AN ABSTRACT OF THE THESIS OF

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Title: The Applicability of a Direct Phosphorus to Chlorophyll Relationship in Three Kansas Lakes

Abstract approved: David C Schroeder

Water samples were collected from three local lakes and analyzed to determine concentrations of phosphorus and chlorophyll. The data were examined to ascertain whether a direct relationship exists between these two quantities. A comparative analysis was made with reported results of similar studies by other researchers. Experimental results suggest that a relationship does exsist but that additional factors have substantial influence and need to be considered.

THE APPLICABILITY OF A DIRECT PHOSPHORUS TO CHLOROPHYLL RELATIONSHIP IN THREE KANSAS LAKES

A Thesis

Presented to

the Department of Chemistry

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Laurie S. A. Brown

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Approved for the Major Department

Approved for the Graduate Council

DIGGING

Seamus Heaney

Between my finger and my thumb
The squat pen rests; snug as a gun.

Under my window, a clean rasping sound
When the spade sinks into gravelly ground:
My father, digging. I look down

Till his straining rump amoung the flowerbeds
Bends low, comes up twenty years away
Stooping in rhythm through potato drills
Where he was digging.

The coarse boot nestled on the lug, the shaft
Against the inside knee was levered firmly.
He rooted out tall tops, buried the bright edge deep
To scatter new potatoes that we picked
Loving their cool hardness in our hands.

By God, the old man could handle a spade.
Just like his old man.

My grandfather cut more turf in a day
Than any other man on Toner's bog.
Once I carried him milk in a bottle
Corked sloppily with paper. He straightened up
To drink it, then fell to right away
Nicking and slicing neatly, heaving sods
Over his shoulder, going down and down
For the good turf. Digging.

The cold smell of potato mould, the squelch and slap
Of soggy peat, the curt cuts of an edge

Through living roots awaken in my head.
But I've no spade to follow men like them.

Between my finger and my thumb
The squat pen rests.
I'll dig with it.

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STATEMENT OF PROBLEM

A correlation between phosphorus concentrations and algal growth can be especially important in multi-purpose lakes due to fish kill problems associated with algal bloom and die-off. Aesthetic considerations are also important with recreational lakes due to unpleasant odors and appearances associated with blooms. Algal blooms can also cause problems with water quality when lake impoundments are used as water supplies.

The concentration of phosphorus was analyzed in near-by lakes throughout the algal growing season. Concentrations of dissolved phosphorus and total phosphorus was determined using ascorbic acid methodology of Standard Methods (Taras, et al.). The corresponding algal levels were monitored using a spectrophotometric method to determine chlorophyll a concentrations. Data collected were examined in order to determine whether a direct relationship exists between phosphorus concentrations and algal growth in near-by lakes.

LITERATURE SUMMARY

A major concern of any municipality is the maintenance of a continuous supply of water in adequate quantity and quality for its populace. Lake impoundments are common water sources because they provide a reserve to buffer against periodic demands for large quantities of water. However, these lakes are not sterile basins lying fallow until needed. They are thriving ecosystems with a myriad assortment of aquatic organisms. Microscopic aquatic life, especially algae, must be dealt with by water users when an algal bloom is stimulated. As the algae die the process of decomposition depletes the oxygen supply vital to fish survival. Resulting fish kills are unacceptable to people who use the lakes for recreational purposes. These lakes are also used as water supply sources for nearby towns; therefore, algal blooms can cause problems with water quality. The presence of algae in water imparts an objectionable taste and odor to treated water (Jackson, 1964). Additionally, algae tend to interfere with the mechanical operation of treatment plants by causing clogging throughout the treatment plant, particularly in the filtering system. The magnitude of the algal standing crop in a lake impoundment depends upon a wide variety of conditions. However, a major controlling condition of algal growth is the availability of nutrients for use by the various aquatic organisms of a lake system. The concentration of nutrients is the condition most affected by man and most easily controlled by him (Vallentyne, 1974).

Early methods which were utilized to predict when a particular impoundment might have problems with excessive algal growth was based on the trophic state of the impoundment. Three basic states are generally used: oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes are generally deep with a small surface area. Consequently, only a small portion of the lake receives enough light for photosynthesis. Additionally, these lakes contain prohibitatively low levels of vital nutrients. These lakes are the so called "trout lakes" which are noted for their very clear pure water and support only small quantities of aquatic life. Mesotrophic lakes either have a greater surface area in relation to their depth or greater abundance of nutrients. A greater surface area to depth ratio expands the photosynthetic zone, thus, providing a greater potential volume for algal habitat. Lakes of this type are considered moderately productive. Eutrophic lakes are generally very shallow with large surface areas. They are also rich in nutrients. This type of lake is capable of supporting abundant growth of aquatic plants and animals.

Three necessary constituents; nitrogen, carbon, and phosphorus must be present in a lake ecosystem in at least certain minimum quantities before algal growth can occur and in greater quantities to sustain growth. Carbon is readily available from the decomposition of plant material and from carbon dioxide absorption. It has been shown that lake systems tend to self adjust carbon concentration levels to optimum growth conditions (Schindler, 1977). Nitrogen is usually available from the air via nitrogen-fixing algae and aquatic plants. Consequently, phosphorus is usually the limiting nutrient to control algal growth in a lake.

Vollenweider (Bachmann, et al., 1976) proposed a model relating lake system phosphorus supplies to algal dynamics. His model is premised on the following assumptions:

1. The rate of supply of phosphorus, the flushing rate and the sedimentation rate are constant through time;
2. The lake is considered as a continuously stirred reactor system defined as a single-compartment, open system;

3. the concentration of phosphorus in the outflow is the same as the concentration in the lake;
4. Sedimentation of phosphorus is proportional to the phosphorus concentration in the lake.

Vollenweider's model suggests that lake systems exist in a steady state and the amount of available phosphorus can be quantified. Since phosphorus levels can be measured; one can attempt to establish a correlation between phosphorus levels and algal growth (Wetzel, 1975). Excess phosphorus stimulates algal bloom. Blue-green algae usually occur as a major component of these blooms and are major contributors to algal problems in lake impoundments. In order to study the relationship between nutrients and blue-green algal growth a technique to measure the quantity of algae must be devised. Measurement of algal quantities by counting each individual organism is unsatisfactory: (1) the organisms are microscopic; (2) it is difficult to obtain a representative sampling of organisms; (3) the number of organisms does not accurately represent concentration levels due to the wide range of organism sizes. An alternative method of quantifying algal concentrations involves the assessment of the photosynthetic pigment, chlorophyll.

A primary characteristic of blue-green and other common algae is the presence of photosynthetic pigments particularly the various chlorophylls; different species of algae utilize different forms or a combination of several chlorophylls. However, all oxygen-evolving algae contain chlorphyll a as their primary pigment (Wetzel, 1975). Chlorophyll a concentrations can be measured spectrophotometrically because it absorbs strongly in the red light region at 663 nm. The concentration of chlorophyll a pigment ([Chl a]) is directly related to absorbance by the equation (Taras, et. al., 1971):

$$[\text{Chl a/ppb}] = 2.86\ (\text{Absorbance}) \qquad (1)$$

Dillon (Dillon, et al., 1974) at the University of Toronto developed the relationship (covering a range of approximately 5-300 ppb P):

$$\log\ [\text{Chl a/ppb}] = 1.449 \log\ [\text{TP/ppb}] - 1.136 \qquad (2)$$

using the average summer concentration of chlorophyll and the spring total phosphorus concentration ([TP]) for some lakes in southern Ontario and in Connecticut and Minnesota. They concluded that the validity of Equation 2 depends upon the nitrogen to phosphorus mass ratio being 12 or above. Thus ensuring nitrogen levels in excess of algal minimum requirements; therefore, generating conditions such that phosphorus would indeed be the limiting nutrient controlling the algal standing crop.

Bachmann (Bachmann, et al., 1976) reported a method of predicting summer algae blooms based on summer total phosphorus levels in selected Iowa lakes. They based their work on Vollenweider's model which correlated the lake system's phosphorus supply to the to the algal growth rate. From a plot of log [P] vs. log [Chl a] Bachmann obtained the equation (for concentrations of approximately 5-300 ppb P):

$$\log [\mathrm{Chl}\ a/\mathrm{ppb}] = -1.09 + 1.46 \log [\mathrm{TP}/\mathrm{ppb}]. \quad (3)$$

Equation 3 does not deal with high turbidity levels. Turbidity reduces the algal population's access to light thereby curtailing growth and placing a limit upon the maximum possible standing crop although there may be more than sufficient nutrients available to support a greater crop.

Canfield (Canfield, et al., 1981) related total phosphorus concentration, chlorophyll a concentration, and turbidity. Turbidity was gauged as the limits of visual transparency using Secchi disc measurements rather than being chemically determined. The researchers compared total phosphorus and chlorophyll a data from EPA-NES lake studies to Bachmann's equation (Eqn. 3). The EPA lake study data seems to fit Equation 3 up to appoximately 400 ppb total phosphorus. Comparison of chlorophyll a to turbidity data as measured by Secchi disc depths also shows that increases in turbidity correspond to decreases in chlorophyll a.

SAMPLE COLLECTION

Three lakes were sampled for this study: Redmond Reservoir, Melvern Lake, and Pomona Lake. The Redmond outlet area is located 12 miles south and 20 miles east of Emporia. Redmond is a shallow lake with a mean depth of 1.5 meters and a volume of 57 cubic hectometers; it covers an area of 38 square kilometers. Water drains into the lake from the Neosho and Cottonwood rivers and their drainage basins. Cattle grazing along with cereal grain and soybean cultivation are the dominate uses of the land compromising Redmond's drainage basin. The municipality of Emporia is a major point source adding phosphorus to the lake impoundment.

Melvern Lake's outlet is 10 miles north and 25 miles east of Emporia. Melvern is both deeper, 6.8 meters and smaller in area, 28 square kilometers. The impoundment encompasses a volume of 190 cubic hectometers. Melvern is part of the Marais des Cygnes drainage basin. No substantial point sources can be identified within the watershed. Agricultural practices analogous to the utilization in the Redmond basin dominate land usage within the drainage basin.

The outlet of Pomona Lake is located 32 miles north and 18 miles east of Emporia. Similarly to Melvern, Pomona is relatively deep, 3.1 meters compared to its surface area of 16 square kilometers. A volume of 50 cubic hectometers is contained by the impoundment. This lake receives drainage from the upper portion of the Marais des Cygnes basin. Similar to the other two lakes land in the Pomona drainage basin is utilized for grazing and grain production. Phosphorus is accumlated from non-point sources as at Melvern.

One liter grab samples were collected at the outlet areas of the three lakes. Samples collected at the outlet areas were assumed to be well mixed and representative of the lake. After collection the samples were immediately placed in ice and transported to the laboratory for chlorophyll analysis with the analysis carried out as quickly as possible to avoid distortion of the results arising from sample deterioration. One milliliter of 1 % (weight/volume) mercuric chloride was added to each sample to aid in preservation of the phosphorus constituent. Two climatic conditions directly influenced the times when samples were taken: water temperature and precipitation. Sampling was not begun until after water temperatures were high enough to allow growth to occur. Due to dry conditions in the spring, this study was begun in the early summer, and samples were collected intermittently when there was sufficient rainfall to cause run-off.

ANALYTICAL PROCEDURE

Samples were analyzed for these components: chlorophyll a; dissolved phosphorus; and total phosphorus.

Chlorophyll a concentration ([Chl a]) was determined as quickly as possible after sample collection. To determine the chlorophyll a concentration, a 100 ml aliquot of lake water was filtered through a glass fiber filter paper by suction filtration. The filter paper and collected material were then macerrated in a 40 ml capacity Ten Broeck tissue grinder with a 90% (volume/volume) acetone-water solution. The slurry was then allowed to set overnight (18-24 hours) in a refrigerator at approximately 4^{o}C. Next, the slurry was refiltered by suction filtration. The filtrate was introduced into a volumetric flask and diluted to volume with 90% (volume/volume) acetone-water solution. Finally the solution was analyzed in a Bausch and Lomb Spectronic 600 spectrophotometer using 5 cm cells. Absorbances were recorded at 630, 645, and 663 nm.

Dissolved phosphorus concentration ([DP]) was determined using a second aliquot of the same sample. A suitable quantity of sample was filtered by suction filtration. Five volumetric flasks were each prepared with 10 ml of mixed reagent.* The contents of one flask was diluted to the mark with distilled water, a second with a standard solution of .15 ppm phosphorus, the final three with filtered sample water. The solutions were thoroughly mixed and allowed to stand for at least 15 minutes but not more than 2 hours. Absorbance at a wavelength of 710 nm was recorded using the Spectronic 600 with 5 cm cells.

Total phosphorus concentration ([TP]) data were obtained by introducing 50 ml of unfiltered sample into Erlenmeyer flasks, adding 0.4 g of ammonium peroxidisulfate and 5 ml of 4 N sulfuric acid. Duplicate samples, a standard, and a blank were boiled gently on a hot plate for 90 minutes. After cooling, the contents of each flask were brought to the methyl orange end point by addition of 3 N sodium hydroxide. They were then filtered with suction filtration and added to 50 ml volumetric flasks prepared as above with mixed reagent. Distilled water was added to bring the samples to volume and the samples were allowed to set for a time period of between 15 minutes and 2 hours. Spectrophotometric readings were taken at a wavelength of 710 nm with the Spectronic 600 and 5 cm cells.

* The mixed reagent consists of: 50 ml of 4 N sulfuric acid, 5 ml antimony potassium tartrate (1.097 g of antimony potassium tartrate in 500 ml of distilled water), 12 ml ammonium molybdate (20.0 g of ammonium molybdate tetrahydrate in 500 ml of distilled water), and 0.42 g of ascorbic acid dissolved in 33 ml of water; these proportions provide a sufficient quantity of mixed reagent for 10 analyses.

DISCUSSION

To facilitate comparisons between the experimental results (Tables 1 & 2) and published studies the experimental data was plotted as log of total phosphorus concentration ([TP]) versus log of chlorophyll a concentration ([Chl a]). When the data for all three lakes were considered collectively the scatter in the data precluded fitting a curve to the data (Figure 1). Consideration of the data from Melvern and Pomona Lakes without Redmond Reservoir data indicates that these two lakes are similar (Figure 2). A separate plot of Redmond Lake data (Figure 3) shows the marked difference between this lake and Melvern and Pomona Lakes.

Several circumstances combine to account for the difference between Redmond and the other two lakes. First, the extreme shallowness of the impoundment combined with a sizable surface area creates a system where there is an enormous amount of algal habitat. Second, the city of Emporia creates a considerable point source of phosphorous upstream from Redmond. This has two effects: the influx of phosphorus into the system is substantial and the total phosphorus loading of the lake is such that phosphorus probably is not a limiting reagent controlling algal growth. Third, the hydraulic residence time at Redmond is on the order of one tenth the residence time of the other two lakes. Low residence time indicates that an impoundment is subject to a rapid transport of water from the drainage basin through the impoundment and on into the downstream system.

At Redmond the combination of a low residence time with a high phosphorus loading greatly enhances the production of algal mass in the lake leading to frequent algal blooms. Considering the abundance of phosphorus and the vast algal habitat available at Redmond it is surprising that the magnitude of the impoundment biomass is not much greater. Apparently, some other factor provides an additional limitation upon the resident algal population. Specific identification of this control factor was outside the scope of this study, however, high turbidity levels is the most probable candidate. Incidental observation during sample collection that the water in Redmond generally appears muddier than the other two lakes lends credence to this suggestion.

As a further comparison with published literature the experimental total phosphorus data were inserted into Eqns. 2 and 3. Predictions for chlorophyll concentrations expected at given phosphorus concentrations were obtained. These predicted concentrations were plotted versus experimental total phosphorus concentrations on Figures 1, 2 and 3. The scatter in the experimental data forestalls either acceptance or rejection of these equations as accurate predictors of chlorophyll concentrations in the impoundments. However, the experimental data grouping on Figures 2 and 3 is sufficiently close to the lines described by Equations. 2 and 3 to suggest that either equation could be used to make a first approximation for the cholorophyll concentration in the impoundments of this study.

Next, the mean seasonal values for both chlorophyll and phosphorus concentration were calculated for Melvern and Pomona. These quantities were plotted on Figure 2 and a tentative line drawn. Then from published tabulations (Wetzel, 1975) a chlorophyll concentration of 10 ppb was selected as representative of a eutrophic system. On the tenative line this chlorophyll concentration corresponds to a phosphorus concentration of 40 ppb. Wetzel predicted a value of approximately 30 ppb phosphorus for this chlorophyll concentration. Equations 2 and 3 predict phosphorus concentrations of 27 ppb and 30 ppb respectively for 10 ppb chlorophyll.

Wetzel's tabulation is a distillation of data encompassing extensive lake conditions. Close agreement between Wetzel and the values obtained from these two equations is not surprising because the equations are empirical models developed to cover a range of lake systems. Also the use of mean annual values for phosphorus concentration bias these equations toward "average" conditions and do not cover the day to day fluctuation of individual impoundments. The graphical prediction is also constrained by the use of average values.

The proximity of the graphical value to literature predictions supports the supposition that the relationship between phosphorus and chlorophyll a in these impoundments could be described by an equation only marginally different from Equations 2 and 3. In order to more accurately evaluate such a relationship several possible actions should be considered: 1. collection of a larger number of samples; 2. greater consideration to stream flow, precipitation, and run-off; including both overall quantities and possible phosphorus contribution; 3. evaluation of turbidity effects; 4. determination of whether the outflow area of the impoundments really is representative of the system; 5. evaluation of the effects of temperature or time of day of collection on sample viability; and 6. consideration of the effect of the presence of calcium on phosphorus concentrations.

SUMMARY

For algal growth to occur in a lake impoundment minimum quantities of certain vital nutritive constituents are required. The magnitudes of the concentrations of these constituents can be instrumental in controlling the extent of algal growth, however, abundant nutrients alone do not determine rapidity of growth or abundance of algal population. This study was instituted to investigate the posssible existence of a direct relationship between one basic nutritive constituent, phophorus, and algal biomass, measured as [Chl a]. Experimental data collected from a small representative group of lakes affected by similar conditions were analyzed in an attempt to develop an equation that adequately predicts algal responses to phosphorus concentrations for lake systems in eastern Kansas.

Nutritive constituent concentrations can be affected by the addition or subtraction of water from the impoundment. Water is added to the impoundment as precipatation, stream flow and as run-off from the surrounding drainage basin. Annual precipatation in the area of this study ammounts to approximately 35 inches per year. It is estimated that

stream inflow contributes 175 cubic hm to Pomona, 200 cubic hm to Melvern and 1495 cubic hm to Redmond per year. Due to practical considerations no attempt was made to experimentally measure either the volume or nutrient content of the run-off from the surrounding area into the impoundment. However, in the context of this study consideration must be given to the fact that these influxes tend to dilute the concentrations of various constituients in the impoundment unless balanced by a corresponding release of water from the lake. A sizable quantity of water is removed from the system by releasing flow downstream out of the impoundment. Additional liquid is lost from the system due to evaporation. In eastern Kansas lakes the quantity of water removed from the system by evaporation ammounts to approximately 1.2 meters of depth per year. Due to the fact that the three lakes included in this study are artificial impoundments the system volumes can be regulated to a certain extent so that a balance is maintained between influx and outflow of water.

The constituent concentration of a system is also subject to change by the addition or removal of constituents. The total mass of nutrient consituents in the impoundment can be increased when the water flowing into the impoundment from the surrounding area carries with it additional nutrients: leached from soils, absorbed from excess or poorly incorporated fertilizers applied to surrounding crop land, or run-off from stockyard feed lots or similar point sources. Reduction of nutrients occurs either as reduction of availability or actual removal from the system. Nutrient availability can be decreased when the constituents are tied up in biomass and are therefore temporarily unavailable to support new growth. This is an exceedingly temporary situation which may actually increase the difficulty of reducing the magnitude of the biomass of the impoundment since it insures the presence in the system of a certain quantity of biologically usable nutrients. Overall reduction of nutrient levels by decreasing phosphorus input to the system is a slow process. Several years can be required after reductive measures are institued for a new phosphorus concentration equilibrium to develop, however, reduction of phophorus imput, particularlly from point sources, has been shown to be the most effective route to lowering the magnitude of biomass production in an impoundment.

Researchers have shown that phosphorus is the most important component of the nutrient content of a lake system in regard to algal growth. Algae incorporate several forms of phosphate into their metabolism. It has further been reported that for algal metabolism the relative amount of phosphorus required as compared to the amounts of nitrogen and carbon is small. However, even in systems with an abundance of phosphorus, it is the nutritive constituent most difficult for organisms to obtain and therefore by definition phosphorus becomes the limiting factor in biomass production.

Various equations have been proposed to predict algal blooms in lake impoundments from measured phosphorus concentrations. Many of these proposed models apply to: mean concentrations, specific geographical areas, or trophic conditions that are inapplicable to Kansas lakes.

Mean values for experimental data are by necessity a compromise because of the act of averaging. Averaging discounts the highs and lows of data and may cause significant seasonal variability in an impoundment to be overlooked. In lake impoundments analogous to the three lakes included in this study the variability of the time periods of maximum algal growth and the magnitude of the algal population at maximum growth are of vital interest. The problems associated with algae are most prevalent when large quantities of algae are present in the lake system. The three lakes of this study are in close geographical proximity and are subjected to similar climatic conditions, however, the conditions in this area differ from those in other study areas.

Classification of a lake system by trophic state is a method of describing the growth potential of a body of water. Assessing an impoundment's potential for algal growth based upon trophic state alone has been found unsatisfactory. Schindler(1977) and others have proposed that an impoundment's potential for algal growth is limited by total phosphorus concentration. The linear regression of Schindler's plot of mean annual total phosphorus concentration versus mean annual chlorophyll a concentration yields a correlation coefficient of 0.86. This indicates that in the actual environmental situation the relationship between these two components subtantially deviates from linearity.

Vollenweider (Lee, et al., 1978) has classified lakes based on phosphorus loading versus hydraulic loading. The quantity of phosphorus carried into an impoundment on a continuous basis by confluent streams is designated as the phosphorus loading of the system. Hydraulic loading is the quotient of mean depth and hydraulic residence time. Since hydraulic residence time is a measure of the time that a water molecule stays in an impoundment or the time that would be required to evacuate an impoundment; it becomes manifest that an impoundment's residence time can have a sizeable affect upon the overall constituient concentrations. A long residence time means that both water and constituients are retained in the system for lengthy periods of time, therefore, the overall concentrations do not fluctuate very quickly. As a corollary, algal concentrations maintain steadier levels. A short residence time leads to rapid variations in both constituient and algal concentrations.

Vollenweider's (Lee, et al.,1978) classification scheme sets limits of 10 grams P/square meter/year total phosphorus or less as permissible phosphorus loading and 20 grams P/square meter/year or higher as excessive phosphorus loading. Lakes which fall into the excessive loading region of the resultant plot are subject to over-production of biomass. A combination of low hydraulic loading and high phosphorus loading fix the three lakes included in this study in this excessive loading region. A serious problem arises in using Vollenweider's scheme because he considered the impoundments he studied as basically steady state systems. The three lakes in this study do not conform to his steady state model.

The equations developed by Dillon (Dillon, et al., 1974) and Bachmann (Bachmann, et al., 1976) are closely related but differ slightly in the circumstances they describe. Dillon's equation (Equation 2) was proposed to predict the summer chlorophyll concentration based on a single phosphorus concentration measured during the spring inversion. Lakes in eastern Canada that are located on the Canadian shield were included in their study. Bachmann's equation (Equation 3) was proposed to enable predictions to be made for a wide variety of impoundment conditions. This equation was based on summer concentration data for total phosphorus and chlorophyll a for 143 lakes in Iowa.

The first questionable issue in using Equation 2 for the impoundments included in this study concerns the difference in geographical location of the lakes being studied. This one difference raises the question of how much variability is due to climatic conditions such as: quantity of precipitation received, evaporation rate, and dissimilar temperature or light conditions. Additionally, this equation was based on a single phosphorus concentration measurement for each lake. The experimental data for the three lakes in this study shows that phosphorus concentrations vary over a sizable range, therefore, it is improbable that a single phosphorus measurement will be representative of the impoundment conditions.

The conditions under which Equation 3 was developed appear to be much closer to circumstances extant at Redmond, Melvern, and Pomona Reservoirs than those of Equation 2. Iowa is geographically closer with greater similarity in climate and geologically very much like Kansas. Also land usage is largely agricultural but more intensively cultivated than eastern Kansas which might have considerable effect upon the phosphorus loading contributed by fertilizers. One reason this equation does not show a closer fit to the experimental data may be that it is based on a compilation of data for lakes of a broad range of trophic states while this study covers very eutrophic lakes only. With out specific reference to turbidity data little can be said about how much of the divergence, between Equation 3 and the experimental data, is due to turbidity effects.

All three lakes included in this study have very short residence times. Consequently, the experimental data shows considerable variability precluding the expression of definite conclusions about trends in the data. Since no experimental data related to turbidity was obtained for this study it is not possible to know how great an effect this factor may have had on either the amount of scatter in the data or on the relationship between phosphorus and chorophyll concentrations. In order to clarify the relationship between the concentrations of phosphorus and chlorophyll in Redmond, Melvern, and Pomona Reservoirs the points raised in the discussion section of this paper must be more thoroughly studied.

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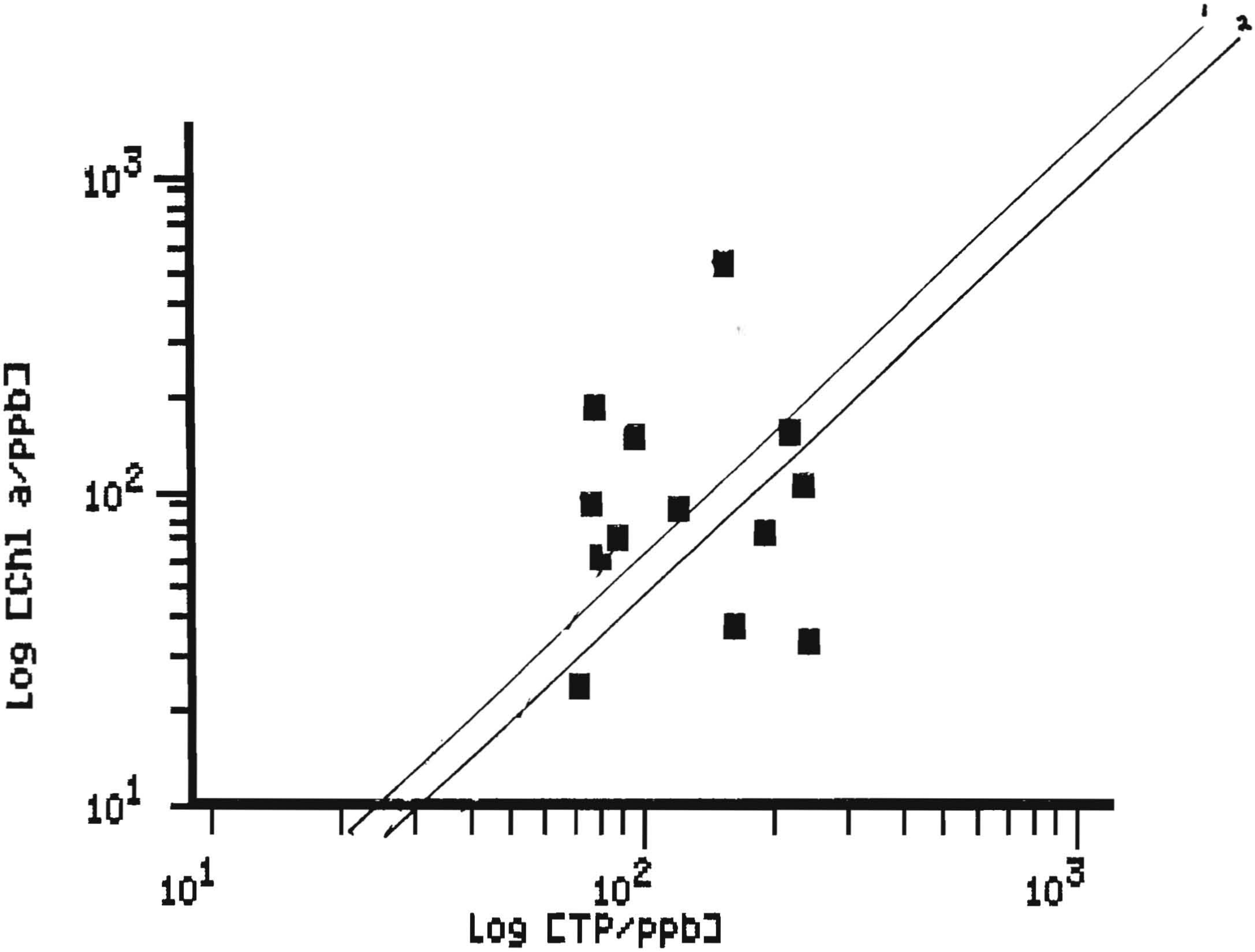
APPENDIX

Figure 1. Plot of [TP] vs. [Chl a] from data collected at Melvern Lake, Pomona Lake, and Redmond Reservoir

line 1 calculated from Equation 3

line 2 calculated from Equation 2

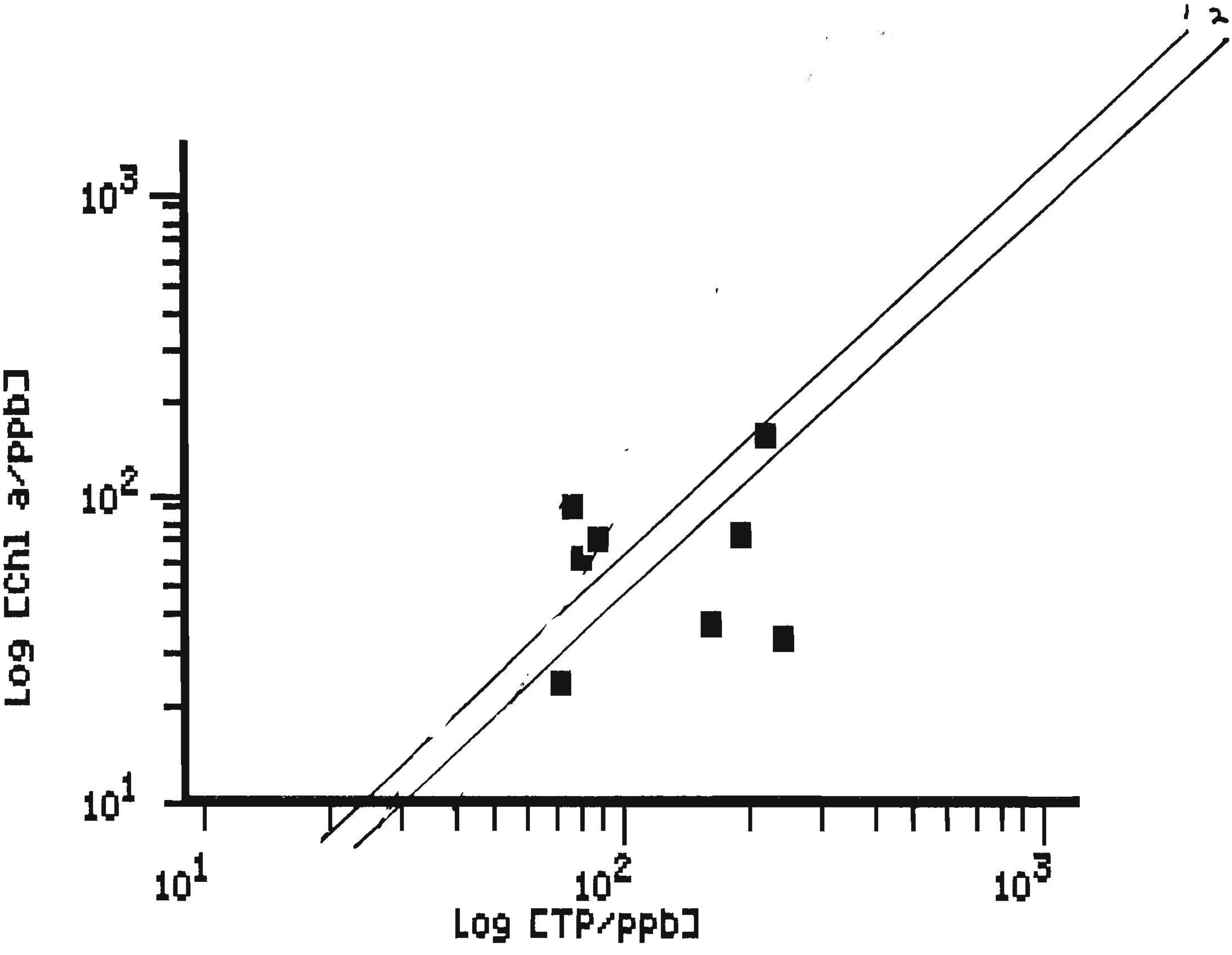


1
2
10^3
10^2
10^1
Log [Chl a/ppb]
10^1
10^2
10^3
Log [TP/ppb]

Figure 2. Plot of [TP] vs. [Chl a] from data collected at Melvern and Pomona Lakes

line 1 calculated from Equation 3

line 2 calculated from Equation 2



1
2
10^3
10^2
10^1
Log [Chl a/ppb]
10^1
10^2
10^3
Log [TP/ppb]

Figure 3. Plot of [TP] vs. [Chl a] from data collected at Redmond Reservoir

line 1 calculated from Equation 3

line 2 calculated from Equation 2

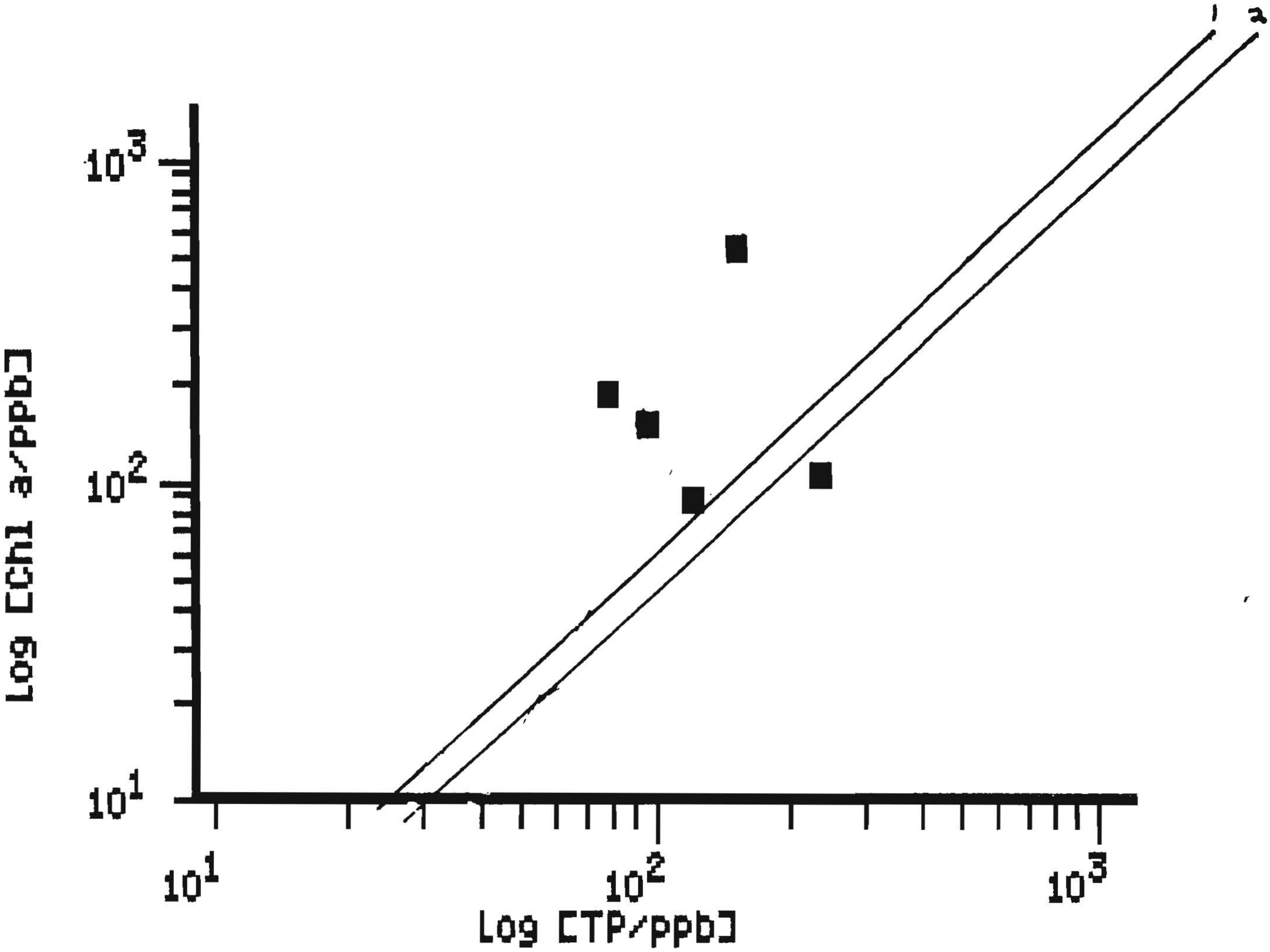

10³
10²
10¹
Log [Chl a/ppb]
10¹
10²
10³
Log [TP/ppb]
1
2

Table 1. Bar graph of [TP] and [DP]

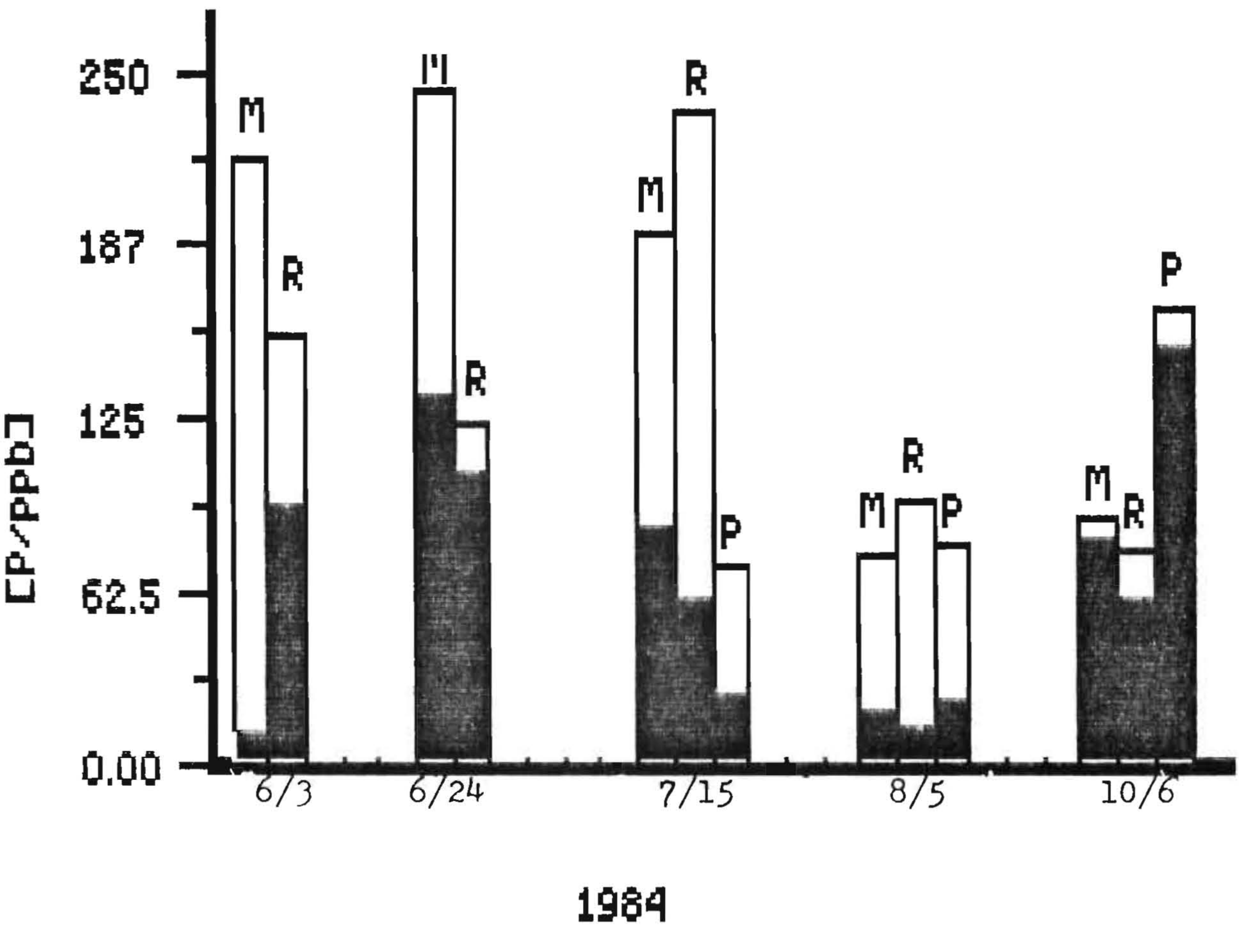
total phophorus concentration

dissolved phosphorus concentration

M Melvern Lake

R Redmond Reservoir

P Pomona Lake



250
187
125
62.5
0.00
[P/ppb]
M
R
M
R
M
R
P
M
R
P
M
R
P
6/3
6/24
7/15
8/5
10/6
1984

Table 2. Comparison of Experimental [Chl a] with calculated [Chl a]

Date	[TP/ppb]	[Chl a/ppb] Experimental	[Chl a/ppb] Equation 3	[Chl a/ppb] Equation 2
Redmond				
6/3	155	549	127	108
6/24	123	91	92	78
7/15	237	106	241	204
8/5	96	153	64	54
10/6	78	192	47	41
Melvern				
6/3	219	157	212	179
6/24	245	34	260	220
7/15	191	74	172	146
8/5	76	92	45	39
10/6	89	72	58	49
Pomona				
7/15	72	25	41	36
8/5	80	62	49	42
10/6	165	38	141	120

Table 3. Absorbance and [TP] calculated with Beer's Law

Date/1984	Lake	Blank	Absorbance			Absorbtivity	[TP]/ppb
6/3	M	0.0119	0.4034	0.3872	0.3872	1.74	219
6/3	R	0.0119	0.2840	0.2848	0.2774	1.74	155
6/24	M	0.0066	0.5100	0.4202	0.4425	1.84	245
6/24	R	0.0066	0.2366	0.2336	0.2291	1.84	123
7/15	M	0.0223	0.5186	0.5129	0.5143	2.58	191
7/15	R	0.0223	0.7167	0.5528	1.1805	2.58	237
7/15	P	0.0269	0.1733	0.2306		2.45	71
8/5	M	0.0269	0.2069	0.2190		2.45	76
8/5	R	0.0269	0.2644	0.2573		2.45	96
8/5	P	0.0269	0.2441	0.2027		2.45	80
10/6	M	0.0209	0.2907	0.2441		2.76	89
10/6	R	0.0209	0.1612	0.2314	0.2418	2.76	78
10/6	P	0.0209	0.4389	0.5100	0.4802	2.76	120