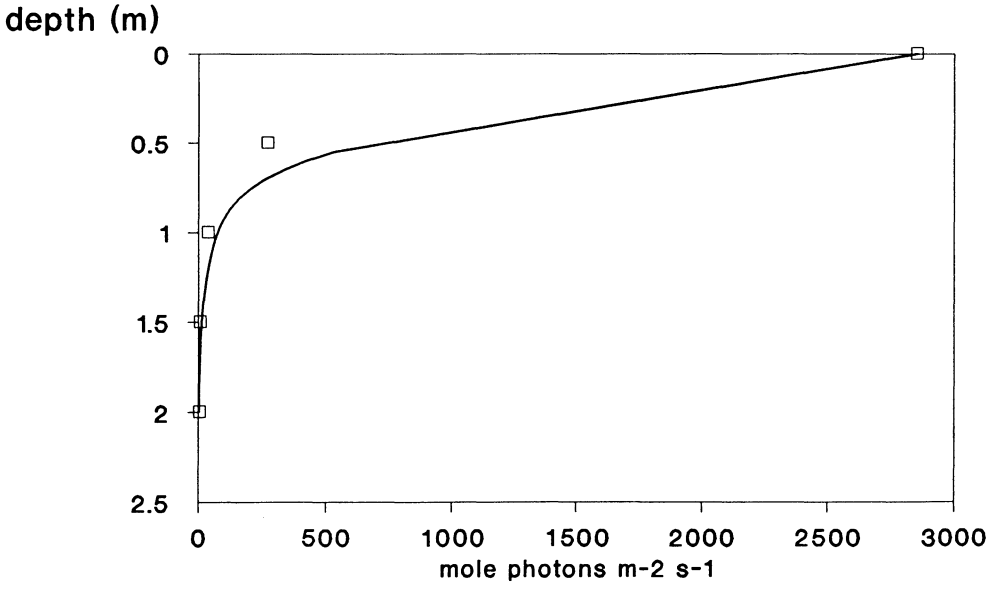
Primary productivity is defined as the rate at which inorganic carbon is converted to organic carbon by the process of photosynthesis. Productivity (mg C fixed $m^{-2} hr^{-1}$) in Lake Taylorville did not correlate ($n = 6$, $(r) = -0.54$ $p > 0.05$) with dissolved phosphorus as would be expected in a phosphorus limited system but productivity did correlate ($n = 6$, $(r) = 0.943$, $p < 0.05$) with Secchi depth. Comparison of a net primary productivity curve with a light extinction curve for the same date (930918 for instance) illustrates that net productivity follows light availability (Fig. 10). Chlorophyll a, a measure of biomass of the phytoplankton, also did not correlate with dissolved phosphorus ($n = 14$, $(r) = -0.015$, $p > 0.05$) but did not correlate with Secchi depth either ($n = 15$, $(r) = -0.239$, $p > 0.05$). Total algal density determined by sample count correlated with surface nutrients (dissolved phosphate; $n = 16$, $(r) = -0.518$, $p < 0.05$ and nitrate; $n = 17$, $(r) = -0.749$, $p < 0.05$) but the relationship is negative indicating that as algal density increases, more nutrients are taken out of solution. Correlation analysis comparing total algal density to Secchi depth ($n = 17$, $(r) = 0.532$, $p < 0.05$) shows a positive relationship with an

Figure 10. Gross, and net primary productivity and respiration (mg O_2 m^{-3} $4hr^{-1}$) (top); and light extinction (mole photons m^{-2} s^{-1}) (bottom) for DAM site, sample date 930918, at Secchi depth 0.5 m.

Productivity



Light



increase in Secchi depth corresponding with an increase in total algal density. Thus, phytoplankton productivity, biomass and density are shown to be light limited rather than nutrient limited in Lake Taylorville.

Reservoir Function

Measurements of the interactions of chemical, physical and biological parameters of a reservoir can be used to characterize that reservoir along its longitudinal axis (Thornton, Kimmel and Payne, 1990). Each zone (riverine, transitional and lacustrine) in a normally functioning reservoir should have distinct characteristics that separate it from the other zones. An ANOVA found no significant differences between sites for nutrients, chlorophyll, conductivity, total suspended solids, pH or dissolved oxygen but significant site differences were found for total solids, total dissolved solids, temperature and Secchi depth (Table 4). Total solids and total dissolved solids are higher at the INFLOW site than at the DAM site although INFLOW and MIDLAKE were not different and MIDLAKE and DAM were not different. Light penetration measured by Secchi disk was less at the INFLOW site than at the MIDLAKE and

Table 4. Analysis of variance (ANOVA) for all parameters comparing DAM (D) site, MIDLAKE (M) site and INFLOW (I) site. Significant differences are at $p < 0.05$.

Parameter	F_{calc}	n	differences
total solids	14.24	54	I > M > D
suspended solids	2.98	54	none
dissolved solids	4.27	54	I > M = D
dissolved oxygen	2.20	55	none
Secchi depth	12.94	55	I > M = D
conductivity	0.54	53	none
pH	0.32	48	none
temperature	6.73	54	I > M > D
alkalinity	0.22	45	none
nitrates	1.57	51	none
total phosphorus	1.56	48	none
dissolved phosphorus	0.25	50	none
chlorophyll a	2.55	24	none
trophic state indeces	1.15	135	none

DAM sites. Temperature was lower at the DAM site than at the INFLOW or at MIDLAKE perhaps due to greater depth and volume of water at that site. Thornton, Kimmel and Payne (1990) assert that in a high flow reservoir, the lacustrine zone will be eliminated and the transitional zone will be expanded to the dam and this is what appears to have occurred in Lake Taylorville.

Precipitation was exceptional for 1993 (the third highest on record) and the assumption may be made that increased rainfall would increase the flow of the reservoir and produce the noted effect of the elimination of a lacustrine zone. However, rainfall data (Wendland, 1993) compared with all other parameters shows little correlation with water quality (Table 5). Cooke, et al (1993) state that rainfall events have a significant effect on lakes but not on rivers. The lack of significant effect of rainfall on water quality parameters in Lake Taylorville suggests that the reservoir functions more like a river than a lake and that the increased rainfall of 1993 did not cause the elimination of a lacustrine zone.

Table 5. Statistical analysis comparing precipitation for 7 days prior to sample dates with water quality parameters at DAM site (n = number of samples, (r) = correlation coefficient, correlations that are significant ($p < 0.05$) are followed by a y.

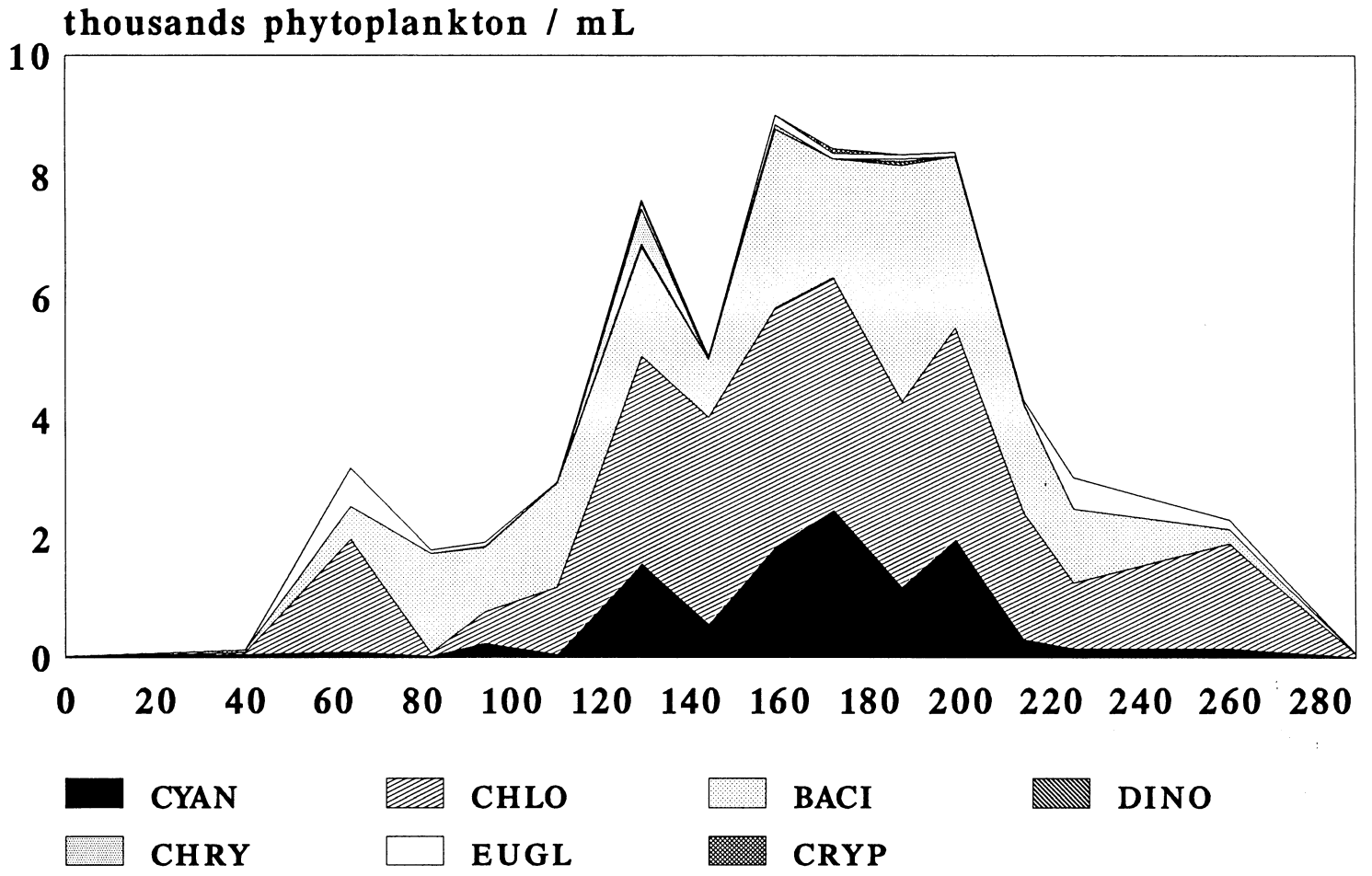
water quality parameter	n	(r)	
total solids	14	-0.099	
suspended solids	14	-0.132	
dissolved solids	14	-0.020	
nitrate	14	-0.572	y
total phosphate	14	-0.103	
dissolved phosphate	14	-0.376	
alkalinity	12	0.389	
dissolved oxygen	14	-0.390	y
conductivity	14	0.336	
secchi depth	14	0.502	
chlorophyll a	12	-0.112	

Future Management Considerations

Larger wetlands and sediment basins function primarily as a hydrologic buffer providing limited nutrient reduction and significant sediment reduction as well as providing ancillary benefits such as recreation (wildlife and fishery), education, and aesthetic improvement (U.S. EPA, 1993). The wetlands and sediment basins being constructed on the tributaries to Lake Taylorville can be expected to reduce sediment and nutrient loading in the reservoir. Wetland mesocosm studies, however, have indicated that while nitrate concentrations may be greatly decreased, wetlands may have little effect on phosphate concentrations (Hammer, 1992). Lake Taylorville has a large supply of phosphorus in the sediment and phosphate concentrations can be expected to remain high regardless of the success of the restoration project. This study has shown that while Lake Taylorville is currently a mesotrophic or mildly eutrophic reservoir, given improved light penetration due to successful sediment reduction, the potential for hypereutrophy exists and is in fact probable.

Increased light penetration coupled with high phosphorus concentration likely will result in frequent algal blooms. Algal populations presently are dominated by Chlorophyceae and Bacillariophyceae (Fig. 11). An expected reduction of nitrogen concentrations (Hammer, 1992) may well result in a nitrate limited nutrient regime that in turn would be expected to cause a shift in algal dominance to the Cyanophyceae. Cyanophycean algae do not provide a suitable energy source for zooplankters (Wetzel, 1975) and this interrupts the food web within the reservoir. Cyanophycean algae are also known to cause taste and odor problems in drinking water (APHA, 1985). Future management options may need to address the problem of nuisance algal blooms.

Figure 11. Total algal units (mL-1) separated to the class level, Cyanophyceae (CYAN), Chlorophyceae (CHLO), Bacilariophyceae (BACI), Dinophyceae (DINO), Chrysophyceae (CHRY), Euglenophyceae (EUGL), and Cryptophyceae (CRYP) for DAM site, sample dates from 0 to 280 days after the initial sample date.


thousands phytoplankton / mL
10
8
6
4
2
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280
CYAN
CHLO
BACI
DINO
CHRY
EUGL
CRYP

SUMMARY

Lake Taylorville is a high flow reservoir with a large watershed in relation to its surface area and that watershed is largely agricultural with row crop farming dominating. This combination results in a rapidly degrading water supply for the City of Taylorville. A large scale restoration project has been initiated that will route most of the tributaries to the reservoir through wetlands, holding ponds or sediment basins. The main focus of this restoration attempt is to reduce the rapid accumulation of sediments in the reservoir as well as reduce nutrient loading.

In Lake Taylorville, primary productivity is limited by the availability of light to less than a meter at the surface. During this year long study, the average Secchi depth at the DAM site was only 37 cm which translates to a photic zone of less than a meter. Nutrient concentration is very high, however, with phosphorus concentrations reaching levels associated with hypereutrophic waters. Trophic state as indexed for Lake Taylorville determined with chlorophyll a concentration is mesotrophic to mildly eutrophic but if successful reduction of suspended solids is achieved by the restoration efforts, the increased light penetration will almost

certainly result in increased algal productivity probably to the point of nuisance blooms - a problem which future management efforts may need to address.

Wetlands have been found to be effective at binding and stabilizing sediments and are effective denitrifiers although somewhat less effective at reducing phosphate concentration (Hammer, 1992). This combination of reduction of sediments and nitrates coupled with the high in-lake phosphorus levels could cause a shift in algal community structure from a currently Chlorophyceaen dominated community to a community dominated by Cyanopyceae.

The use of constructed wetlands as hydrologic buffers has been widely suggested but rarely does the opportunity exist to test their beneficial effects on such a large scale project. The main focus of the restoration of Lake Taylorville is to improve the water quality and maintain the storage capacity of the reservoir by the reduction of suspended solids and nutrient loads, however, the construction of wetlands may have many other benefits to future citizens of Taylorville. Wetlands have been found to be effective as biochemical sinks, trapping a variety of substances (pesticides,

herbicides, heavy metals) and immobilizing them in the bottom sediments (Hammer, 1992; U.S.EPA, 1993). Wetlands increase habitat area for a wide variety of plant and animal species and offer both aesthetic and educational value. It is hoped that this restoration effort will prove successful and that this study has provided sound data for evaluation of the project and planning of future management strategies.

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APPENDIX

Table 6. Total algal units (mL-1) for 18 sample dates by class; Cyanophyceae (CYN), Chlorophyceae (CHL), Bacilariophyceae (BAC), Dinophyceae (DIN), Chrysophyceae (CHR), Euglenophyceae (EUG) and Cryptophyceae (CRY).

date	CYA	CHL	BAC	DIN	CHR	EUG	CRY	total
930205	0	0	21	0	0	0	0	21
930317	49	45	38	0	0	0	0	133
930410	98	1892	552	0	0	649	0	3191
930428	17	66	1676	0	0	61	0	1816
930510	251	524	1075	11	17	63	6	1941
930523	47	1152	1739	0	0	17	0	3003
930614	1548	3464	1781	56	580	112	35	7591
930629	576	3464	964	0	0	29	6	5035
930714	1878	3966	2933	12	63	161	0	9218
930723	2486	3848	1962	0	0	87	77	8443
930811	1208	3094	3883	63	49	63	0	8310
930823	1997	3527	2811	0	0	70	0	8380
930910	314	2109	1830	12	0	52	6	4316
930918	157	1117	1236	0	0	524	0	3024
931023	161	1767	230	0	0	161	0	2311
931120	0	63	7	0	0	0	0	70
940121	0	0	0	0	0	0	0	0
940211	0	0	0	0	0	0	0	0

Table 7. Secchi depth (cm) at DAM, MIDLAKE and INFLOW sites for all dates.

date	DAM	MIDLAKE	INFLOW
930205	23	19	27
930317	23	24	23
930410	32	32	18
930428	17	10	9
930510	15	10	15
930526	27	27	25
930614	41	19	8
930629	43	41	28
930714	47	55	25
930727	60	61	27
930811	46	53	30
930823	48	47	27
930907	28	25	23
930918	51	52	30
931023	39	39	25
931120	13	10	10
940121	69	51	58
940211	15	17	13

Table 8. Light extinction coefficients from submarine photometer readings of PAR at DAM site.

date	extinction coefficient
930205	6.66
930428	5.13
930510	5.26
930526	4.55
930614	3.43
930714	3.03
930811	3.64
930918	3.83
931023	3.84
931120	8.08

Table 9. pH at DAM site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m	2.0m	3.0m	4.0m	5.0m
930205	6.5	6.6	6.4	6.3	6.6	6.8	6.8	6.5
930317	6.4	6.4	6.4	6.4	6.3	6.4	6.4	6.3
930410	6.8	6.6	6.4	6.8	6.8	6.9	6.8	6.8
930428	6.7	6.2	6.4	6.2	6.3	6.3	6.4	6.3
930510	6.5	6.2	6.2	6.2	6.3	6.3	6.3	6.3
930526	6	6.3	6.3	6.5	6.4	6.4	6.4	6.3
930614	6.9	6.5	6.7	6.5	6.5	6.4	6.3	6
930629	6.3	6.4	6.4	6.4	6.4	6.5	6.5	6.5
930714	6.3	6.4	6.4	6.4	6.5	6.5	6.4	6.4
930727	6.4	6.5	6.6	6.6	6.5	6.5	6.5	6.5
930811	6.4	6.5	6.5	6.4	6.5	6.5	6.5	6.5
930823	6.5	6.6	6.6	6.7	6.7	6.6	6.7	6.7
930907	6.8	6.6	6.8	6.6	6.6	6.6	6.6	6.7
930918	6.9	6.4	6.3	6.4	6.4	6.4	6.4	6.4
931023								
931120								
940121	6.8							6.9
940211	6.7							6.7

Table 10. pH at MIDLAKE site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m	2.0m	bottom
930205	7	7.1	7	7	6.9	7
930317	6.7	6.6	6.7	6.7	6.8	
930410	6.9	6.7	6.8	6.9	6.8	6.8
930428	6.4	6.4	6.4	6.4	6.4	6.4
930510	6.2	6.4	6.3	6.2	6.3	6.3
930526	7.3	7	6.7	6.7	6.7	6.7
930614	6	6.3	6.3	6.6	6.3	6.3
930629	6.4	6.4	6.5	6.5	6.5	6.5
930714	6.4	6.5	6.5	6.5	6.5	6.5
930727	6.6	6.5	6.5	6.5	6.6	6.6
930811	6.5	6.6	6.6	6.6	6.5	6.5
930823	6.9	6.6	6.6	6.7	6.7	6.7
930907	6.9	6.8	6.8	6.8	6.8	6.7
930918	6.2	6.3	6.3	6.4	6.4	6.4
931023						
931120						
940121	7					6.9
940211	6.6					6.6

Table 11. pH at INFLOW site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m
930205	7.1	7.2	7.4	7.4
930317	6.4	6.5	6.4	6.4
930410	6.9	6.9	6.9	6.9
930428	6.5	6.4	6.4	6.3
930510	6.2	6.2	6.3	6.3
930526	7.5	7.7	7.5	7.2
930614	6.5	6.4	6.4	6.4
930629	6.4	6.5	6.5	6.5
930714	6.5	6.5	6.5	6.4
930727	6.5	6.5	6.5	6.6
930811	6.7	6.5	6.6	6.6
930823	6.6	6.6	6.7	6.7
930907	6.8	6.7	6.7	6.7
930918	6.2	6.3	6	6
931023				
931120				
940121	6.9			6.8
940211	6.5			6.5

Table 12. Conductivity (umho's cm^{-1}) at DAM site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m	2.0m	3.0m	4.0m	5.0m
930205	225	245	245	295	295	295	295	290
930317	250	250	260	250	250	250	250	250
930410	380	380	360	360	360	360	360	360
930428	420	400	400	400	400	400	400	400
930510	460	420	380	380	380	370	360	360
930526	450	460	460	460	460	420	380	380
930614	510	510	500	480	500	460	460	480
930629	480	460	460	460	460	440	440	440
930714	480	480	470	460	460	460	460	460
930727	490	470	450	470	460	460	460	460
930811	420	420	420	430	420	420	420	420
930823	420	420	410	410	420	420	410	410
930907	320	320	310	320	320	320	320	320
930918	280	280	280	280	280	280	280	270
931023	420	420	400	400	410	410	400	400
931120	300	290	300	300	300	300	300	300
940121	430							430
940211	240							240

Table 13. Conductivity (umho's cm^{-1}) at MIDLAKE site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m	2.0m	bottom
930205	265	265	265	265	265	280
930317	310	310	300	310	310	310
930410	420	380	380	400	400	400
930428	340	320	320	300	300	300
930510	420	420	400	400	400	380
930526	440	480	500	500	440	440
930614	450	450	460	460	480	465
930629	470	480	500	500	500	520
930714	480	470	460	460	460	460
930727	480	470	460	460	460	450
930811	430	400	420	420	420	420
930823	430	430	420	400	400	410
930907	280	280	270	270	260	270
930918	280	280	280	270	270	260
931023	430	420	420	420	420	420
931120	320					
940121	440					470
940211	240					270

Table 14. Conductivity (umho's cm^{-1}) at INFLOW site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m
930205	405	400	410	410
930317	390	390	390	390
930410	540	520	580	580
930428	320	320	320	340
930510	500	500	500	480
930526	480	480	500	440
930614	350	350	350	340
930629	500	500	520	480
930714	520	500	500	500
930727	360	350	350	350
930811	340	340	360	360
930823	390	400	400	390
930907	260	250	250	270
930918	320	320	320	320
931023	400	400	400	380
931120				
940121	490			560
940211	350			280

Table 15. Temperature (∘C) at DAM site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m	2.0m	3.0m	4.0m	5.0m
930205	3	2	2	2	2	2	2	2
930317	1	1	1	2	2	2	2	2
930410	11	11	11	11	10	11	11	11
930428	12	15	15	15	15	15	15	15
930510	21	21	21	21	21	20	20	20
930526	20	20	19	19	19	19	19	19
930614	25	25	25	25	25	24	23	22
930629	27	27	27	27	27	27	27	27
930714	28	27	27	27	27	27	27	27
930727	28	28	28	28	28	27	27	27
930811	27	26	26	26	26	26	26	26
930823	27	27	27	27	27	27	27	27
930907	23	23	23	23	23	23	23	23
930918	18	18	18	18	18	18	18	18
931023	14	14	14	14	14	14	14	14
931120	7	7	7	7	7	7	7	7
940121	1	1	2	2	2	3	4	4
940211	1	2	2	2	2	2	2	2

Table 16. Temperature (°C) at MIDLAKE site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m	2.0m	bottom
930205	3	2	2	2	2	2
930317	2	2	2	2	2	2
930410	12	12	12	12	11	11
930428	17	15	15	15	15	15
930510	22	21	21	21	21	21
930526	24	21	20	20	20	19
930614	25	25	25	24	23	23
930629	27	27	27	26	26	26
930714	28	28	28	28	28	28
930727	29	28	28	28	28	27
930811	28	28	28	27	26	26
930823	28	28	28	27	27	27
930907	23	23	23	23	23	23
930918	19	18	18	18	18	16
931023	14	14	13	13	13	13
931120	7	7	7	6	6	6
940121	1	1	2	2	3	3
940211	1	2	2	3	3	3

Table 17. Temperature (oC) at INFLOW site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m
930205	3	3	3	3
930317	2	2	2	2
930410	14	14	13	13
930428	17	17	15	15
930510	23	23	23	22
930526	25	24	20	20
930614	26	25	24	22
930629	29	27	27	26
930714	29	29	28	28
930727	31	30	28	27
930811	28	28	27	26
930823	28	28	27	27
930907	22	22	22	21
930918	18	17	17	17
931023	13	13	13	12
931120	6	6	6	6
940121	1	2	2	2
940211	1	2	2	2

Table 18. Dissolved oxygen (mg L^{-1}) for DAM site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m	2.0m	3.0m	4.0m	5.0m
930205	9.7	9.8	9.8	9.8	9.8	9.5	9.2	9.7
930317	12.6	12.5	12.6	12.7	12.6	12.5	12.9	12.6
930410	10	10	10	10	9.8	9.4	9.8	9.2
930428	8.1	7.7	7.7	7.7	7.8	7.7	7.7	7.8
930510	7.2	7	7.2	6.8	7.1	7	6.9	6.6
930526	8	7.7	7.5	6.9	6.8	6.8	7	6.9
930614	10.4	10.2	10	9.3	8.5	5.6	4.5	2.2
930629	6.9	6.8	6.8	6.2	5.5	5.2	4.8	4.8
930714	6.7	6.7	6.8	6.2	5.4	6.4	5.5	5.1
930727	9.7	9.5	9.4	9.4	6.9	5.2	2.9	1.9
930811	7.2	6.7	5.8	4.3	4.6	4.6	4.4	3.6
930823	6.1	5.7	5.6	5.4	5.3	5.3	5.2	5.1
930907	2	1.8	1.7	1.5	1.5	1.5	1.6	1.7
930918	2.3	2.4	1.9	1.9	1.8	1.6	1.7	1.7
931023	9.2	8.6	8.4	8.2	8.2	8.1	8	7.9
931120	8.6	8.4	8	7.9	7.9	8	8	7.8
940121	7.8							5.1
940211	8.7							7.8

Table 19. Dissolved oxygen (mg L^{-1}) for MIDLAKE site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m	2.0m	bottom
930205	10.3	10.6	10	10.7	10.4	10.4
930317	13.1	13.2	13.4	13.1	13	13
930410	10.2	10.2	10.2	10	9.9	9.8
930428	6.9	6.9	6.6	6.5	6.6	6.6
930510	7.3	6.9	6.8	6.8	6.6	6.2
930526	11.4	10	8.7	8.3	8.2	7.6
930614	7.2	7.2	6.5	5.2	4.4	3.8
930629	7.4	6.6	6.1	6	5.4	5
930714	8.1	7.9	6.9	5.6	5	4.6
930727	10.2	8.6	7.9	7.3	5.6	1.9
930811	10.3	10.3	10.3	9.4	6.2	2.7
930823	6.1	5.4	4.9	4.3	4.2	4.2
930907	3.9	3.5	3.3	3.3	3.2	3
930918	5.4	5.6	5.3	5	4.8	1.1
931023	8.1	7.3	6.9	6.7	6.7	6.5
931120	8.6	9	8.9	8.9	8.9	8.9
940121	8.5					7.5
940211	7.2					4.8

Table 20. Dissolved oxygen (mg L^{-1}) for INFLOW site at discrete depths.

date	0.0m	0.5m	1.0m	1.5m
930205	12.3	12.3	12.2	12.2
930317	13.1	12.2	13.3	13.1
930410	9.8	10	9.8	9.2
930428	7.1	6.8	6.7	6.5
930510	7.8	7.6	7.4	7.3
930526	16.2	16.8	15	9.4
930614	4.8	4.3	3.6	1.5
930629	8.9	7.7	5.8	4.4
930714	9.6	8.1	5.8	4.6
930727	8.7	7.9	5	1.4
930811	11.1	10.8	7.6	6.6
930823	7	6.1	5.1	4.2
930907	3.9	3.8	3.6	2
930918	4.4	3.9	3.9	3.7
931023	7.1	6.6	6.5	5.9
931120	9.9	9.8	9.5	9.1
940121	12.6			14.3
940211	6.9			7.3

Table 21. Alkalinity (mg $CaCO_3$ L^{-1}) surface and bottom for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

date	D,surf.	D,bot.	M,surf.	M,bot.	I,surf.	I,bot.
930205	84.5	84.5	86.4	88.3	126.7	107.5
930317	86.4	96	56.6	72	76.8	86.4
930410	93.1	95	95	96	124.8	115.2
930428	106.6	100.8	108.5	110.4	104.6	110.4
930510	106.6	111.4	98.9	109.4	73	76.8
930526	105.6	111.4	112.3	114.3	126.7	129.6
930614	113.3	112.3	113.3	112.3	127.7	130.6
930629	121	122.9	122.9	123.8	93.1	95
930714	117.1	119	113.3	113.3	88.3	90.2
930727	112.3	112.3	113.8	121.4	120	121
930811	98.9	101.8	81.6	83.5	73.9	88.3
930823	113.3	105.6	104.6	97	97	95
930907	115.2	113.3	121	121	111.4	112.3
930918	84.5	85.4	79.7	84.5	87.4	86.4
931023	139.2	143	144	147.8	145	146.9

Table 22. Nitrogen (NO_3-N mg L^{-1}) surface and bottom for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

date	D,surf.	D,bot.	M,surf.	M,bot.	I,surf.	I,bot.
930205	6.9	6.2	6.6	7.4	10.6	12.6
930317	4.9	4.6	4.5	5.1	3.9	3.8
930410	9.8	11.8	8.4	6.8	8	8.2
930428	7.6	6.9	4.3	2.5	3	3.5
930510	4.5	4.7	4	4.7	6	5.4
930526	5.4	5.1	4.9	4.6	3.1	2.6
930614	4.5	4.3	5.3	4.2	6.7	6.2
930629	3.1	2.6	2.9	2.8	2.6	3
930714	2.2	2.1	2.2	2.2	1.2	1.3
930727	1.1	1.1	0.9	0.8	0.9	1.1
930811	0.6	0.8	0.6	0.7	0.6	0.6
930823	0.2	0.2	0.1	0.2	0.2	0.1
930907	0.7	0.6	1.2	1.1	1.4	1.7
930918	1.9	1.7	1.4	1	2.3	2.7
931023	3.6	4	4	3.8	3.8	3.7
931120	5.3	5.6	4.9	4.6	3.9	5.2
940121	12.9	7.6	5.6	6.3	6.6	6.2

Table 23. Total phosphorus (PO_4-P mg L^{-1}) surface and bottom for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

date	D,surf.	D,bot.	M,surf.	M,bot.	I,surf.	I,bot.
930205	0.215	0.326	0.516	0.449	0.131	0.229
930317	0.409	0.327	0.232	0.309	0.236	0.185
930410	0.224	0.106	0.088	0.197	0.106	0.075
930428	0.273	0.265	0.542	0.454	0.384	0.542
930510	0.121	0.112	0.109	0.107	0.079	0.062
930526	0.18	0.221	0.158	0.163	0.163	0.134
930614	0.155	0.195	0.241	0.278	0.393	0.647
930629	0.099	0.287	0.147	0.124	0.174	0.144
930714	0.144	0.106	0.119	0.088	0.122	0.099
930727	0.092	0.092	0.058	0.077	0.131	0.131
930811	0.146	0.202	0.173	0.167	0.247	0.284
930823	0.129	0.203	0.084	0.185	0.234	0.203
930907	0.23	0.198	0.238	0.271	0.282	0.198
930918	0.221	0.278	0.235	0.241	0.287	0.33
931023	0.145	0.156	0.33	0.271	0.704	0.438
931120	0.039	0.028	0.028	0.021	0.024	0.021

Table 24. Dissolved phosphorus (PO_4-P mg L^{-1}) surface and bottom for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

date	D,surf.	D,bot.	M,surf.	M,bot.	I,surf.	I,bot.
930205	0.326	0.399	0.307	0.317	0.165	0.145
930317	0.243	0.264	0.223	0.185	0.131	0.131
930410	0.119	0.088	0.082	0.077	0.022	0.029
930428	0.12	0.12	0.172	0.184	0.167	0.153
930510	0.102	0.116	0.088	0.088	0.053	0.053
930526	0.126	0.112	0.091	0.078	0.028	0.017
930614	0.08	0.131	0.114	0.134	0.224	0.205
930629	0.045	0.105	0.103	0.069	0.045	0.063
930714	0.054	0.069	0.052	0.08	0.052	0.052
930727	0.021	0.096	0.058	0.048	0.067	0.103
930811	0.094	0.121	0.072	0.098	0.094	0.117
930823	0.105	0.1	0.058	0.141		0.181
930907	0.115	0.163	0.168	0.163	0.157	0.154
930918	0.202	0.233	0.178	0.161	0.271	0.249
931023	0.088	0.063	0.202	0.255	0.391	0.359
931120	0.029	0.019	0.017	0.019	0.016	0.016
940121	0.3		0.426		0.259	

Table 25. Total solids (mg L^{-1}) surface and bottom for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

date	D,surf.	D,bot.	M,surf.	M,bot.	I,surf.	I,bot.
930205	158.5	151.3	163.4	207.4	263.4	285.3
930317	273.3	261.1	397.7	385.3	327	324.5
930410	319.6	341.6	368.4	363.6	449	507.5
930428	410	392.5	477.5	490	507.5	505
930510	372.5	362.5	345	392.5	385	422.5
930526	324.5	295.2	309.9	317.2	351.4	341.6
930614	337.5	377.5	350	355	390	552.5
930629	345	370	375	392.5	420	450
930714	325	317.5	320	322.5	370	395
930727	212.5	232.5	212.5	207.5	187.5	242.5
930811	332.5	382.5	375	420	355	425
930823	167.5	155	155	167.5	195	205
930907	242.5	255	200	242.5	247.5	335
930918	170	217.5	187.5	185	262.5	317.5
931023	252.5	270	282.5	307.5	305	310
931120	350	357.5	370	362.5	352.5	367.5
940121	340	342.5	340	347.5	382.5	430

Table 26. Dissolved solids (mg L^{-1}) surface and bottom for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

date	D,surf.	D,bot.	M,surf.	M,bot.	I,surf.	I,bot.
930205	97.5	92.8	104.9	148.9	219.5	251.1
930317	200.1	197.7	329.4	322.1	248.9	236.7
930410	278.1	302.6	324.5	322.1	385.6	414.8
930428	340	330	327.5	322.5	302.5	370
930510	310	300	297.5	305	327.5	332.5
930526	270.8	268.4	244	261	253.8	251.3
930614	327.5	330	305	270	277.5	312.5
930629	190	180	210	265	277.5	262.5
930714	305	302.5	292.5	285	317.5	322.5
930727	195	192.5	172.5	170	147.5	167.5
930811	195	247.5	240	260	252.5	240
930823	87.5	80	70	97.5	102.5	107.5
930907	120	157.5	117.5	120	135	175
930918	123.2	150.5	134.5	146	216	249.5
931023	235.5	245	261.5	274.5	261	261
931120	275	277.5	296	290.5	297.5	304.5
940121	329	330.5	328	324.5	357.5	407

Table 27. Suspended solids (mg L^{-1}) surface and bottom for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

date	D,surf.	D,bot.	M,surf.	M,bot.	I,surf.	I,bot.
930205	61	58.5	58.8	58.5	43.9	34.2
930317	73.2	63.4	68.3	73.2	78.1	87.8
930410	41.5	39	43.9	41.5	63.4	92.7
930428	70	62.5	150	167.5	205	135
930510	62.5	62.5	47.5	87.5	57.5	90
930526	53.7	26.8	65.9	56.1	97.6	90.3
930614	10	47.5	45	85	112.5	240
930629	155	190	165	127.6	142.5	190
930714	20	15	27.5	37.5	52.5	72.5
930727	17.5	40	40	37.5	40	75
930811	85	82	82.5	107.5	50	132.5
930823	80	75	85	70	92.5	97.5
930907	122.5	97.5	82.5	112.5	112.5	160
930918	46.8	67	53	39	46.5	68
931023	17	25	21	33	44	49
931120	75	80	74	72	55	63
940121	11	12	12	23	25	23

Table 28. Chlorophyll a (mg m^{-3}) surface, for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

date	D	M	I
930410	4.2		
930428	2.1		4.1
930510	76.4	72.3	100.8
930526	57.6	32.4	101.8
930614	86.3	113.4	188.8
930629	42.2	18.5	109.4
930714	24.9	17.8	26.7
930727	5.3	2.7	3.5
930811	13.4	8	26.7
930823	8	10.7	32
930907	26.7	16	21.4
930918	10.7	13.4	32
931023	0	10.68	0
931120	5.34	5.34	2.67

Table 29. Carlson's Trophic State Index for chlorophyll a (TSIchl), total phosphorus (TSItp) and Secchi depth (TSIsd) for DAM (D), MIDLAKE (M) and INFLOW (I) sites.

	TSIchl			TSItp			TSIsd		
date	D	M	I	D	M	I	D	M	I
930205				82	94	74	81	84	79
930317				91	83	83	81	81	81
930410	45			82	69	71	77	77	85
930428	38		44	85	95	90	86	93	95
930510	73	73	76	73	71	67	87	93	87
930526	70	65	76	79	77	78	79	79	80
930614	74	77	82	77	83	90	73	84	97
930629	67	59	77	70	76	79	72	73	78
930714	63	59	63	76	73	74	71	69	80
930727	47	40	43	69	63	75	67	65	79
930811	56	51	63	76	79	84	71	69	77
930823	51	54	65	74	68	83	71	71	80
930907	63	58	61	83	83	86	78	80	81
930918	53	56	65	76	88	99	70	69	77
931023	0	54	0	76	88	99	73	73	80
931120	47	47	40	97	95	93	90	93	93
940121				94	94	96	65	70	68