ECOLOGICAL FACTORS AFFECTING TURBIDITY AND PRODUCTIVITY OF PRAIRIE PONDS

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PREFACE

The objectives of this study were: (1) to measure various chemical parameters of pond water and to determine if these chemical factors may be related to various turbidity levels in the ponds; (2) to assess the effects of morphoedaphic features of the ponds and basins on turbidity levels in the ponds; (3) to determine the effects of turbidity on chlorophyll a and community succession in the phytoplankton.

Dr. Troy C. Dorris served as major adviser. Dr. Dale Toetz directed the research and criticized the manuscript. Dr. Robert D. Morrison and Nancy Norton assisted with the computer program for data analyses. Freddie L. Rainwater, Wayne F. Hadley, John H. Carroll, Jr. and other personnel of the Aquatic Biology Laboratory helped make field collections. The assistance of all these people is appreciated.

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CHAPTER I

INTRODUCTION

During the past two decades, great numbers of small artificial impoundments have been constructed in Oklahoma. Dendy (1963) reported the number of ponds in Oklahoma was approximately 250,000 in 1962. These ponds are primarily utilized to water livestock, as sources of potable water and as sites for water based recreation. Their secondary role in erosion control is also important.

Many ponds in Oklahoma are continuously turbid due to clay particles suspended in the water, while neighboring ponds remain relatively clear. The effect of this turbidity is of considerable importance. High levels of inorganic solids are detrimental to water quality (Stroud, 1967) and are often as damaging as organic pollution (Wilson, 1960). An indirect deleterious effect, due to scattering of light and absorption of radiant energy, results in decreased primary production (Bartsch, 1960). Suspensoids also produce chemical changes in the aquatic medium (Ellis, 1936).

Previous studies on turbidity in prairie ponds have been limited to intensive work on only a few ponds or work for short periods of time on larger numbers of ponds. An attempt was made to obtain large amounts of data on many ponds for comparative purposes in this study to (1) measure various chemical parameters of pond water and to determine if these chemical factors may be related to various turbidity levels in the ponds, (2) assess the effects of morphoedaphic features of the ponds and basins on turbidity levels in the ponds, (3) determine the effect of turbidity on chlorophyll a and community succession in the phytoplankton.

The rationale behind the first objective has its basis in prior knowledge of the nature of turbidity. Most of the inorganic solids creating the muddy appearances in these ponds are clay particles weathered from Permian red beds which lie exposed in this region (Hall, 1949). The turbid particles are a montmorillonite type clay (Irwin and Stevenson, 1951) and approach colloidal sizes of 0.5 μ to 5 μ. The shape of the particles is usually flattened and disc-like.

Many dispersions of colloidal size clay particles do not settle readily. Gravitational forces may cause the larger particles to settle, but wind and convection currents tend to sustain suspension of smaller colloidal particles in the waters of many ponds. The suspension mechanism appears to be related to electrical properties of the clay and to the chemistry of the water.

Montmorillonite type clays have an octahedral structure with trivalent aluminum present in two of three possible positions. All three positions may be filled by divalent magnesium. Such substitutions of electropositive elements by those of lower valence result in a negative charge of the lattice (van Olpen, 1963).

According to van Olpen (1963), the negative charge is compensated by the accumulation of ions of opposite charge from the solution. The concentration of ions is high near the surface of the particle and decreases outward resulting in a counter-ion atmosphere. Lattice charge and counter-ion atmosphere together constitute the electric double layer which is responsible for repulsive forces between the particles. The repulsive forces counteract the general van der Waals forces and do not allow the clay particles to agglomerate. Addition of electrolytes compresses the counter-ion atmosphere toward the particle and facilitates agglomeration. Ions with a higher valence give a more pronounced compression. At high ionic concentration, electrical repulsive forces cannot counteract van der Waals forces, thus aggregation and precipitation of clay particles occurs.

The above theory is strengthened by field observations and by experiments in the field. Calcium, magnesium and sodium aid the precipitation of clay particles in Oklahoma (Mathis, 1965). Irwin (1945) and Irwin and Stevenson (1951) precipitated clay particles in ponds by introduction of organic matter. Decomposition of the organic matter supposedly produced greater quantities of hydrogen ions which neutralized the negatively charged particles. Esmey et al. (1955) found that addition of gypsum to turbid ponds aided in flocculation and precipitation of clay particles. Keeton (1959) used oil field brines to clear farm ponds in Oklahoma. Harrel (1966) and Mathis (1965) showed that seepage of oil field brines reduced turbidity in streams.

This explanation of clearing is by no means exclusive. Butler (1964) suggested that a natural system for clearing clay turbidity in ponds exists in the activity of producer and decomposer organisms. Daily fluctuations in hydrogen ion concentration as a result of productivity and respiration initiate flocculation. Knudson (1970) believed that hydroxyl ions produced by photosynthesis in the breakdown of bicarbonate combine with cations to form positively charged sols which neutralize the charge on negative colloids, such as clay particles, permitting them to agglomerate.

An effort was made to learn the relationships of water chemistry to turbidity by an extensive survey of these parameters in a large number of ponds with different levels of turbidity. In taking this approach we felt some light could also be shed on the most likely clearing mechanism which might be of greatest importance in the majority of ponds.

The second objective, the effort to relate morphoedaphic features to turbidity, had its basis in the following somewhat contradictory observations. Initial turbidity of pond water would logically depend upon the amount of clay entering the pond as well as pH, organic matter and available cations in the water. The sediment load of water entering the ponds is affected to a large degree by the nature of the watershed. Esmey et al. (1955) stated that small, well grassed watersheds used only for collection of water yielded more turbid runoff water than cultivated or grazed areas. Daniel (1953) reported that ponds with cultivated land in their watersheds cleared while ponds with grass watersheds remained muddy. Irwin (1954) found that highly turbid ponds received water from fields and roadways. Sediment production is affected by differences in basal cover of grasses according to Kincaid et al. (1966). Basal cover is the area of soil surface covered by the base of the plants. Greater sediment yields are found in watersheds with lower percentage basal cover.

Differential grazing has a measurable effect on runoff from watersheds (Gard et al., 1943). Severely grazed areas produce runoff of up to 30% of incoming precipitation while moderately grazed areas produce only a small proportion (4%) in runoff. Ground cover is directly related to runoff water and sediment yield (U. S. Forest Service, 1950). As ground cover increases runoff water and sediment yield decrease.

The amount of water available to supply these ponds, with all other factors being equal, is a function of the watershed area (Calkins, 1947). If the drainage area is too large for pond capacity, a high percentage of the runoff must pass through the pond. The pond may receive a large amount of sediment with the runoff.

The chemistry of pond water is related to that of the surrounding land. It has already been shown how important water chemistry might be to flocculation of clay particles. For this reason certain other features of the watershed are of particular importance. Esmey et al. (1955) found a highly significant correlation between conductivity of soil and conductivity of pond water. Ionic concentration of pond water also varies in relation to dilution from runoff and concentration by evaporation; therefore, inflow and outflow are of fundamental importance in pond water quality control. Most ponds received sufficient nutrients from the watershed to maintain fertility (Irwin, 1949). However, in many cases morphometic features allow some ponds to be flushed by runoff, thereby reducing fertility. Continued flushing results in infertile conditions and increased turbidity.

The size and nature of watershed, pond capacity and other morphometic features affect the chemistry of pond water and load of sediments delivered to the pond. Thus, these morphoedaphic features will have a profound effect upon turbidity. Only an extensive survey of these parameters would permit evaluation of their importance.

The last objective, an evaluation of the effects of turbidity on phytoplankton, was in order because of conflicting results in other studies. Phytoplankton pulses occurred after increases in turbidity in Lake Michigan (Daily, 1938). Harris and Silvey (1940) found maximum net plankton at high turbidity in two Texas lakes and at low turbidity in two other lakes. In Oklahoma, Claffey (1955) found the greatest amount of plankton in clear ponds and reservoirs while very turbid impoundments contained the least amount. Such results illustrate the need for further information on the relationship of turbidity to phytoplankton. Estimates of phytoplankton production were obtained in this study by pigment analysis (Odum et al., 1958) in an effort to define the effects of turbidity on this community.

Phytoplankton pigments may be analyzed to determine biochemical diversity of the plankton community (Margelef, 1968). The pigment diversity index is the ratio of optical density of 90% acetone pigment extracts at 430 and 665 mu. Yellow pigments absorb heavily at 430 mμ and green pigments (chlorophyll *a*) absorb greatly at 665 mμ. The "yellow/green" ratio yields information on the number of molecules of one pigment relative to the other.

Aging is a prominent factor influencing relative amounts of pigments (Margelef, 1958, 1963). Yellow pigments predominate in older stable populations; thus, the ratio is greatest in older populations and lowest in young growing populations (Odum, 1962, 1963). Thus, trends in succession of phytoplankton are shown by pigment diversity indices.

CHAPTER II

DESCRIPTION OF AREA

The twenty-nine ponds studied are located in mixed grassed prairie of Payne and Noble Counties, Oklahoma (Fig. 1). Surface area of the ponds ranged from 0.19 to 0.88 hectares (Table I). Selection of ponds was based on proximity to Stillwater, access (roads and permission by owners), size and apparent turbidity. Ponds were selected in the above size range to rule out those with atypically large or small surface areas. Apparent turbidity was used as a selection criterion and twenty-nine ponds (ten clear, ten intermediate turbid and nine turbid) were eventually selected representing a range of turbidity.

Predominant soils in the area are Vernon and Kirkland loam types (U. S. Dept. of Agric., Bureau of Soils, 1917; Dept. of Agric., SCS, 1937). Drainage areas of the ponds ranged from 0.6 to 17 hectares. The land was primarily utilized to graze cattle. Watersheds are defined as follows:

Type I.	Well grassed watershed properly used for grazing or water collection
Type II.	Overgrazed grass watershed
Type III.	Watershed with drainage from cultivated or road ditch areas

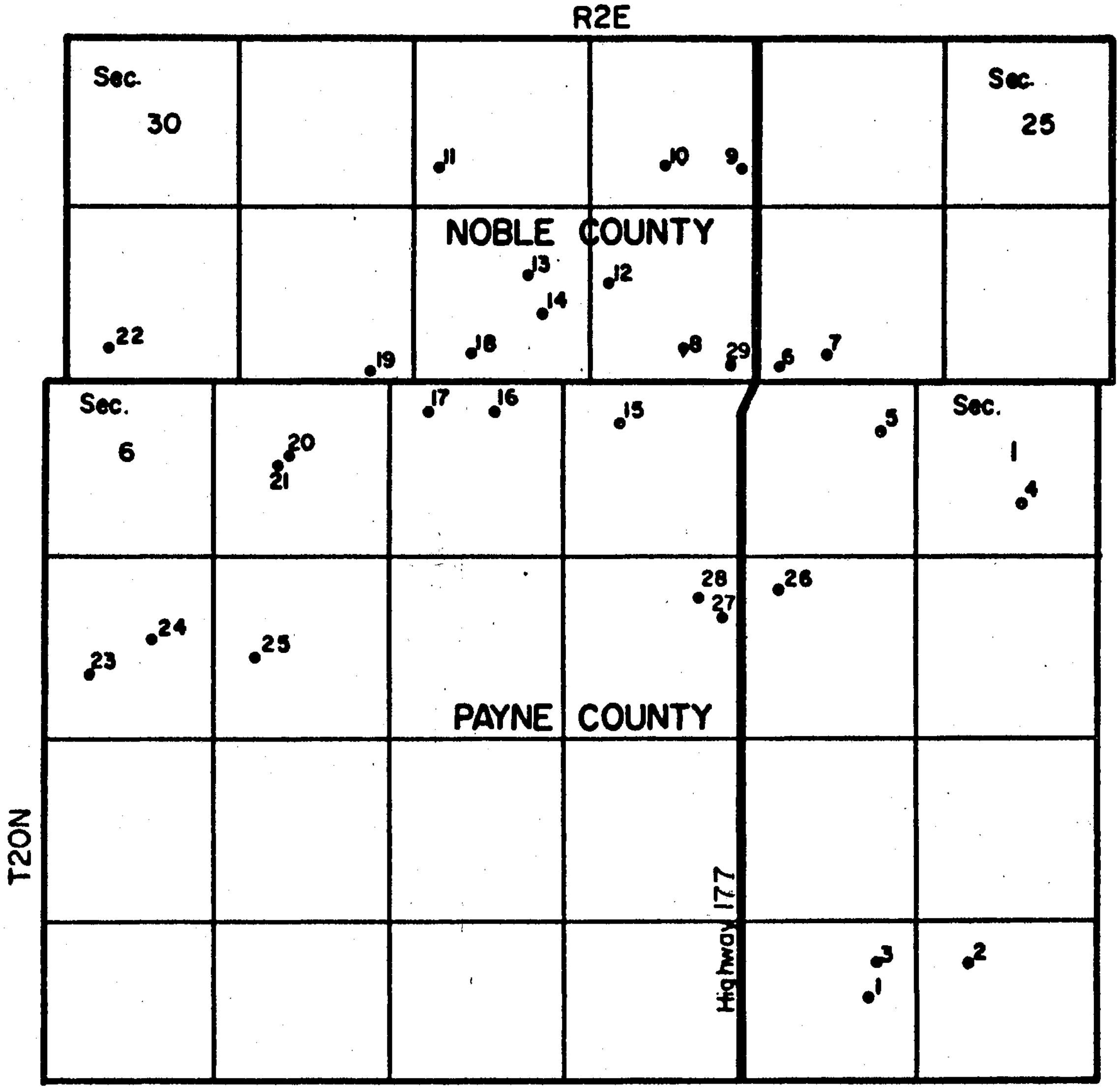

Figure 1. Location of Ponds in Study Area, Payne and Noble Counties, Oklahoma

TABLE I

CLASSIFICATION OF WATERSHED TYPES AND MORPHOMETRIC DIMENSIONS OF PONDS IN THE STUDY REGION OF PAYNE AND NOBLE COUNTIES, OKLAHOMA

Pond Identification	Mean Annual Light Transmission (%)	Watershed Type	Area at Spillway Level (m^2)	Volume at Spillway Level (m^3)	Mean Depth Volume/Surface Area	Maximum Depth at Spillway Level (m)	Basin Size (ha)	Basin Size/Volume Index
1	81.9	I	5823	4866	0.84	3.11	11.6	23.8
20	84.3	I	2648	2945	1.11	3.05	5.5	8.4
21	90.8	I	3030	4461	1.47	3.51	0.9	2.0
22	83.8	I	4441	4798	1.08	3.26	3.7	7.7
23	94.0	I	3114	6503	2.09	6.10	3.0	4.6
26	92.0	I	2473	3027	1.22	3.11	1.1	3.6
2	53.3	II	5609	8602	1.53	3.17	11.1	12.9
3	12.3	II	2496	1541	0.62	1.52	6.1	52.0
6	81.6	II	7441	6062	0.81	2.35	16.8	17.8
7	52.9	II	3513	3526	1.00	3.11	1.5	4.2
9	41.1	II	3531	3303	0.94	1.86	2.6	7.9
15	84.8	II	2315	2432	1.05	3.11	0.6	2.5
17	76.9	II	3413	5913	1.73	4.11	1.4	2.4
18	68.6	II	5270	3300	0.63	1.52	8.2	24.8
19	79.9	II	4685	5866	1.25	2.48	1.1	1.9
24	40.9	II	3731	5054	1.35	3.69	4.0	7.9
25	16.5	II	7023	8862	1.26	3.26	17.0	19.2
27	19.1	II	2341	1882	0.80	2.50	2.9	13.3
28	72.5	II	3902	2438	0.62	2.00	0.6	2.5

TABLE I (Continued)

Pond Identification	Mean Annual Light Transmission (%)	Watershed Type	Area at Spillway Level (m^2)	Volume at Spillway Level (m^3)	Mean Depth Volume/Surface Area	Maximum Depth at Spillway Level (m)	Basin Size (ha)	Basin Size/Volume Index
4	40.4	III	1900	1397	0.74	1.66	1.1	7.9
5	14.1	III	3839	1693	0.44	0.91	10.1	59.6
8	24.1	III	4731	2161	0.46	1.34	6.9	31.9
10	0.9	III	4261	2791	0.65	1.98	3.1	10.4
11	50.6	III	5255	4684	0.89	2.87	5.3	11.3
12	17.3	III	5682	2528	0.44	1.46	5.5	21.8
13	27.3	III	3345	2850	0.85	3.08	5.8	20.3
14	44.5	III	2510	1217	0.48	1.04	2.3	18.9
16	0.0	III	6100	5971	0.98	2.26	1.9	3.2
29	64.5	III	8800	6372	0.72	2.13	5.5	8.6

Principal grasses in Type I watersheds are *Andropogon scoparius*, *Andropogon gerardi* and *Sorghastrum nutans*. Grazing varied from unused to moderate. Grasses in ungrazed basins were generally between one and two feet in height and provided maximum cover of the area. Moderate grazing reduced the height of the vegetation to approximately one foot, but cover was still very good.

In overgrazed watersheds (Type II), *Bouteloua hirsuta*, *Buchloe dactyloides*, *Aristida oligantha* and *Andropogon saccharoides* are prevalent grasses with *Ambrosia psilostachya*, *Achillea lanulosa* and *Baptista leucophea*, common forbs. Utilization was often severe with elimination of many characteristic grass species. Repetitive grazing reduced grass height to less than six inches and exposed much of the soil.

Type III watersheds had tilled areas or roadside ditches which served as sources for large amounts of sediments in the runoff. In addition, extensive grazing often reduced the height of vegetal cover on the watershed to two inches or less with a resultant exposure of the soil surface to erosion.

CHAPTER III

PROCEDURES

Field measurements of physical and chemical factors were made and water samples were collected at approximate monthly intervals from all 29 ponds between December, 1965 and December, 1966, inclusive. Water samples were collected by wading into the pond. A surface sample site was located in a fixed sector of each pond about four meters from shore. Phenolphthalein and methyl orange alkalinity were determined in the field by titration with 0.02 N sulfuric acid (APHA, 1960). Hydrogen ion concentration of a water sample was estimated in the field with a Hellige pH comparator. Water temperature was measured with a mercury thermometer. A surface water sample from each pond was also collected in glass containers for later analyses in the laboratory. Samples were collected by submerging the glass container.

Since all 29 ponds were sampled in a day along a circuitous route, the samples in glass containers were chilled in ice chests during transport to limit changes in the sample due to sunlight and high temperature. Laboratory analysis of the samples was undertaken immediately upon return from the field. Turbidity was measured with a Bausch and Lomb Spectronic 20 colorimeter at 450 mμ. Conductivity at 25° C was measured with an Industrial Instruments Wheatstone Bridge.

The concentration of total solids was determined by evaporating 50.0 ml of unfiltered pond water in a tared crucible for 24 hours at 104 ± 1° C and reweighing after cooling in a desiccator (APHA, 1960). Residue in the crucible was ignited at 500° C in a muffle furnace for one hour and then cooled in a desiccator and reweighed. Subtraction of weight after ignition from weight before ignition yields the concentration of organic matter.

The dissolved solids concentration was determined by filtering a 200 ml fraction of pond water through two acetone soluble membrane filters with pore sizes of 5.0 and 0.45 μ, respectively. Then 50.0 ml of filtered liquid was evaporated in a tared crucible. After reweighing, the crucible was ignited, cooled in a desiccator and weighed again. Subtraction of weight after evaporation from the tare yields an estimate of total dissolved matter. Subtraction of weight after evaporation from weight after ignition determines the dissolved organic matter.

Phytoplankton retained on the filters was analyzed for pigment content. The pigments were extracted in 90% acetone for 24 hours in the dark at 5° C (Odum et al., 1958). After centrifugation, the optical density of the extract was measured in a 2.54 cm tube with a Bausch and Lomb Spectronic 20 colorimeter at wavelengths of 665 and 430 mμ, respectively. The instrument was calibrated with 90% acetone in a 2.54 cm tube.

Morphometric data for the construction of a contour map for each pond were obtained with a transit and plane tables. Area at 0.6 m contour intervals was determined by use of an electric grid counter and plotted against depth of each pond to construct hypsographs

(Welch, 1948). By measuring the water level and using a hypsograph, area and volume of each pond could be calculated for the sampling dates. Water level was measured with a permanent pole gauge calibrated to spillway level. The drainage area of each pond was calculated from aerial photographs and field observations. Rainfall data were obtained from records of the U. S. Weather Station at Stillwater, Oklahoma.

Statistical Analyses

Analysis of variance and tests for differences among ponds were made using Factorial and Duncan's Multiple range computer programs of the Oklahoma State University Statistical Laboratory. Least squares regression lines were fitted through data points according to the procedures of Steele and Torrie (1960).

Since duplicate observations of parameters were not made, estimates of true error could not be determined. In analysis of variance for these parameters a factorial design of ponds composed levels of one factor and dates composed the levels of the second factor. The pond X date interaction was used as an estimate of error in making F-tests for significant difference. It is likely that interaction was present for the parameter during the year; therefore, interaction "error terms" used in testing for significant differences were too large. The use of large error terms would result in decreased sensitivity of statistical tests used to detect significant differences among pond means. However, confidence can be placed in conclusions drawn from means shown to be statistically different because the true probability of a significant difference actually was higher than the demonstrated probability.

Duncan's Multiple Range test was used to determine homogeneous subsets, if a significant difference was declared by analysis of variance. Any means not underscored by the same line are significantly different ($\alpha = 0.05$).

CHAPTER IV

TURBIDITY AND ECOLOGICAL CONSIDERATIONS

Rainfall and Water Levels

Climatic conditions peculiar to central Oklahoma include hot summers and relatively mild winters. Evaporation is 150 to 180 cm or approximately twice the annual rainfall. Precipitation is mainly from cyclonic thunderstorms which are often erratic in frequency and distribution. Such precipitation patterns often lead to great changes in the water levels of the ponds.

Total precipitation during the study (December, 1965 through December, 1966) was approximately 70 centimeters. Monthly distribution of rainfall was unusual in that 65% of the total amount for the year occurred from May through August (Fig. 2). Generally larger amounts of rainfall occur in March and April with very little occurring in the hot summer months. However, 18.6 cm of rainfall in July raised the water level in all ponds and caused twenty of the ponds to overflow. Concurrent with the raised water level was a general decline in alkalinity, conductivity and hydrogen ion concentration in the ponds.

Reduction of water level by evaporation or seepage occurred before and after the heavy summer rains. Ponds 18, 19 and 22 were arbitrarily selected to show the fluctuations in water level of

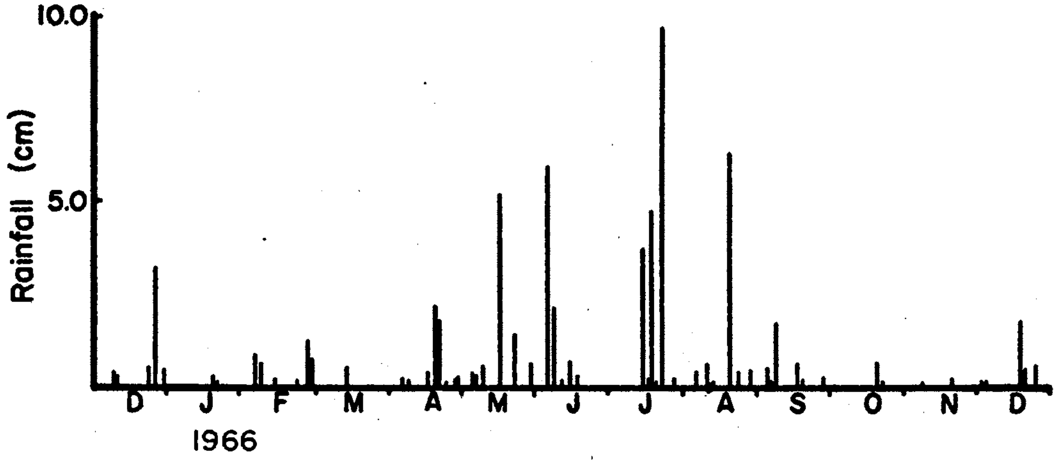

Figure 2. Daily Precipitation at Stillwater, Oklahoma, December, 1965 through December, 1966

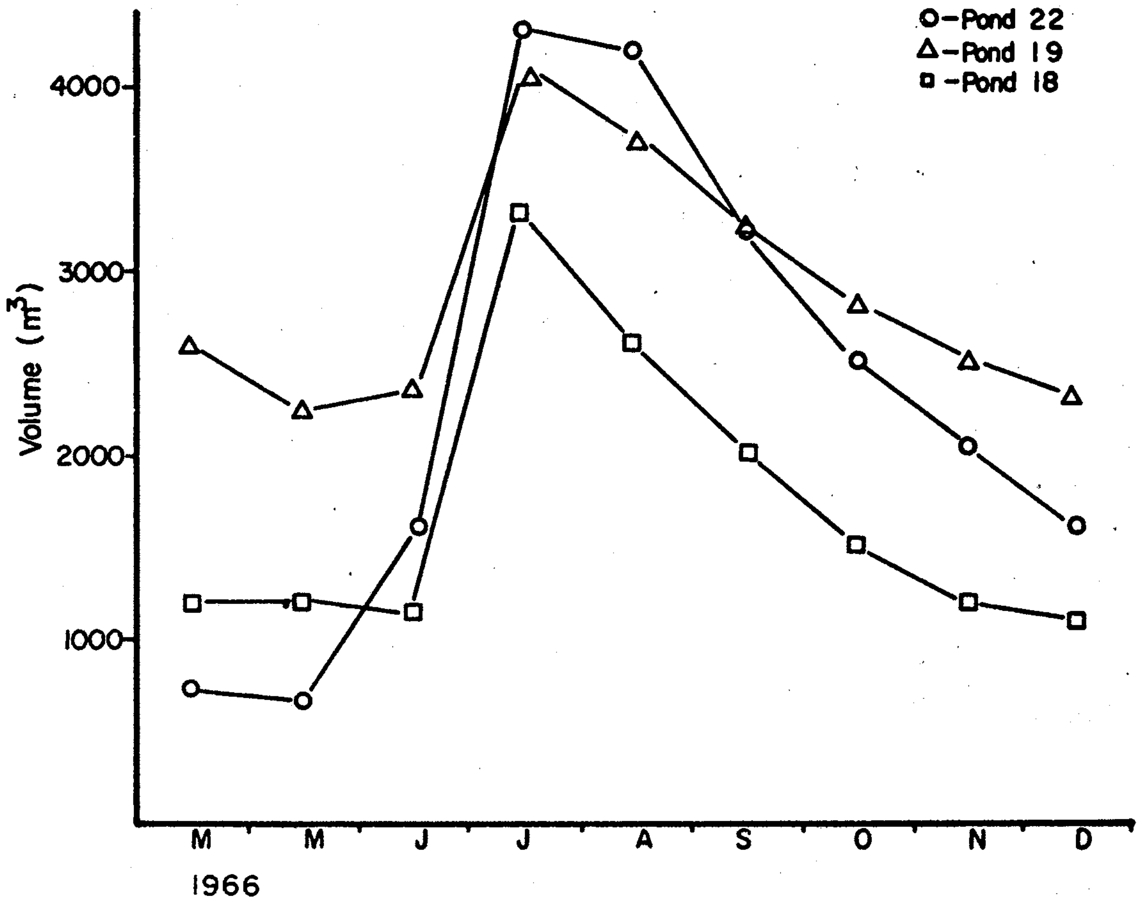

Figure 3. Annual Variation of Volume of Three Ponds during 1966

the ponds (Fig. 3). After the heavy summer rainfall period, the water level decreased in all ponds by about 60 cm in four and one-half months between August and December.

Turbidity

All of the following factors probably influenced fluctuations in water transparency: rainfall and runoff rate, condition of the vegetation in the drainage basin, size of the drainage basin, aquatic macrophyte abundance, phytoplankton, wind action and roiling by livestock and waterfowl using the ponds.

Buck (1956) arbitrarily grouped bodies of water in Oklahoma into three categories on the basis of water transparency. Those with less than 25 ppm particulate solids were "clear", those with 25-100 ppm particulate solids were "intermediately turbid" and those having particulate solids greater than 100 ppm were "turbid". Using this classification and calibrating light transmission against a Jackson turbidimeter, ponds with a mean annual light transmission greater than 80% are "clear", ponds between 40 to 79% light transmission were "intermediate" and those with less than 40% light transmission were "turbid".

Mean annual light transmission among the ponds ranged from 0.0% in Pond 16 to 94.0% in Pond 23 (Appendix, Table A). Pond 16 never exhibited any measurable light transmission. Conversely, Pond 23 was never below 90% in light transmission. The stability of water transparency in Pond 23 was probably due to a small catchment basin above the pond which reduced the sediment load entering the pond. The other clear ponds received runoff directly from their watershed.

The effects of the heavy runoff in July caused a reduction of water transparency in clear ponds (Fig. 4). The three ponds were selected as typical of clear ponds for annual variation in light transmission. Following the heavy runoff, settling of the erosion material during August in clear ponds resulted in an increase in light transmission to levels prior to the rainfall.

Annual variation in light transmission in some of the turbid ponds was different than in the clear ponds (Fig. 5). A major difference was noted during the summer months. Wind action in June evidently caused a reduction in light transmission. In July water transparency increased when runoff water materially diluted the heavy load of suspensoids already present in the ponds. Between June and July, light transmission in Pond 25 increased from 3.5 to 13.9% as the volume increased from 8341 to 8862 m^3. In Pond 3 the variation was from 6.6 to 13.7% light transmission for the same time interval as volume increased from 107 to 619 m^3. The greatest increase in light transmission was noted in Pond 9 (Fig. 4). For the six months prior to July, light transmission averaged approximately 6%, but it increased to 27.5% after the rainfall as the volume increased from 423 to 2161 m^3 between June and July. Settling of particulate matter continued during the autumn and by December the light transmission was 93.0%.

Roiling of the ponds by livestock was often responsible for reduction in light transmission. Short-term increases in turbidity were created by cattle in Ponds 19 and 20 during February (Fig. 4). Landowners often move large numbers of cattle into an area for short periods for grazing or feeding. This results in greater use of ponds.

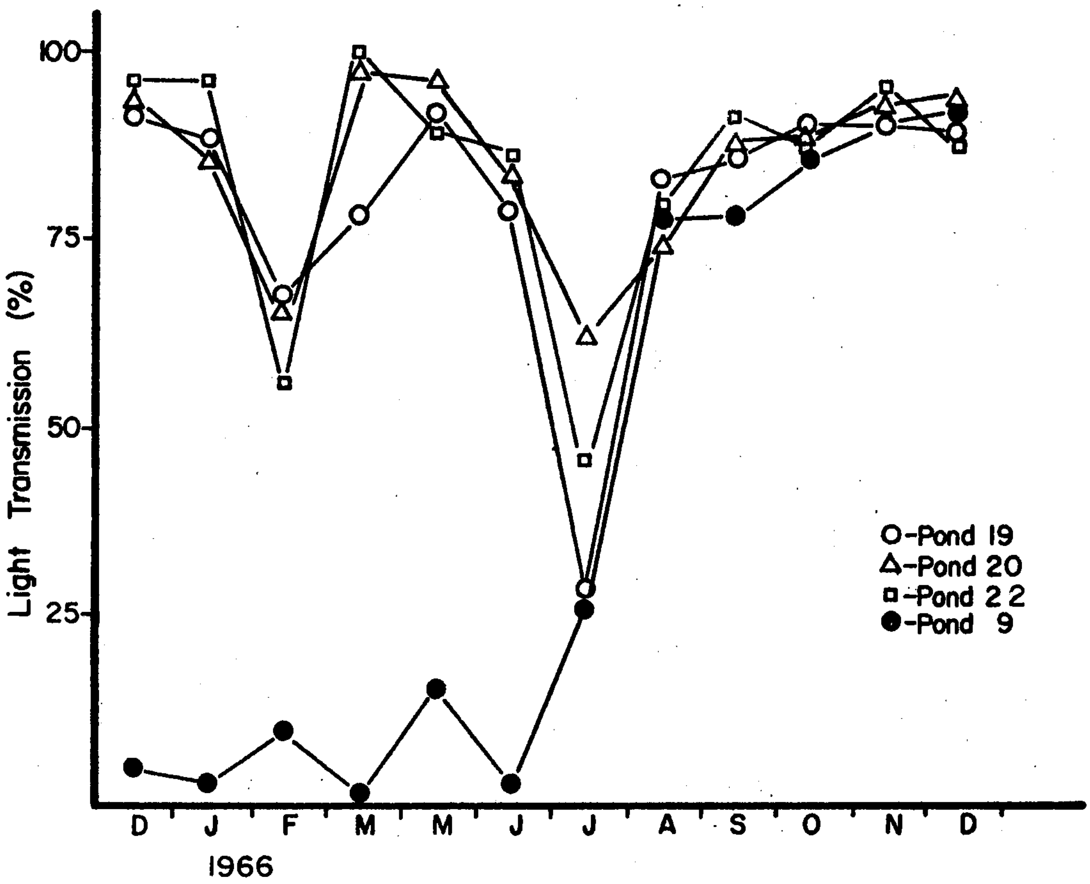

Figure 4. Annual Variation in Light Transmission of Four Ponds

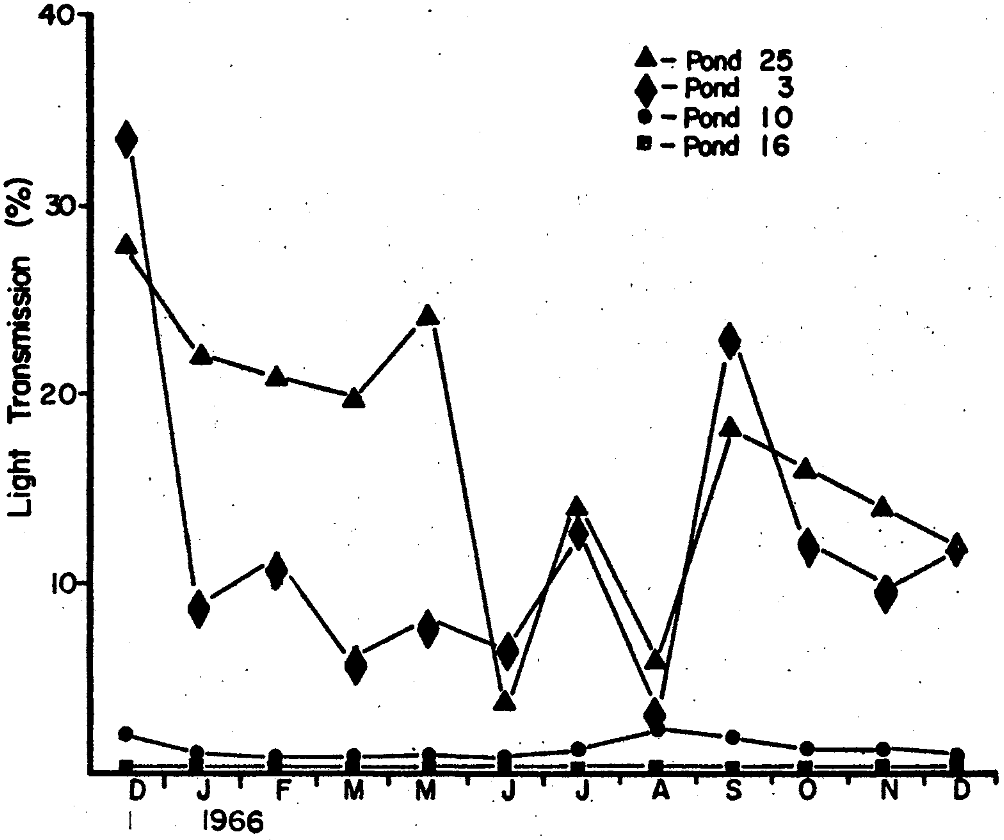

Figure 5. Annual Variation in Light Transmission of Four Turbid Ponds

Light transmission decreased from 85 to 66% in Pond 20 when approximately 60 head of cattle had access to the pond. Light transmission in Pond 15 decreased from 92.0 to 67.5% between January and February due to roiling by cattle. Light transmissions in Ponds 11 and 14 averaged 29.2 and 16.0%, respectively under heavy use by livestock and 61.3 and 65.4% without cattle present. Ponds 12 and 27 averaged 1.5 and 5.8% light transmission, respectively when livestock roiled the ponds, but increased to 36.8 and 28.6% when the cattle were removed. Roiling activity by cattle affected clear ponds as well as intermediate and turbid ponds.

Roiling activity was not limited to livestock. During February, extended use of Pond 22 by waterfowl reduced light transmission from 96 to 56%.

Phytoplankton was largely responsible for the turbidity in Pond 28 as evidenced by chlorophyll analysis. This pond had the highest mean annual chlorophyll a concentration at 0.153 mg/1. Great numbers of phytoplankers were often visible in the pond water. Inorganic particulate matter constituted the major source of turbidity in intermediate and turbid ponds.

Solids

Dissolved solids generally increased as water transparency increased (Figs. 6 and 7 and Appendix, Table B). The correlation coefficient of dissolved solids with light transmission was 0.48 which was significantly different from zero at the 95% confidence level. The correlation coefficient of dissolved organic solids with

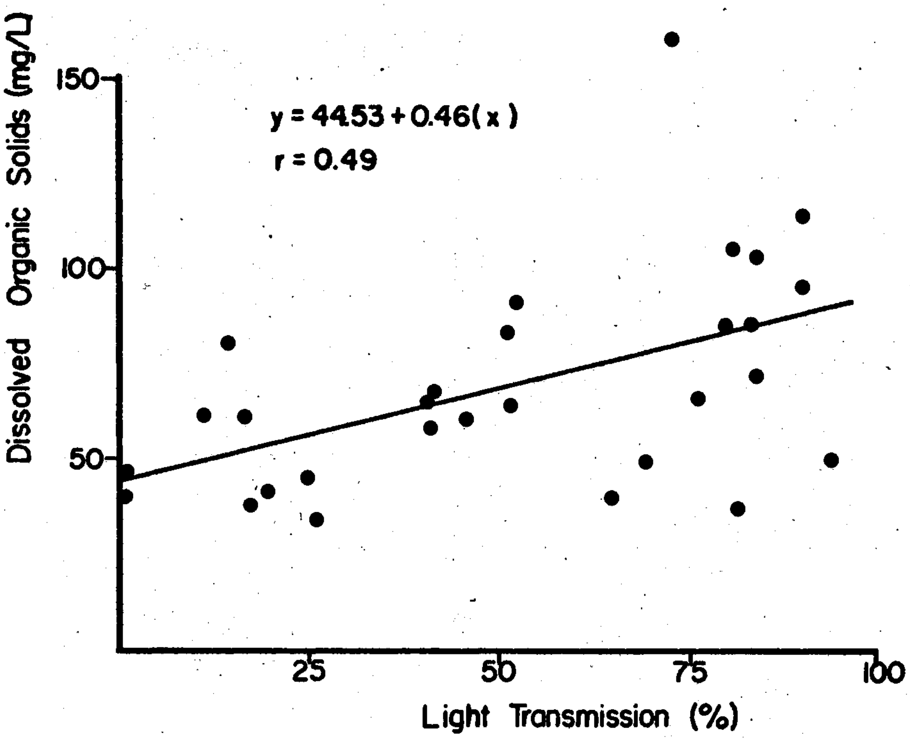

Figure 6. Comparison Between Light Transmission and Dissolved Organic Solids Among All Ponds

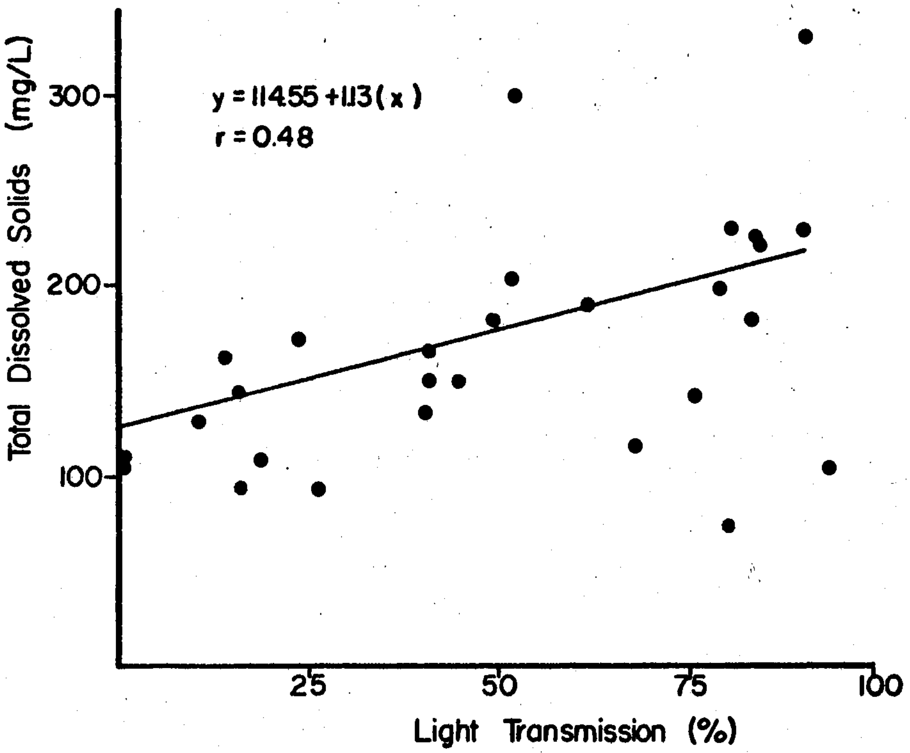

Figure 7. Comparison Between Light Transmission and Total Dissolved Solids Among All Ponds

light transmission was 0.49 which was also significantly different from zero at the 95% confidence level.

Fluctuations in total dissolved solids concentration followed the same general pattern throughout the study. Three clear and three turbid ponds were arbitrarily chosen to illustrate the pattern (Figs. 8 and 9). An oscillating pattern occurred during the first five months. In June and July, total dissolved solids fell as water level rose. This was followed by increases in solids as evaporation occurred in the autumn.

Dissolved organic solids were present in higher concentration in clear ponds (Fig. 6 and Appendix, Table C). Higher organic solids in clear ponds probably resulted from greater primary productivity by algae and macrophytes. Organic solids may have been produced not only from the decomposition of plants, but also from the organic material which aquatic plants release (Fogg, 1965).

The concentration of dissolved organic solids generally peaked during the spring months, probably as a result of decomposition of organic material (Fig. 10). Chlorophyll a concentration was quite low at this time. As chlorophyll a concentration increased in early summer there was a reduction in dissolved organic solids concentration. Dissolved organics gradually increased through the summer to a small peak in early autumn.

Dissolved inorganic solids were directly related to water transparency (Fig. 11 and Appendix, Table D). The correlation coefficient of 0.41 was significantly different from zero at the 95% confidence level. Dissolved inorganic solids fluctuated through the year with the concentration being higher in December, May,

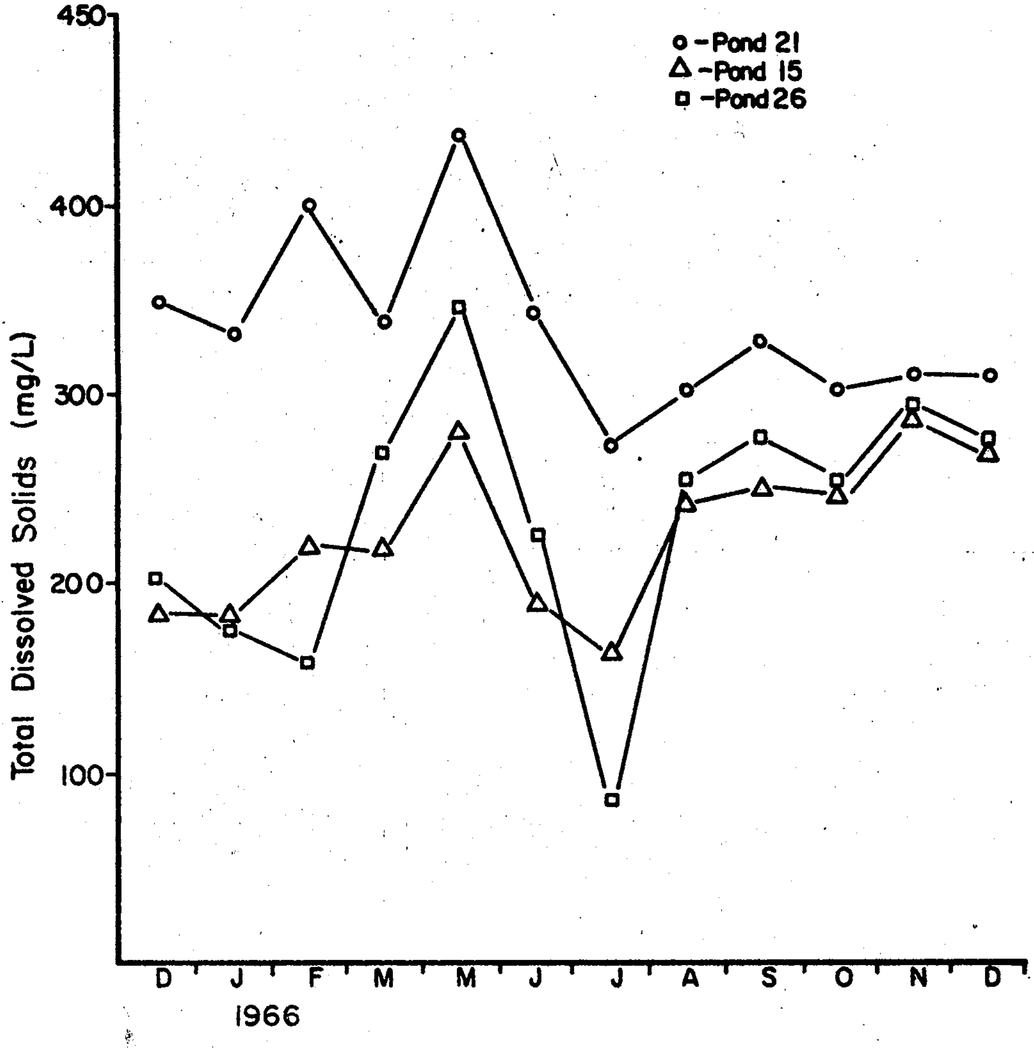

Figure 8. Annual Variation in Total Dissolved Solids of Three Clear Ponds

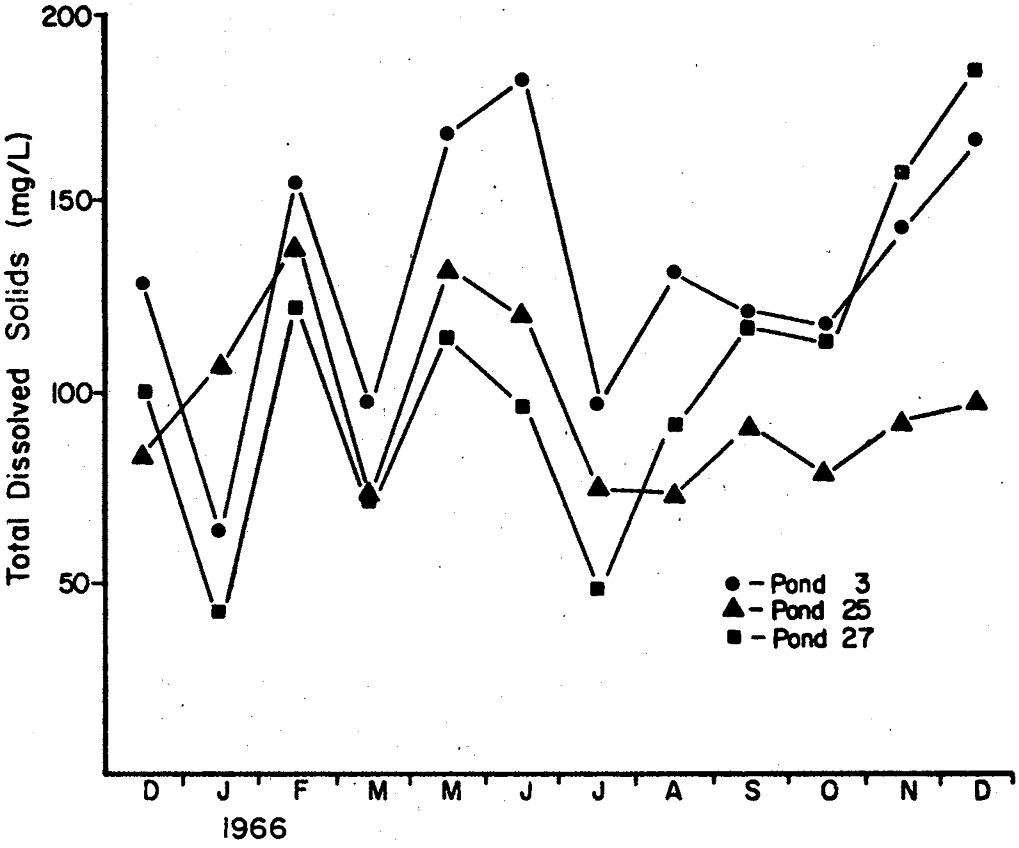

Figure 9. Annual Variation in Total Dissolved Solids of Three Turbid Ponds

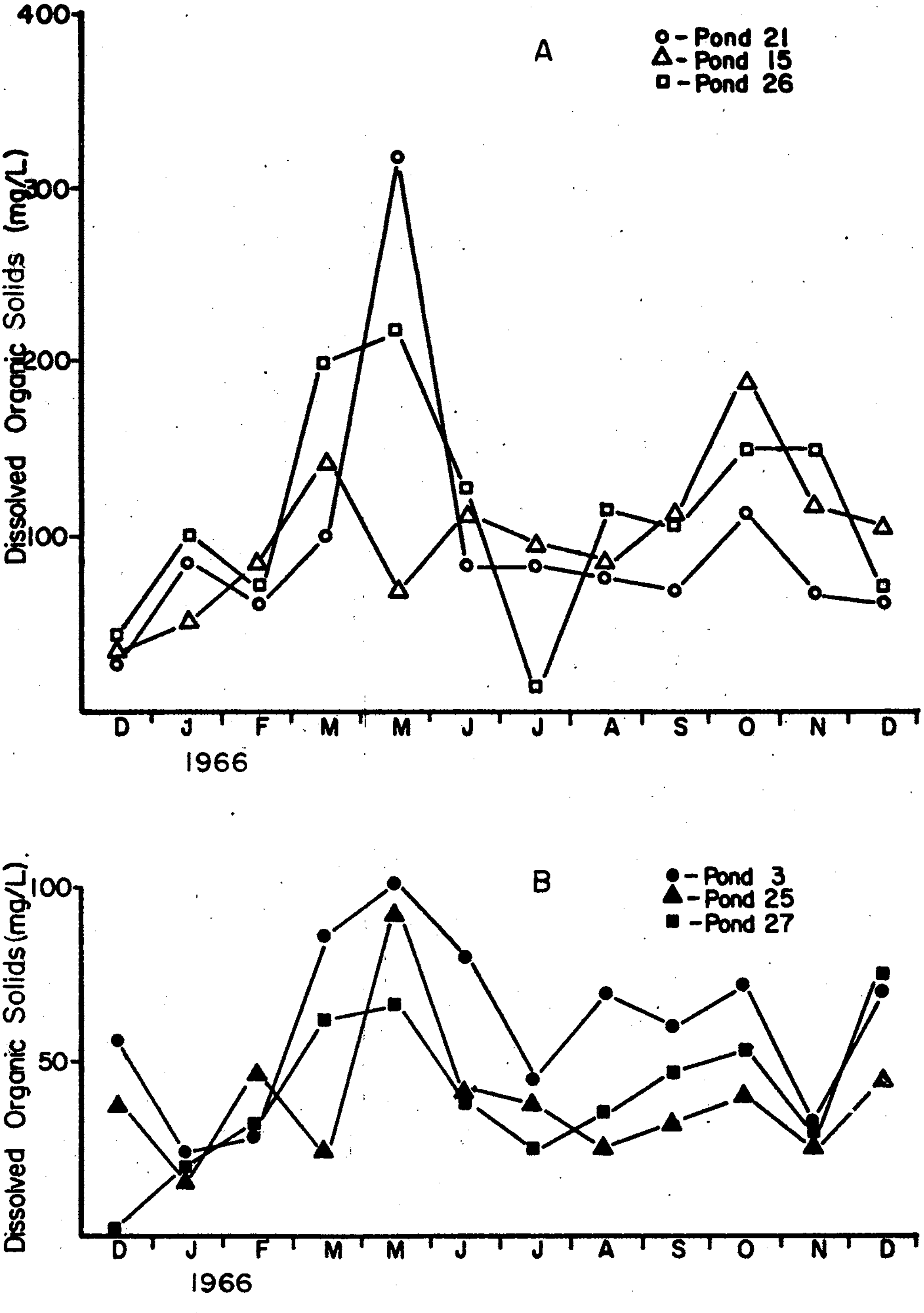

Figure 10. Annual Variation in Dissolved Organic Solids of Three Clear (A) and Three Turbid (B) Ponds

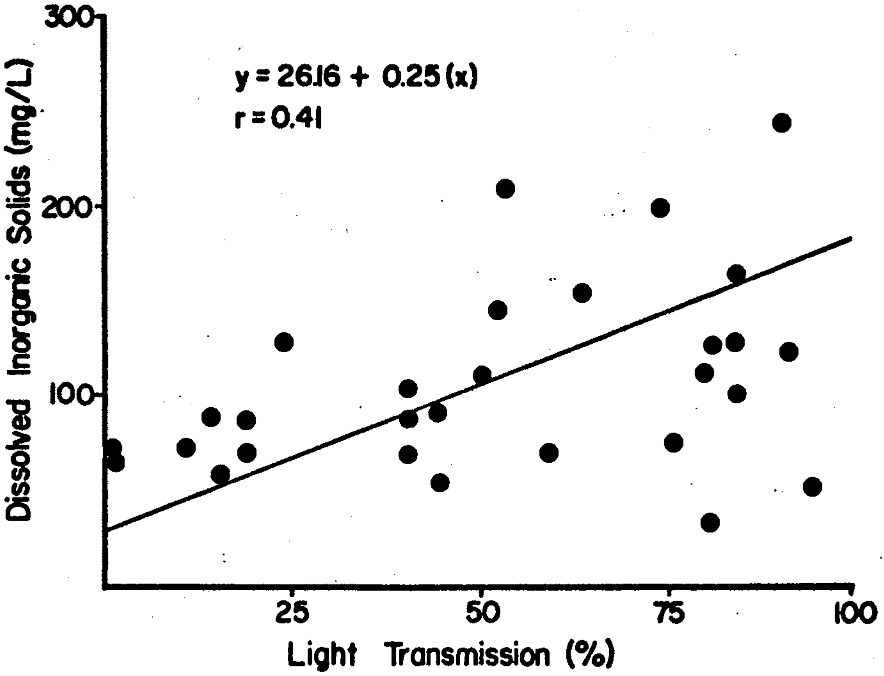

Figure 11. Comparison Between Light Transmission and Dissolved Inorganic Solids Among All Ponds

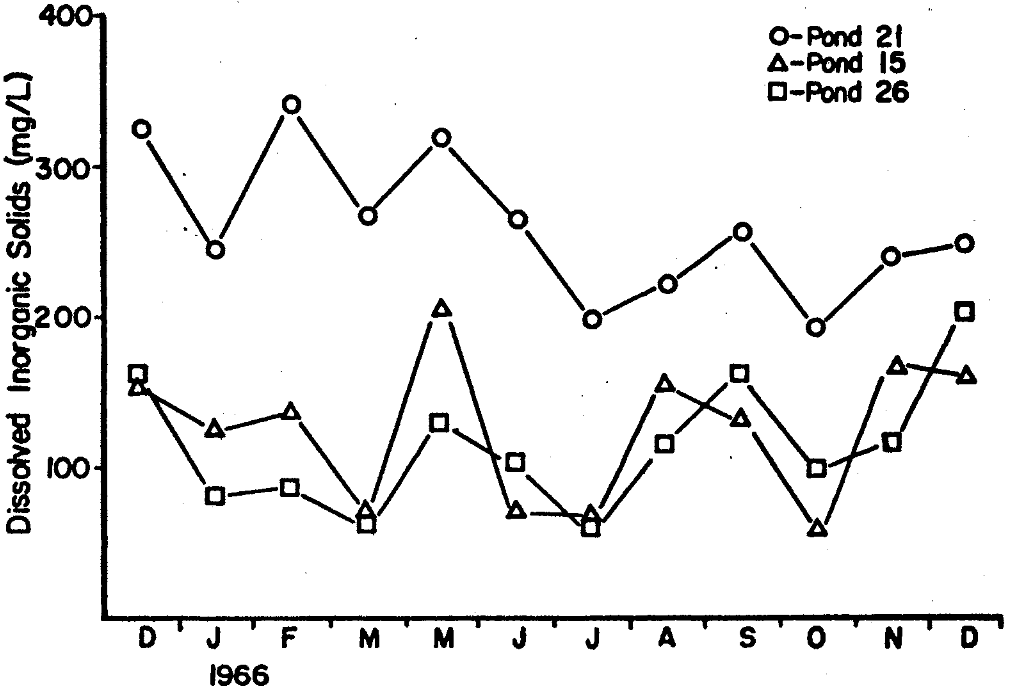

Figure 12. Annual Variation in Dissolved Inorganic Solids of Three Clear Ponds

September and December (Fig. 12). Reductions occurred in March, July and October. Dissolved inorganics peaked in May prior to reductions in summer when rainfall occurred. A gradual increase followed through late summer as evaporation caused concentration until the reduction occurred in October.

Total solids generally increased as turbidity increased (Appendix, Table E). Mean annual total solids content among the ponds ranged from 88.2 to 1461.8 mg/l. Turbid ponds with over 500 mg/l total solids were shown to be significantly different from all other ponds. Total solids content in some turbid ponds was not significantly different from the clear and intermediately turbid ponds. This is explained by variations in the ratio of the particulate and dissolved fractions making up the total solids content of a pond. Ponds 28 and 21 with 72.5 and 90.8% light transmission, respectively had mean total solids concentrations of 376.5 and 356.7 mg/l, but dissolved solids made up 358.7 and 335.9 mg/l of the total.

Particulate inorganic solids were inversely related to light transmission (Fig. 13). The correlation coefficient of -0.71 was significantly different from zero at the 95% confidence level. A large fraction of the total solids content in turbid ponds was particulate inorganic solids which caused low water transparency.

Wind action and runoff cause considerable variation in total solids. Twenty-four ponds exhibited increases in total solids in June evidently due to wind action. Pond 16 had a maximum total solids content of 1922.0 mg/l during June. This pond contained 8.5 metric tons of solids in suspension in 3638 m^3. Between June and July, total solids decreased sharply from 1922 to 1170 mg/l in

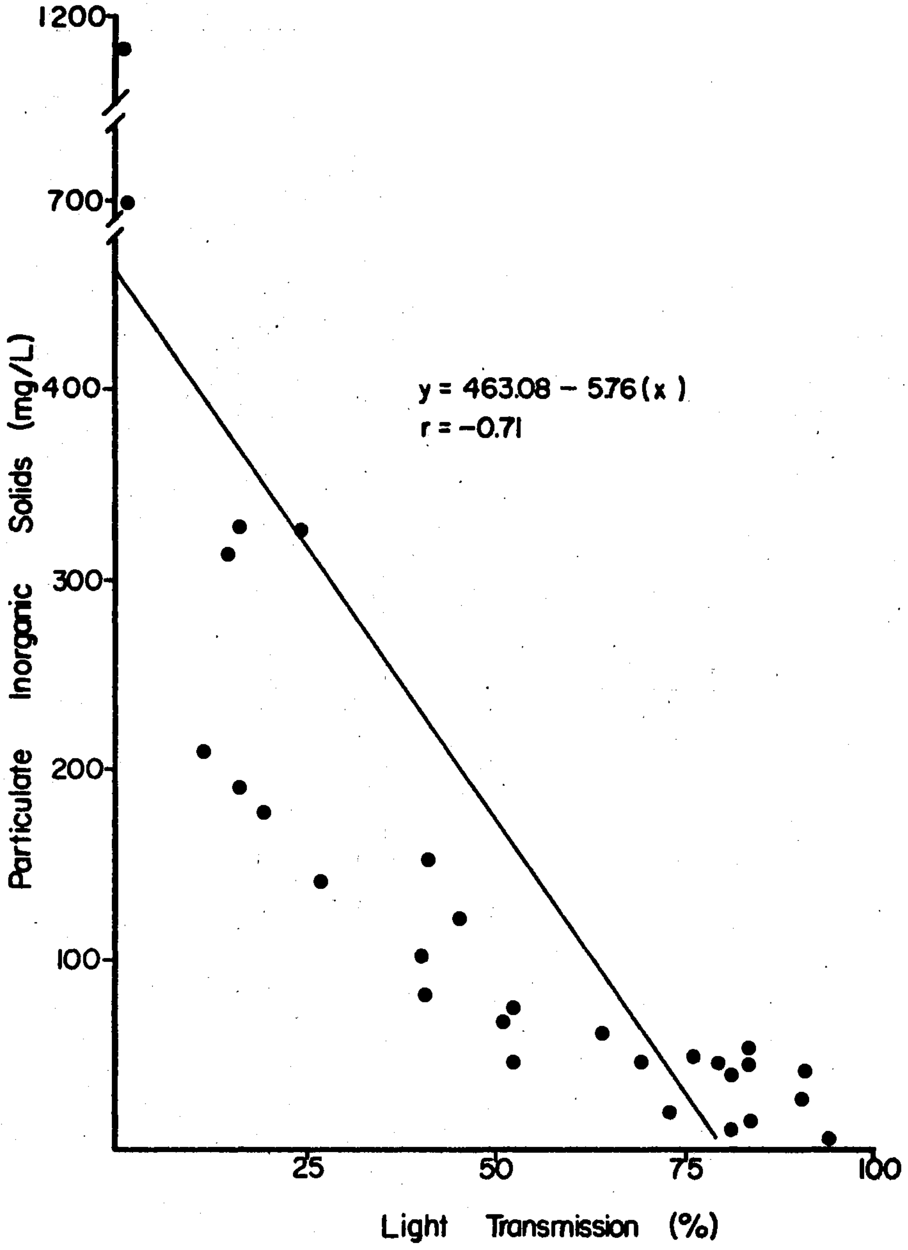

Figure 13. Comparison Between Light Transmission and Particulate Inorganic Solids Among All Ponds

Pond 16. This reduction was noted in all but three ponds and occurred concurrently with a great increase in water levels due to very heavy runoff.

Conductivity

Generally, conductivity was directly related to light transmission. As water transparency increased the conductivity rose (Fig. 14 and Appendix, Table F). Correlation of conductivity with light transmission was significantly different from zero at the 95% confidence level ($r = 0.53$). Most of the ponds with light transmission greater than 80% had corresponding conductivity greater than 350 micromhos/cm. Exceptions were noted in Ponds 6, 23 and 18. These ponds had light transmission of 81.9, 94.0 and 68.6%, respectively, but had conductivity of 97.0, 182.3 and 205.7 micromhos/cm, respectively, which are considerable below the 350 micromhos/cm level. In addition, Pond 2 with one of the highest mean annual conductivities (478.6 micromhos/cm) never exceeded 63.0% light transmission.

Ponds with greater conductivity had greater dissolved solids content (Figs. 15 and 16). The correlation coefficients for conductivity with dissolved inorganics and dissolved organics were 0.93 and 0.83, respectively. Both coefficients were significantly different from zero at the 95% confidence level.

Conductivity appeared to be inversely related to water level of the ponds (Figs. 3 and 17). Heavy rainfall in June and July increased the water level of the ponds and brought about sharp reductions in conductivity. Conductivity increased again in late summer and fall of 1966 when rainfall was low.

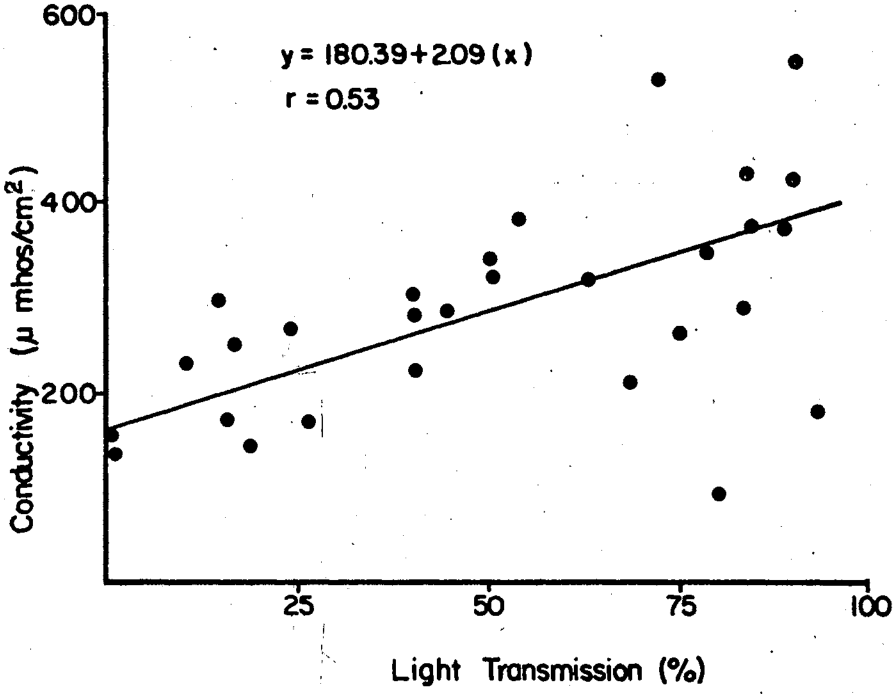

Figure 14. Comparison Between Light Transmission and Conductivity Among All Ponds

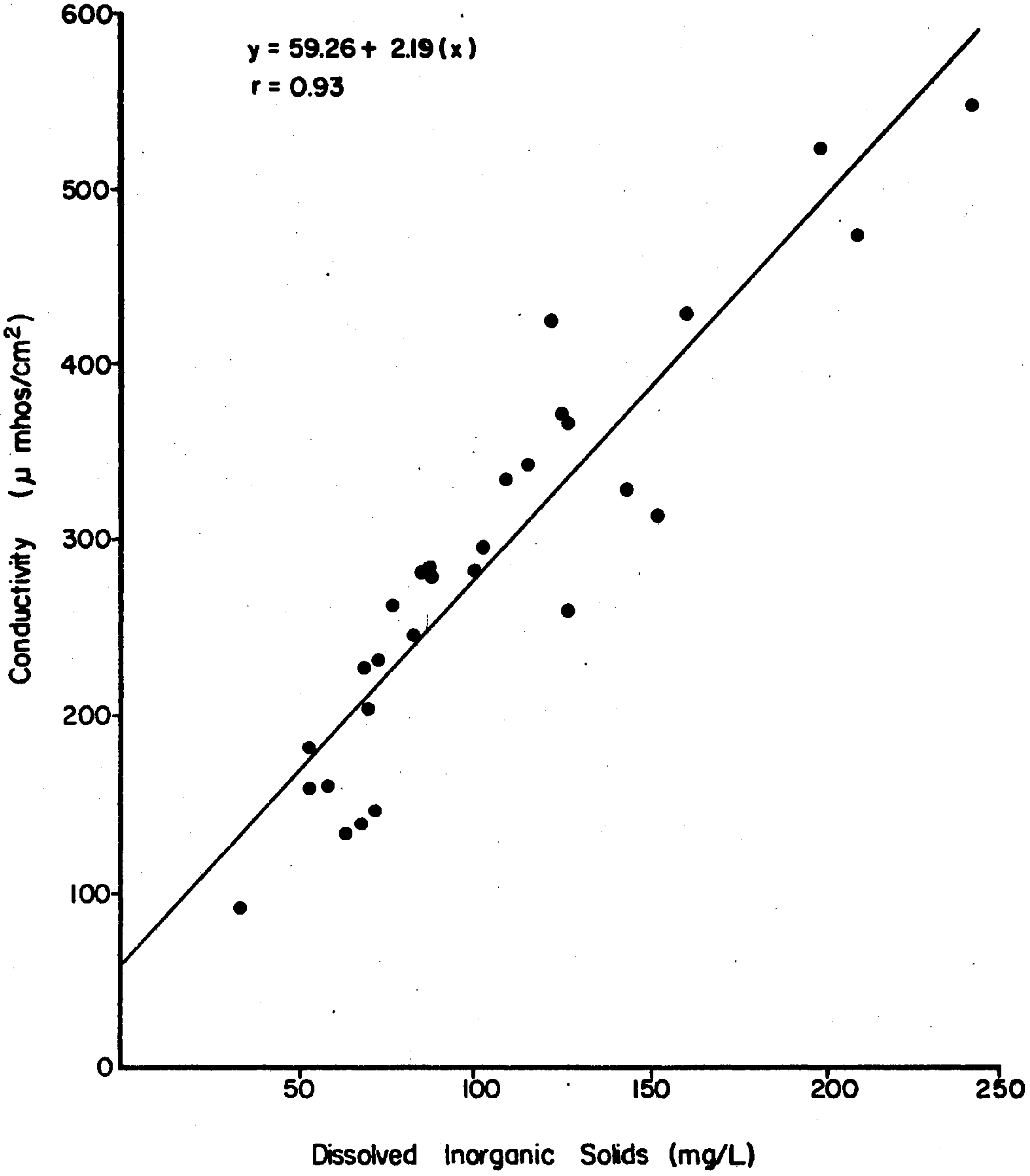

Figure 15. Comparison of Conductivity and Dissolved Inorganic Solids Among All Ponds

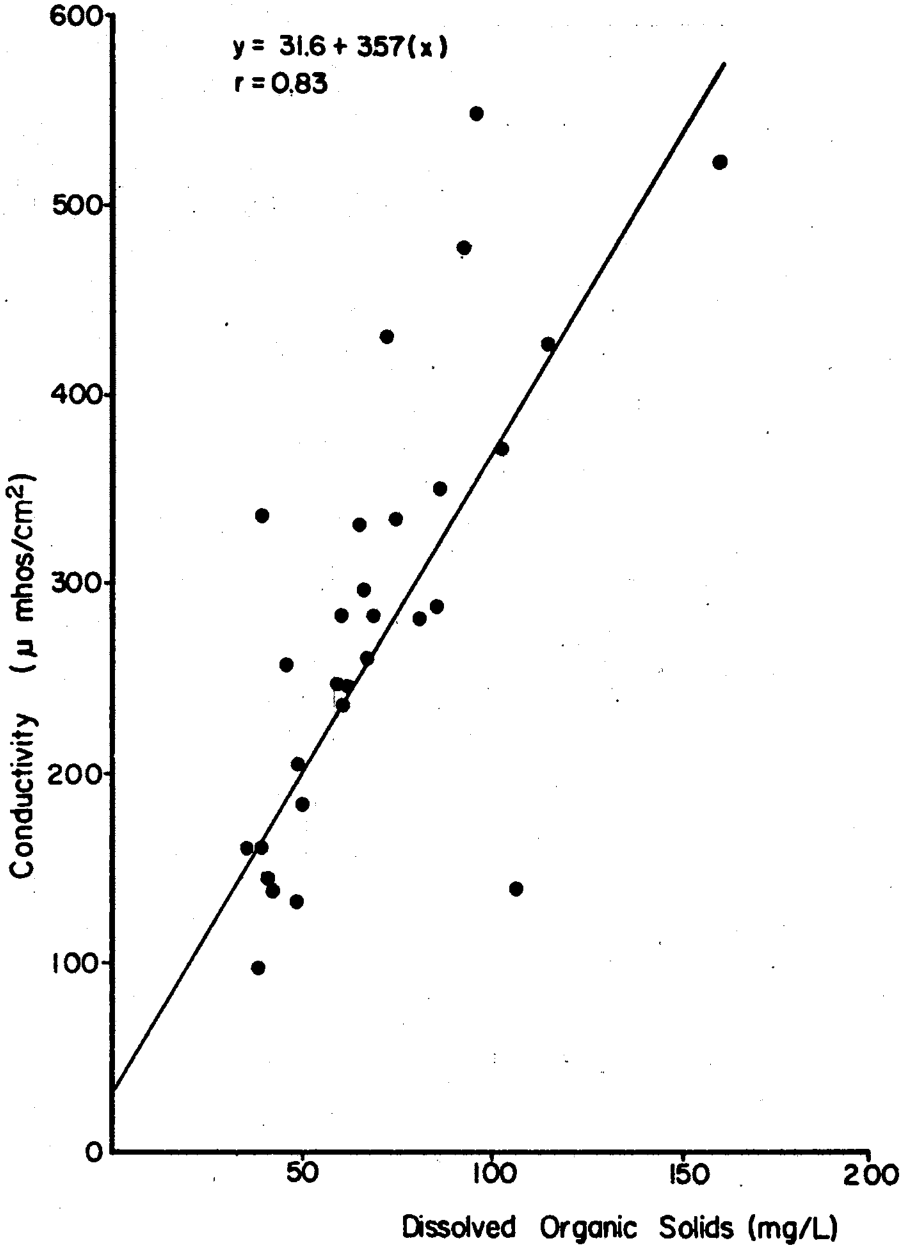

Figure 16. Comparison of Conductivity and Dissolved Organic Solids Among All Ponds

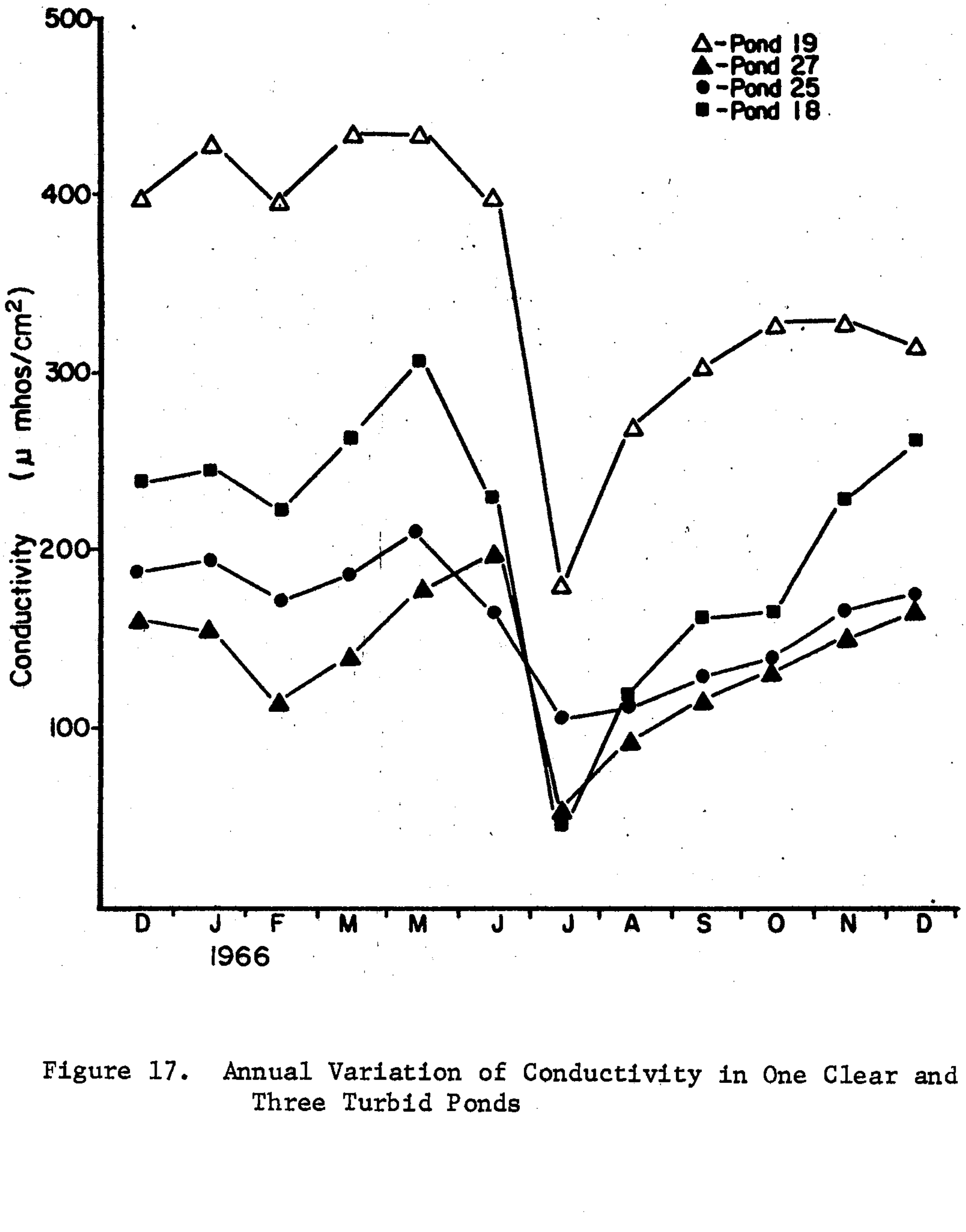

Figure 17. Annual Variation of Conductivity in One Clear and Three Turbid Ponds

The sharp reduction in conductivity in July may have been due to dilution as well as loss of ions from overflow. Twenty ponds overflowed with a loss of ions accumulated by evaporation over extended periods (Fig. 17). Such water loss by overflow depends on the amount of precipitation and the size of the drainage basin.

Morphoedaphic Features Affecting Turbidity

Morphoedaphic features of the ponds and basins seem to be related to turbidity levels in the ponds. A direct relationship was noted between volume/surface area ratio and water transparency (Fig. 18). Larger ratios were usually associated with clearer ponds. The correlation coefficient of 0.50 was significantly different from zero at the 95% confidence level. Smaller ratios occurred in ponds subjected to greater roiling activity by wind and cattle. Roiling by wind action and livestock in the shallower ponds greatly increased turbidity levels by resuspending sediments from the edge of the ponds.

Water transparency decreased as basin size/volume index increased (Fig. 19). The correlation coefficient for drainage basin size/volume index with light transmission was significantly different from zero at the 95% confidence level ($r = -0.49$). Eight turbid and four intermediately turbid ponds had indices which exceeded ten, while six clear ponds had lower indices (Table I, Page 10). In some cases turbid ponds had indices less than ten, but other characteristics of the watershed had profound influences on turbidity of the pond water. Ponds 10 and 16 were extremely turbid (0.9 and 0.0%, respectively), but had lower indices. However, a large part of their watersheds was devoted to plowed fields. Pond 3 and 5 had indices greater than

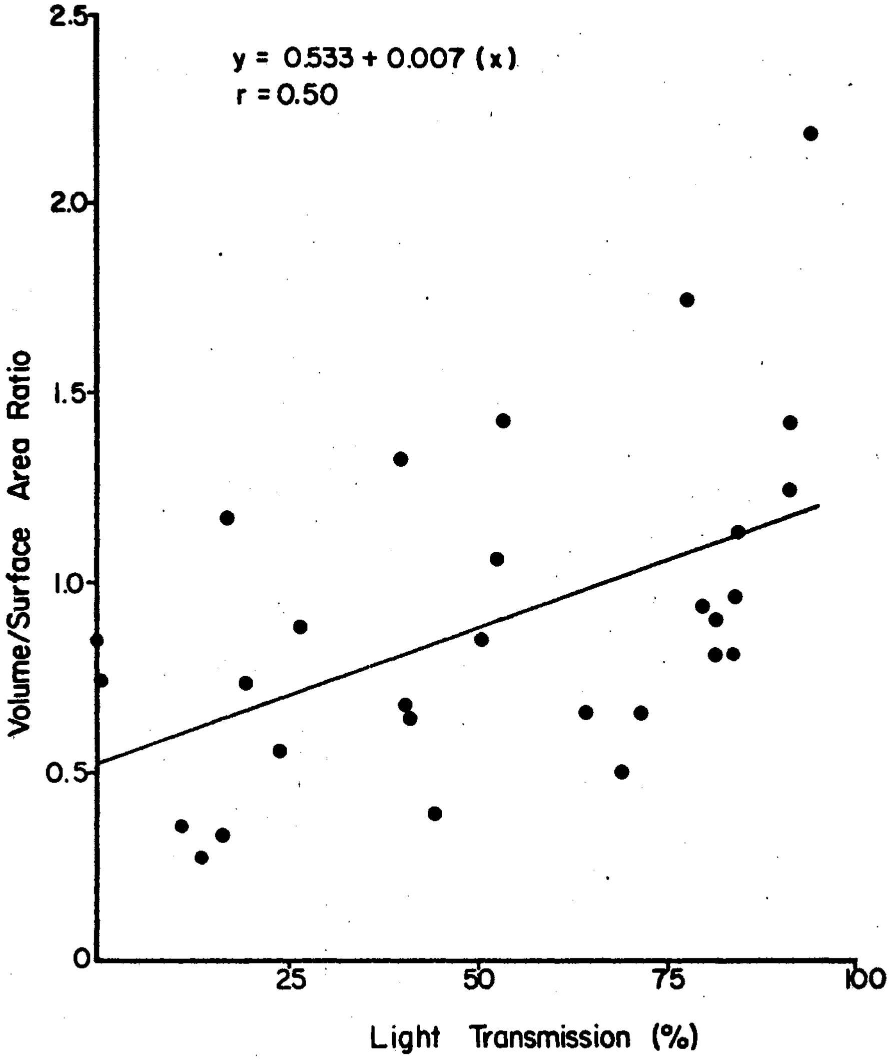

Figure 18. Comparison of Volume/Surface Area Ratio to Light Transmission for All Ponds

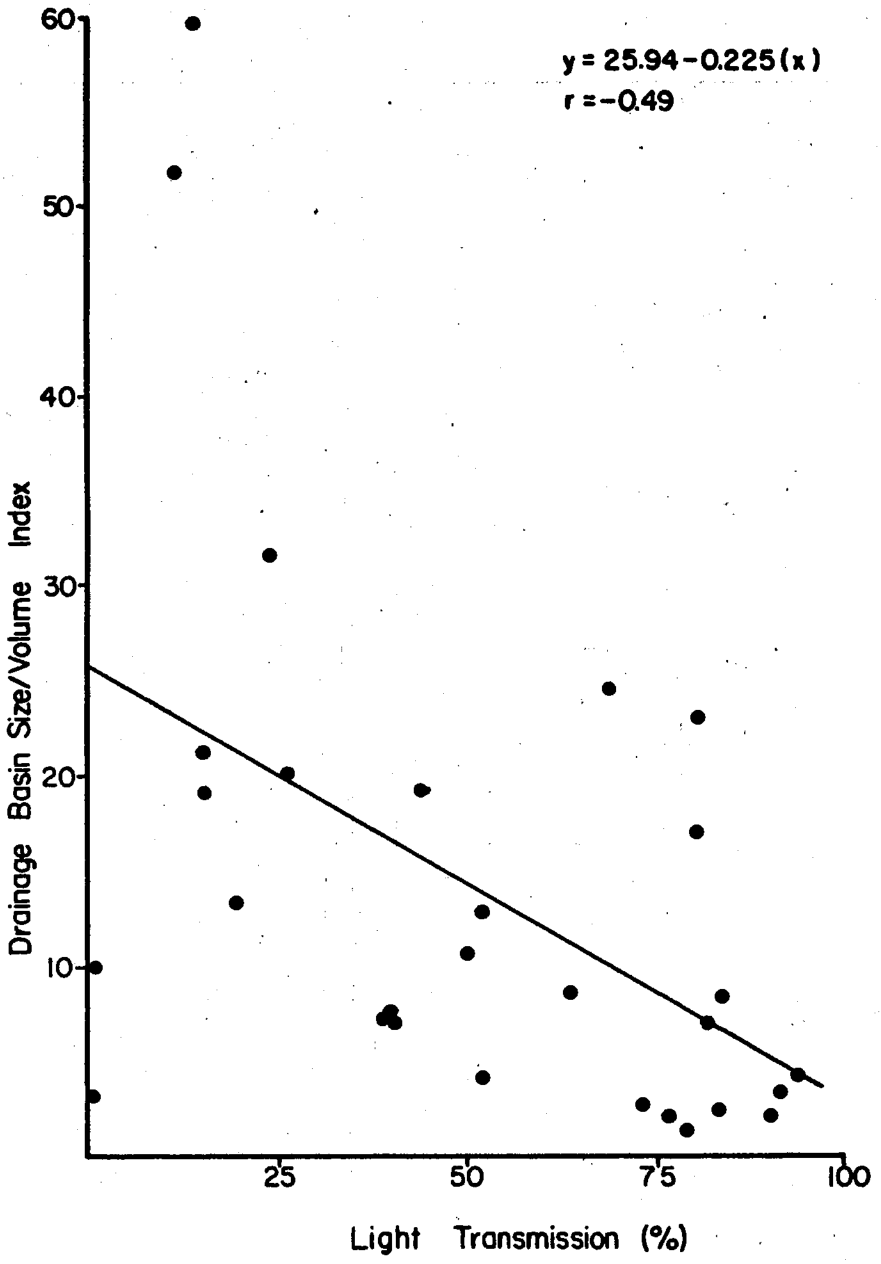

Figure 19. Comparison of Drainage Basin Size/Volume to Light Transmission for All Ponds

50 which resulted in their receiving a great amount of runoff. As would be expected these ponds were turbid.

The effect of a large basin size/volume index was shown in July when twenty ponds overflowed. The overflow resulted in the loss of material accumulated by evaporation prior to the heavy rainfall. Reductions in dissolved solids and conductivity indicate a loss of ions as excess runoff passed through the ponds. In many of the ponds conductivity and dissolved solids were reduced to one-third of previous concentration as overflow carried materials out of the ponds.

The ponds were influenced not only by watershed size, but by condition of the vegetal cover in the watersheds as well. The extent of grazing was reflected in the condition of vegetation, which in turn appeared to reflect some relation to turbidity. Ponds in well grassed watersheds, and not overgrazed by cattle, retained higher light transmissions throughout the study. Pond 23 and 26 with light transmissions of 94.0 and 92.0%, respectively had ungrazed watersheds. The vegetation in the watersheds was quite heavy and apparently prevented the influx of erosional material into the ponds. Other ponds with Type I watersheds (Table I, Page 10) were subjected to proper grazing management. These ponds retained light transmission ranging from 81.9 to 90.8%.

Ponds with Type II watersheds were more turbid (Table I, Page 10). Here grazing was repetitive and often very close which resulted in the exposure of much of the soil to erosion. This apparently was important in the cases of Ponds 4, 9 and 24 where light transmission in each was approximately 41%, but the watershed size/volume indices were less than ten. The deterioration of the vegetal cover evidently resulted in the increased turbidity.

An anomalous condition was noted in Pond 6 which exhibited a relatively high mean annual light transmission (81.9%), yet the watershed was severely overgrazed. Buchloe dactyloides was the dominant plant forming a dense matted growth less than three inches in height. Apparently, the dense vegetal growth reduced erosion.

The high light transmission in Pond 15 (83.7%), which was situated in a Type II watershed, may have been due to seepage of oil field brines from a nearby well.

Hydrogen Ion Concentration and Alkalinity

Light transmission was directly related to pH ($r = 0.64$), since a progressive increase in water transparency occurred at increasing pH levels (Fig. 20). The correlation coefficient was significantly different from zero at the 95% confidence level. Eight of the clear ponds had mean annual pH values above 8.3 with the highest mean value of 9.0 in Pond 26 (Appendix, Table G). The lowest mean pH was 7.2 in Pond 8 which was extremely turbid. Monthly pH values of 6.8 were recorded in February, May and July in Pond 8. Eight additional ponds had a pH of 6.8 in July after heavy rainfall and runoff. Pond 6 exhibited a range of 2.8 pH units (9.6 to 6.8) in the year. In May the pH reached 9.6 with an accompanying depletion of bicarbonate ions. Previously, the pH was 7.6 or lower. A sharp reduction to 6.8 occurred following the rainfall.

Total alkalinity did not appear to be directly related to turbidity since statistically significant differences did not occur

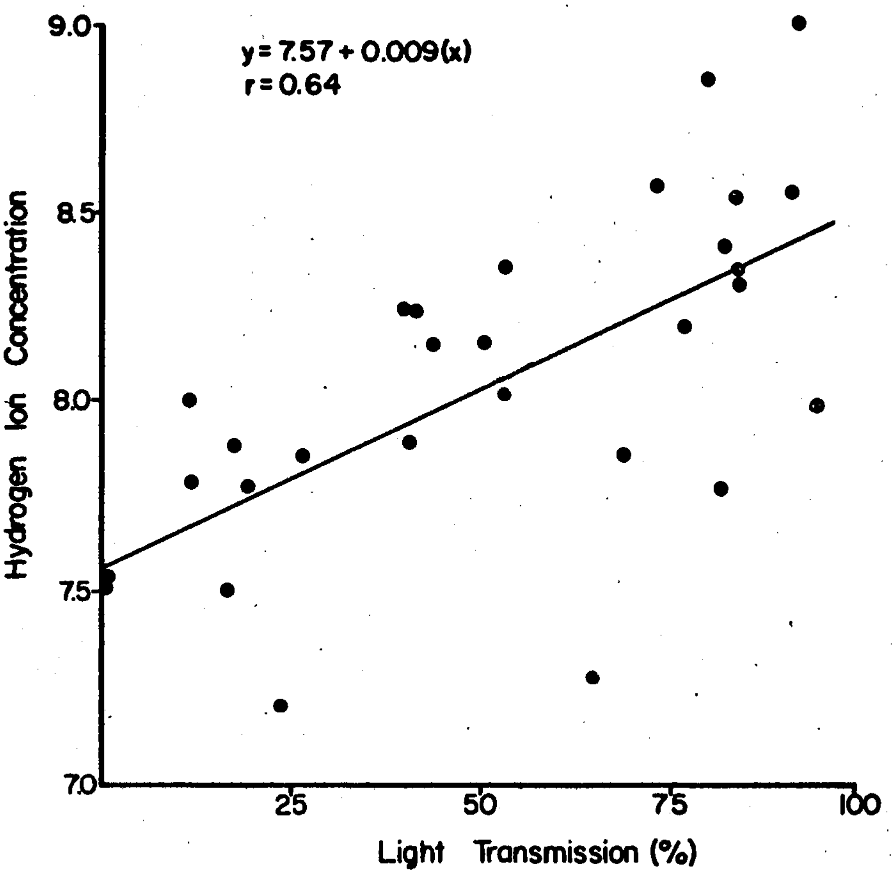

Figure 20. Comparison of Hydrogen Ion Concentration to Light Transmission for All Ponds

among clear, intermediate and turbid ponds. Mean annual total alkalinity ranged from 24.7 to 197.3 ppm (Appendix, Table H). Total alkalinity decreased between December and January followed by a steady increase during the spring months. A sharp reduction was noted in July with the total alkalinity increasing again until a decline occurred in October (Fig. 21).

Bicarbonate ions comprised the major form of alkalinity in turbid ponds; consequently, variations are reflected in total alkalinity curves. Table I (Appendix) shows differences in bicarbonate alkalinity ($\alpha = 0.05$). Aquatic plants can use bicarbonates as a carbon source for photosynthesis when carbon dioxide is limiting (Ruttner, 1953). The breakdown of bicarbonate results in the formation of carbonate ions. Evidently, carbon dioxide was limiting in some of the intermediately turbid and clear ponds during the spring months. In May, 21 ponds had carbonate alkalinity, but by June the number was reduced to only 15 ponds. Carbonate alkalinity was never present in two intermediate and six turbid ponds (Appendix, Table J). However, in some intermediately turbid ponds, carbonates were present in limited amounts from March through June. In the clear ponds, carbonates were present in greater amounts and persisted throughout most of the sample period (Figs. 22 and 23).

Pigment Diversity

Turbidity does not limit successional changes in the phytoplankton of the surface waters in the ponds. Mean annual pigment diversity ratios were similar in all ponds. No statistically significant differences occurred at $\alpha = 0.05$.

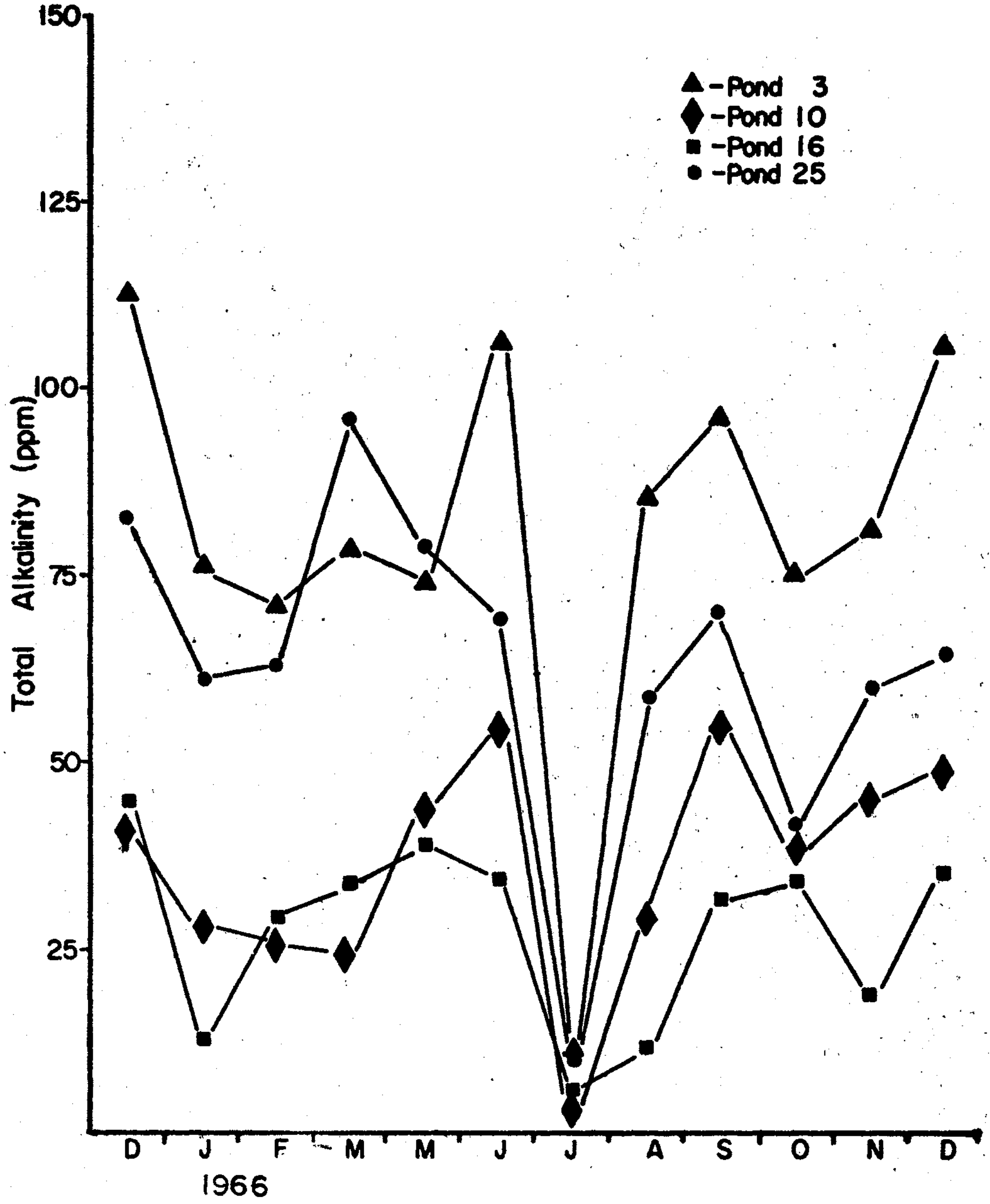

Figure 21. Annual Variation in Total Alkalinity in Four Turbid Ponds

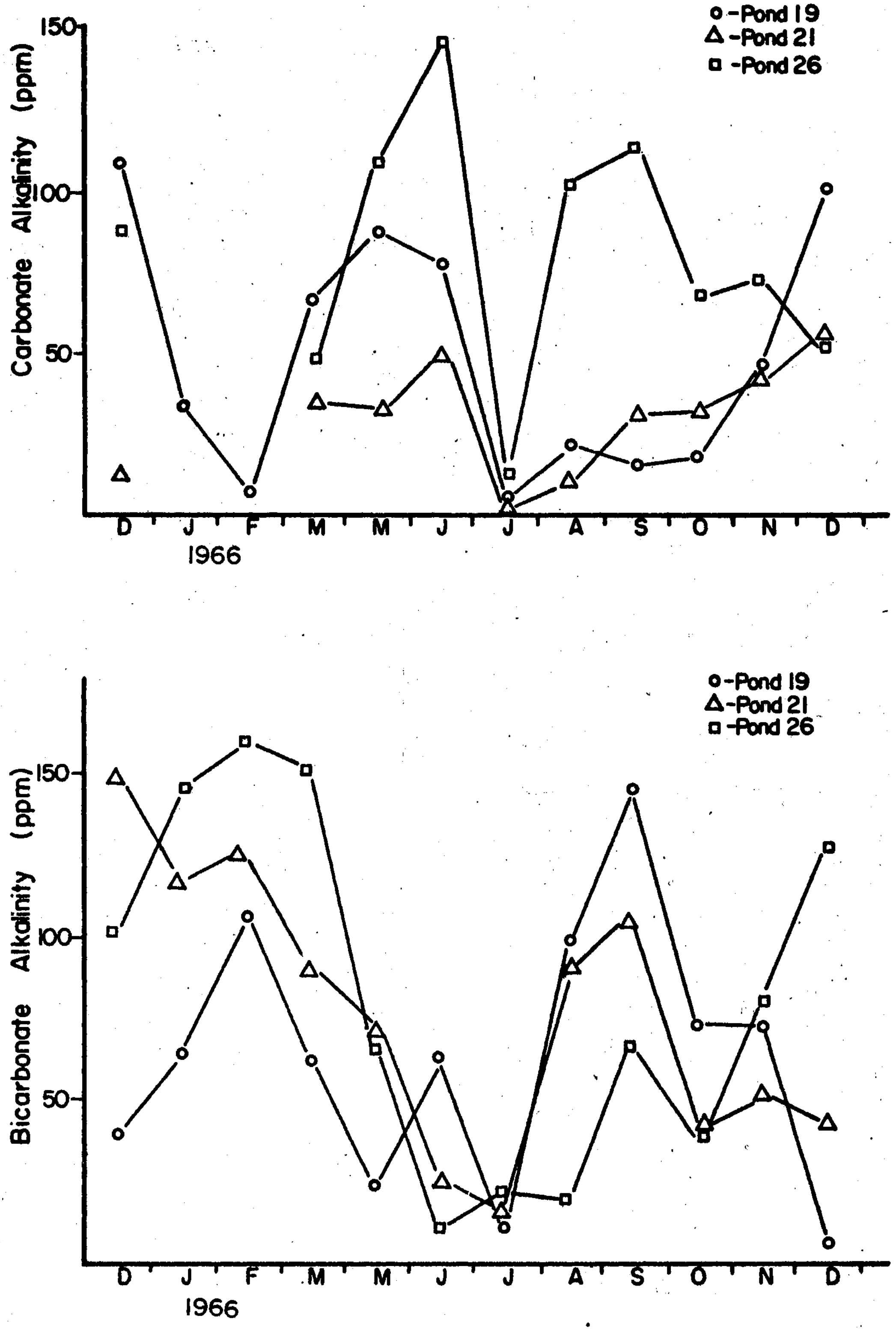

Figure 22. Annual Variation in Bicarbonates and Carbonates of Three Clear Ponds

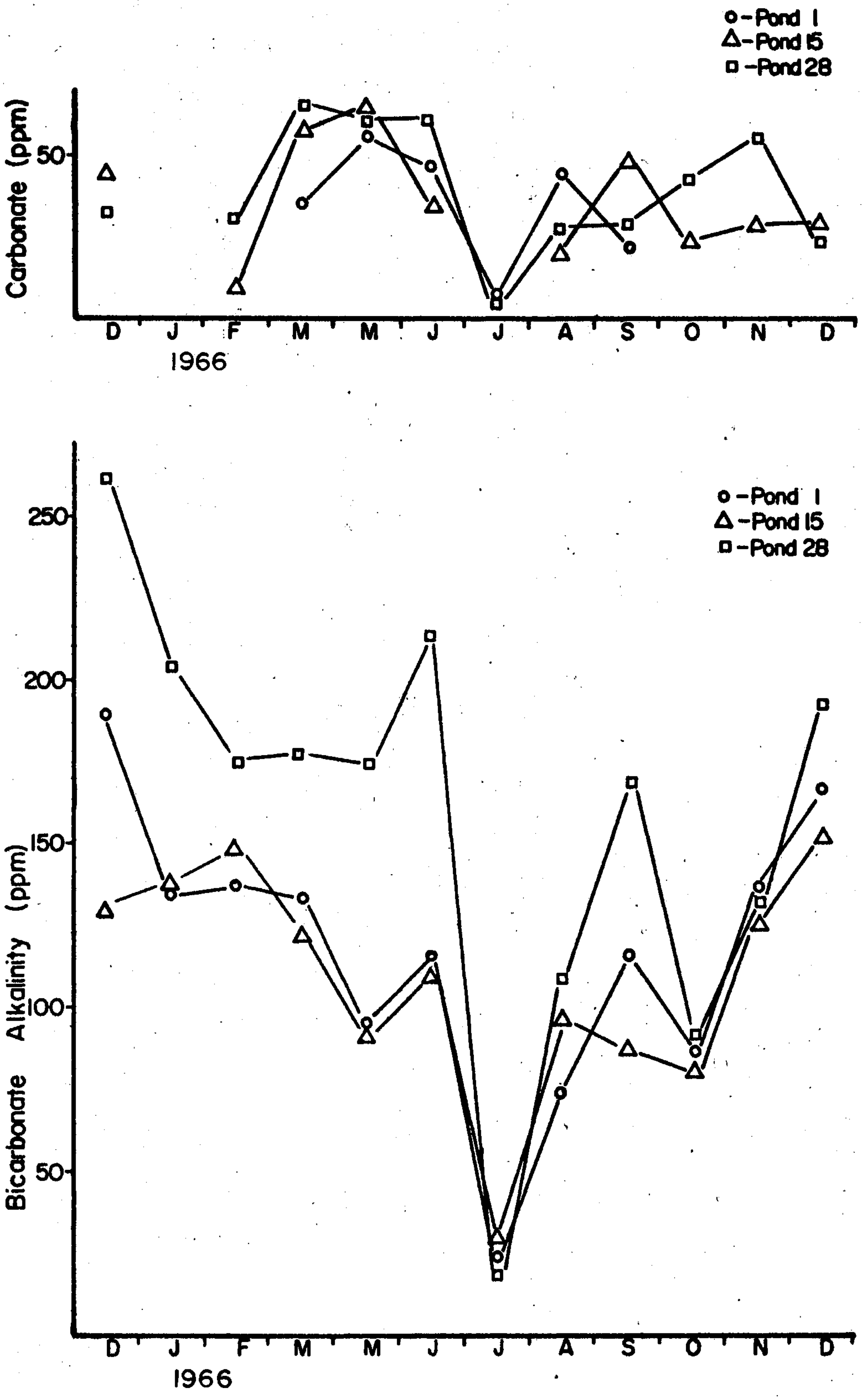

Figure 23. Annual Variation in Bicarbonates and Carbonates of Three Clear Ponds

Pigment diversity changes followed the same seasonal pattern in all ponds. Three clear and three turbid ponds were selected to show these patterns (Fig. 24). Ratios were low during January and February indicating a greater abundance of chlorophyll a. Only four ponds had a ratio greater than 1.0 in January while five ponds had similar values in February. A marked increase in pigment diversity occurred in March through May when all ratios were above 2.0. The high ratios in spring would indicate aging in the phytoplankton populations. Dissolved organic solids were highest during this period apparently due to decomposition of algal cells. Also, chlorophyll a was correspondingly low. In June when chlorophyll a increased, all pigment diversity ratios were below 1.0. A small peak occurred in July following heavy rainfall. Reduction in chlorophyll a concentration occurred concurrently with reductions of total alkalinity, conductivity, dissolved solids and pH. Pigment diversity declined in August, then increased steadily as populations aged during the fall. Chlorophyll a peaked in the autumn in turbid ponds, but carotenoids also increased which resulted in ratios similar to clear ponds.

Chlorophyll a

There was little relationship between chlorophyll a and turbidity among the ponds. Mean annual chlorophyll a concentrations varied from a low of 0.069 to a high of 0.153 mg/l among the ponds. Statistical analysis produced only two homogeneous subsets for chlorophyll a at $\alpha = 0.05$ (Appendix, Table K).

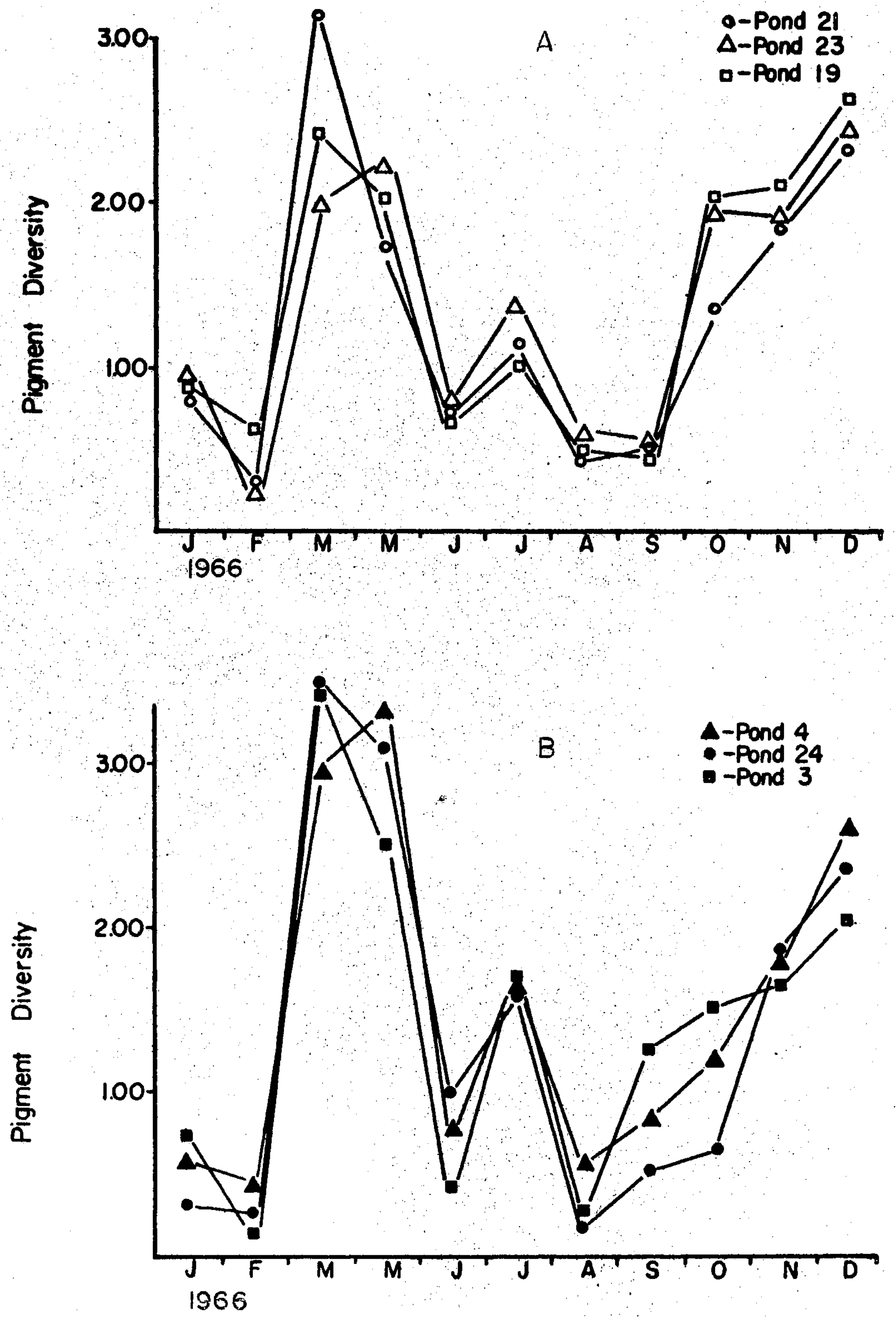

Figure 24. Annual Variation in Pigment Diversity Indices of Three Clear (A) and Three Turbid (B) Ponds

Variations in seasonal patterns for chlorophyll a were dissimilar between clear and turbid ponds. Maxima in chlorophyll a concentrations were observed in clear ponds during January and June (Fig. 25). Chlorophyll a content decreased from the January peak through the spring months to a minimum in May then increased again in June. Chlorophyll a concentrations in these ponds gradually declined again to low concentrations in early winter. Turbid ponds also had peaks in chlorophyll a in late winter and mid-summer; however, an additional peak occurred in late autumn.

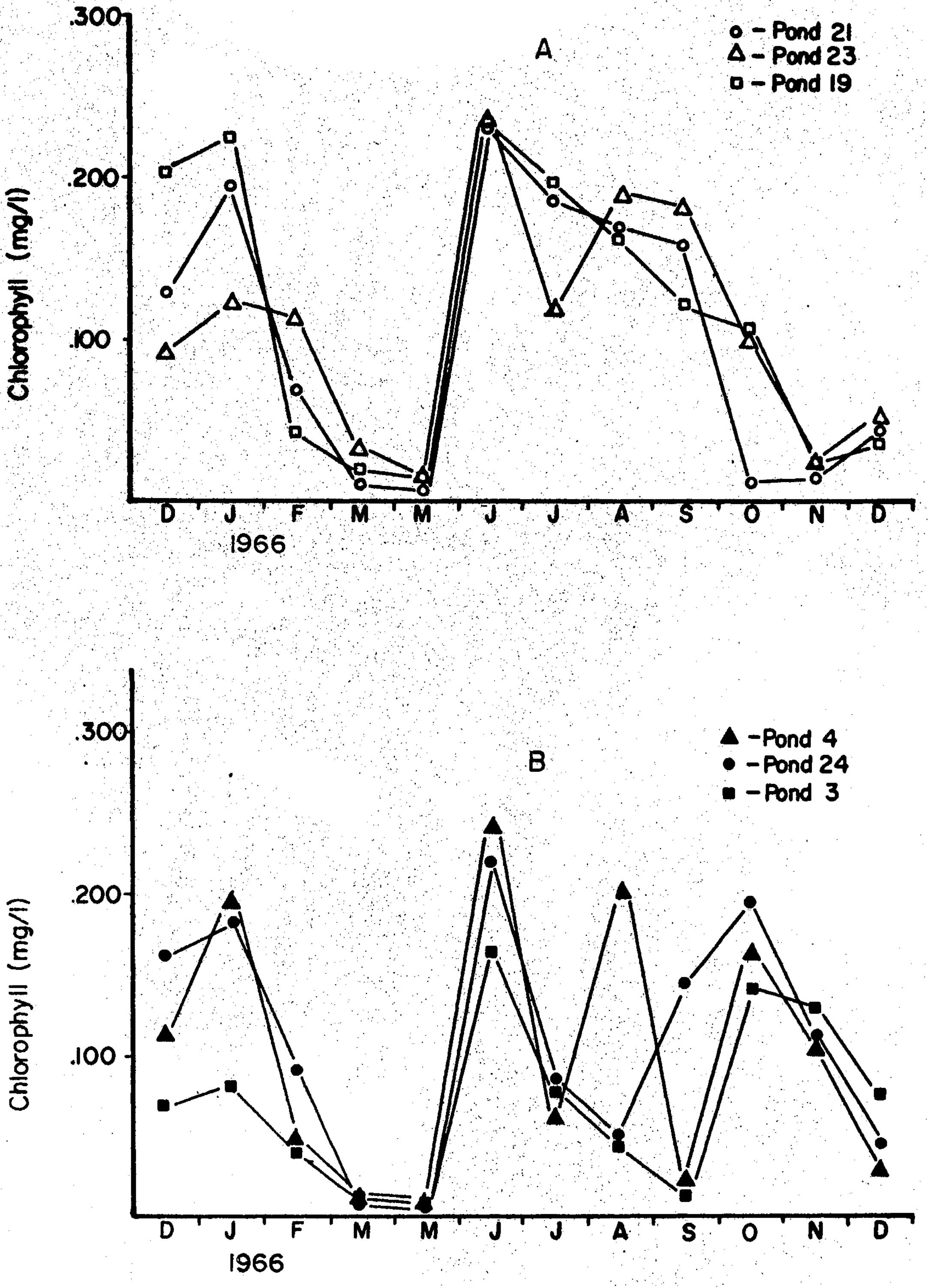

Figure 25. Annual Variation in Chlorophyll _a_ of Three Clear (A) and Three Turbid (B) Ponds

CHAPTER V

DISCUSSION

Many workers have investigated the phenomenon of clay-induced turbidity in natural waters, but none has tried to unify their results into a cohesive theory. This discussion will attempt to reconcile the observations presented here and reported in the literature to achieve some understanding of the clearing mechanism.

Resuspension of sediments by wind action is an important contribution to the high turbidity of Oklahoma waters. Norton (1968) suggested that the turbidity in Lake Carl Blackwell, a 1215 ha impoundment in Oklahoma, was due to suspension of sediments by wind and wave action. He found maximum turbidity of 180 mg/l and a range of 68 to 115 mg/l in areas less than one meter in depth. Turbidity in deeper areas of the lake ranged from 20 to 60 mg/l.

Between 50 and 82% of the particles measured 20 μ or less in the majority of samples taken by Norton. At the end of a 24-hour period only particles with a diameter of 2 μ or less remained in suspension. If wind action on the lake were less, most of the clay particles settled to the bottom. In the lake, finer sediments ($< 8\ \mu$) were deposited in water over 4 m deep while coarser particles were more abundant near the shore.

Wind action also resuspends solids in farm ponds. Ponds having a volume/surface area ratio of less than 1 m generally had higher turbidity. In the clear ponds, the volume/surface area ratios were greater, thus wind action was less and settling of the clay particles resulted in decreased turbidity. These observations plus Norton's observations (1968) implicate gravity as an important mechanism in the clearing of natural waters in Oklahoma.

In addition to gravitational means, chemical mechanisms of clearing clay particles from natural waters have also been proposed. These include theories on electrolytes (Keeton, 1959), dissolved solids (Butler, 1964), hydrogen ions (Irwin and Stevenson, 1951) and hydroxyl ions (Knudson, 1970).

Keeton (1959) used oil field brine to reduce turbidity in farm ponds. This resulted in an increase in conductivity and in the concentration of metal cations. Addition of electrolytes resulted in greater water transparency.

Butler (1964) found that in laboratory microecosystems the optimal level of dissolved inorganic solids was 300 mg/1 when turbidity was between 0 and 25 mg/1. The clearing mechanism functions the same as with electrolytes.

One mechanism explaining clearing by electrolytes or dissolved solids is as follows: The counter-ion atmosphere surrounding clay particles is compressed toward the surface of a clay particle when the electrolyte concentration is increased (van Olphen, 1963). The greater the concentration and the higher the valence of the ions of opposite sign, the more the double layer is compressed. When two ions of different valence are involved, there is a preference by the counter-ion coating for ions of higher valence. The compression thus results in a lessening of the repulsive forces and allows the particle to aggregate.

Single analyses on water from four clear and four turbid ponds in the present study showed Ca 25 and Na 60 mg/l. Keeton (1959) added electrolytes to ponds to decrease turbidity and thus increased Ca and Na to 174 and 201 mg/l, respectively, while the conductivity was increased to 1196 micromhos. Conductivity of the ponds in the present study were half or less than conductivities in ponds cleared by brine. Pond 21 exhibited the highest conductivity and dissolved inorganic solids of 550.6 micromhos and 242.2 mg/l, respectively. Thus, concentrations of metal cations in the water of ponds investigated here appeared to be insufficient to reduce turbidity. This mechanism of clearing clay particles is apparently achieved at high concentrations of electrolytes.

Precipitation of clay particles has been achieved through the use of organic matter and commercial fertilizers. This suggests still another mechanism. Supposedly, the hydrogen ion concentration of the water is increased because decomposition of organic matter yields carbon dioxide and thus increases the concentration of carbonic acid in the water (Irwin and Stevenson, 1951). Dissociation of the carbonic acid yields hydrogen ions which satisfy the negative charges on the clay particles allowing them to aggregate. In laboratory experiments, the above authors were able to clear one liter of water having a turbidity of 440 mg/l with five ml of 0.25 N HCl acid within 24 hours. The initial pH of 8.0 had been reduced to 6.9. As the amount of clay in suspension increased, more hydrogen ions were needed to clear the water. However, Knudson (1970) was unable to clarify turbid water by passing pure CO_2 through it even though the pH was reduced from 7.6 to 5.3. In the present study, hydrogen ion concentrations were greater in turbid ponds.

Knudson (1970) postulated that a natural clearing mechanism exists in ponds through photosynthetic activity of aquatic plants. During intense photosynthesis, hydroxyl ions are produced. These complex with calcium, magnesium and other cations and this complex then aids the precipitation of clay particles. These colloidal hydroxides adsorb cations to form a positively charged sol, which neutralizes the negative charge on the clay particles, permitting them to agglomerate. The hydroxide sol is neutralized and precipitated by negatively charged particles and as this complex precipitates, additional clay particles may be collected and removed. Laboratory observations by Knudson indicated that formation of magnesium, manganese, cupric and ferric hydroxides caused rapid agglomeration in turbid waters, but unfortunately he gave no description of this experiments.

The present study supports elements of Knudson's thesis. High photosynthetic activity is reflected in the high pH and carbonate alkalinity found in clear ponds. The inverse relationship between the hydrogen ion concentration and light transmission and the continued presence of carbonates in clear ponds would indicate that photosynthetic activity of macrophytes could create chemical conditions conducive to the clearing mechanism set forth by Knudson. As colloidal clay particles are resuspended by roiling activity or enter ponds with runoff, they are flocculated in clear ponds with macrophytes, but remain in suspension in turbid ponds without macrophytes.

Aquatic macrophytes were abundant in Ponds 1, 6, 15, 19, 20, 21, 22, 23 and 26 which were all clear ponds. Common species represented were *Najas guadalupensis*, *Ceratophyllum demersum*, *Potamogeton* sp. and *Jussea repens*. Sparse populations of macrophytes were noted in two intermediately turbid ponds (Ponds 17 and 18). The other ponds, all turbid or intermediately turbid, contained no rooted aquatics.

Photosynthetic activity by macrophytes, not phytoplankton, results in clearing since there is little difference in the concentrations of planktonic chlorophyll *a* between clear and turbid ponds. Knudson (1970) also found higher concentrations of pigments in a small turbid pond than in a small clear pond which he studied concurrently. He explained this apparent anomaly by postulating that the narrow euphotic zone in turbid ponds contains higher densities of more productive organisms.

The hydrogen ion mechanism proposed by Irwin and Stevenson (1951) has been invalidated by data of Knudson (1970) and the results of this study. Actually, cations with higher valence are much more effective than hydrogen in causing agglomeration of clay particles (van Olphen, 1963). Irwin and Stevenson (1951) erroneously concluded that hydrogen ions were responsible for the clearing of turbid waters. It is more likely the clearing activity reported by these authors was due to organic substances derived from the decomposition of vegetation or manure which had been added to the ponds.

The electrolyte mechanism proposed earlier and supported in theory and the data of Keeton (1959) might be effective in clearing farm ponds with relatively few suspended particles. However, the concentrations of electrolytes needed to clear highly turbid ponds appear to be out of the range of the concentrations expected in most surface waters.

The hydroxyl ion theory of Knudson (1970) depends on the establishment of macrophytes in the ponds. The presence of macrophytes in the ponds of this study was limited to those with high water transparency. Again this mechanism may be effective in clearing farm ponds with relatively few suspended particles.

The most effective means of clearing turbidity is physical. The morphoedaphic characteristics of the ponds are important in the settling of clay particles. The ponds having greater mean depths are subject to less resuspension of clay particles by roiling action; thus, as clay particles settle out of suspension, the turbidity in the ponds decreases. Such action would account for the annual variations in turbidity of the turbid ponds. As larger particles settle, smaller particles may be entrapped resulting in further clearing. This settling in properly constructed ponds with greater mean depths plus the possible low level clearing action of the electrolyte and hydroxyl mechanisms would result in clear ponds.

Reduction of turbidity in existing ponds could probably be done by managing the watershed. Ponds located in watersheds where grazing had not cropped the vegetation below 6 inches generally had greater water transparency, conductivities, carbonate alkalinities and dissolved solids. Many intermediately turbid ponds in Type II or overgrazed watersheds may be aided by reducing grazing. Extremely turbid ponds in Type III watersheds need terraces and diversion ditches to reduce the influx of erosion material from fields and roadways. These structures may be used to reduce the drainage basin size which is often too large for the capacity of the ponds.

Baumgartner (1949) suggested the fencing of a pond and locating a watering tank outside the fence in order to protect the dam from livestock. This practice would also serve as a means of controlling turbidity created by livestock roiling the pond. Hall (1959) stated that many potentially clear ponds have been made turbid by cattle. As pointed out in this study, cattle do create problems in water transparency of the ponds.

In the construction of new ponds careful consideration should be given to the drainage basin size/pond capacity index. Willrich (1961) suggested that the ratio of watershed area to pond capacity affected turbidity. Drainage basin size should be no larger than ten times the capacity of the pond to reduce the flow of excess runoff through the ponds. The volume/surface area ratio should exceed 1.5 m for ponds of this size, thus limiting the area exposed to roiling activities. All these suggested practices may be effective in the control of turbidity in farm ponds.

CHAPTER VI

SUMMARY

1. A study of physical and chemical conditions and morphoedaphic features as related to turbidity in 29 ponds was conducted from December, 1965 through December, 1966 in Payne and Noble Counties, Oklahoma.
2. Mean annual light transmission varied from 0.0 to 94.0% among the ponds. Fluctuations in light transmission were evidently caused by rainfall and runoff, wind action, plankton and roiling by livestock and waterfowl.
3. Morphoedaphic features such as removal of watershed vegetation by grazing, drainage basin size/pond volume index and pond volume/surface area ratio appeared to influence turbidity level of the ponds.
4. Dissolved solids were directly related to light transmission. Total solids concentrations were greater in turbid ponds with values often exceeding 500 mg/l. The major portion of the total solids in the turbid ponds was particulate inorganic solids.
5. Conductivity was generally greater in clear ponds and annual variations occurred with dilution by runoff and evaporation; consequently, conductivity was inversely related to water levels.

6. An inverse relationship between hydrogen ion concentration and turbidity of the ponds was noted. Clear ponds generally had a higher pH.
7. Mean annual total alkalinity ranged from 24.7 to 197.3 ppm among the ponds. Bicarbonate ions comprised the major form of alkalinity in turbid ponds. Carbonate alkalinity was never present in two intermediate and six turbid ponds. In the clear ponds, carbonates were present in greater amounts and persisted throughout most of the study.
8. Statistical analysis shows few differences among the ponds for chlorophyll _a_ in the surface waters. Mean annual chlorophyll _a_ concentration varied from 0.069 to 0.153 mg/1 among the ponds.
9. Annual variations in pigment diversity were similar in all ponds and no statistical differences were found for various turbidities.
10. In the settling of clay particles gravitational means appear to be important in these small impoundments. Ponds having a volume/surface area ratio of less than one meter generally had higher turbidity. The higher turbidity resulted from resuspension of inorganic particles from the exposed shoreline by wind action.
11. Turbidity in existing ponds may be reduced by proper management of drainage basins to control the influx of erosion material.

12. Future research might be directed toward the effects of multivalent cations, such as Fe, and organic products of macrophytes on the clearing of suspended clay particles.

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APPENDIX

TABLE A

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN LIGHT TRANSMISSION OF POND WATER

Light Transmission (%) Annual $\bar{X}$	Pond Identification	Rank									
0.0	16	1	│								
0.9	10	2	│								
12.3	3	3	│	│							
14.1	5	4	│	│							
16.5	25	5		│							
17.3	12	6		│							
19.1	27	7		│							
24.1	8	8		│							
27.3	13	9		│	│						
40.4	4	10			│	│					
40.9	24	11			│	│					
41.1	9	12			│	│					
44.5	14	13				│					
50.5	11	14				│	│				
52.9	7	15				│	│				
53.4	2	16				│	│				
63.7	29	17					│	│			
68.6	18	18						│	│		
72.5	28	19						│	│		
76.9	17	20						│	│	│	
79.9	19	21							│	│	│
81.5	6	22							│	│	│
81.9	1	23							│	│	│
83.8	15	24							│	│	│
83.8	22	25							│	│	│
84.3	20	26							│	│	│
90.8	21	27							│	│	│
92.0	26	28								│	│
94.0	23	29									│

TABLE B

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN TOTAL DISSOLVED SOLIDS

Light Transmission (%) Annual $\overline{X}$	Total Dissolved Solids (mg/l) Annual $\overline{X}$	Pond Identification	Rank
81.5	68.5	6	1
27.3	86.8	13	2
16.5	97.2	25	3
94.0	101.2	23	4
19.1	107.3	27	5
0.9	111.7	10	6
0.0	112.0	16	7
68.6	117.7	18	8
41.1	128.0	9	9
12.3	131.7	3	10
76.9	142.8	17	11
17.3	143.0	12	12
44.5	148.0	14	13
40.9	153.8	24	14
14.1	164.7	5	15
40.4	167.8	4	16
24.1	168.3	8	17
50.5	180.3	11	18
83.8	183.5	22	19
63.7	190.5	29	20
79.9	197.8	19	21
52.9	206.7	7	22
83.8	227.2	15	23
81.9	230.3	1	24
84.3	230.8	20	25
92.0	234.7	26	26
53.4	301.0	2	27
90.8	335.0	21	28
72.5	358.7	28	29

TABLE C

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DISSOLVED ORGANIC SOLIDS

Light Transmission (%) Annual $\bar{X}$	Dissolved Organic Solids (mg/l) Annual $\bar{X}$	Pond Identification	Rank
27.3	34.5	13	1
81.6	36.8	6	2
16.5	38.8	25	3
63.7	39.0	29	4
0.0	40.3	16	5
19.1	40.8	27	6
24.1	44.8	8	7
0.9	48.2	10	8
94.0	48.5	23	9
68.6	48.7	18	10
41.1	58.7	9	11
44.5	60.2	14	12
12.3	60.5	3	13
17.3	60.5	12	14
52.9	64.3	7	15
40.4	65.5	4	16
76.9	67.5	17	17
40.9	67.8	24	18
84.3	70.5	20	19
50.5	72.7	11	20
14.1	80.3	5	21
83.8	83.8	22	22
79.9	84.8	19	23
53.4	92.3	2	24
90.8	95.3	21	25
83.8	101.3	15	26
81.9	105.3	1	27
92.0	113.7	26	28
72.5	160.0	28	29

TABLE D

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN DISSOLVED INORGANIC SOLIDS

Light Transmission (%) Annual $\overline{X}$	Dissolved Inorganic Solids (mg/l) Annual $\overline{X}$	Pond Identification	Rank
81.6	31.7	6	1
44.5	52.3	13	2
94.0	52.7	23	3
16.5	58.3	25	4
0.9	63.5	10	5
19.1	66.5	27	6
68.6	69.0	18	7
41.1	69.3	9	8
12.3	71.2	3	9
0.0	71.7	16	10
76.9	75.3	17	11
17.3	82.5	12	12
14.1	84.3	5	13
40.9	86.0	24	14
44.5	87.8	14	15
83.8	99.7	22	16
40.4	102.3	4	17
50.5	107.7	11	18
79.9	113.0	19	19
92.0	121.0	26	20
24.1	123.5	8	21
81.9	125.0	1	22
83.8	125.8	15	23
52.9	142.3	7	24
63.7	151.5	29	25
84.3	160.3	20	26
72.5	198.7	28	27
53.4	208.7	2	28
90.8	242.2	21	29

TABLE E

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN TOTAL SOLIDS CONTENT

Light Transmission (%) Annual $\bar{X}$	Total Solids (mg/1) Annual $\bar{X}$	Pond Identification	Rank
81.6	88.2	6	1
94.0	107.3	23	2
68.6	175.7	18	3
76.9	183.2	17	4
83.8	220.3	22	5
40.9	242.0	24	6
27.3	250.2	13	7
83.8	253.2	15	8
79.9	258.3	19	9
63.7	261.8	29	10
50.5	264.0	11	11
92.0	273.7	26	12
81.9	275.0	1	13
40.4	288.9	4	14
84.3	289.5	20	15
52.9	290.3	7	16
41.1	291.0	9	17
44.5	297.3	14	18
16.5	304.0	25	19
19.1	308.7	27	20
53.4	355.0	2	21
90.8	356.7	21	22
12.3	367.5	3	23
72.5	376.5	28	24
17.3	510.8	12	25
14.1	514.7	5	26
24.1	521.2	8	27
0.9	887.5	10	28
0.0	1461.8	16	29

TABLE F

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN CONDUCTIVITY

Light Transmission (%) Annual $\bar{X}$	Conductivity (umhos/cm^2) Annual $\bar{X}$	Pond Identification	Rank
81.9	97.0	6	1
0.9	135.3	10	2
19.1	140.3	27	3
0.0	143.7	16	4
27.3	162.4	13	5
16.5	162.6	25	6
94.0	182.3	23	7
68.6	205.7	18	8
41.1	226.7	9	9
12.3	236.4	3	10
17.3	244.8	12	11
24.1	260.2	8	12
76.9	260.9	17	13
44.5	281.6	14	14
40.9	284.8	24	15
83.8	286.8	22	16
14.1	291.0	5	17
40.4	298.4	4	18
63.7	318.4	29	19
52.9	332.8	7	20
50.5	338.2	11	21
79.9	353.4	19	22
83.8	370.1	15	23
81.9	371.8	1	24
92.0	423.3	26	25
84.3	430.0	20	26
53.4	478.6	2	27
72.5	526.3	28	28
90.8	550.6	21	29

TABLE G

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN HYDROGEN ION CONCENTRATION

Light Transmission (%) Annual $\overline{X}$	Hydrogen Ion Concentration Annual $\overline{X}$	Pond Identification	Rank
24.1	7.2	8	1
63.7	7.3	29	2
17.3	7.5	12	3
0.9	7.5	10	4
0.0	7.5	16	5
19.1	7.7	27	6
81.6	7.7	6	7
12.3	7.8	3	8
68.6	7.8	18	9
27.3	7.9	13	10
16.5	7.9	25	11
41.1	7.9	9	12
94.0	7.9	23	13
14.1	8.0	4	14
52.9	8.1	7	15
44.5	8.1	14	16
50.5	8.2	11	17
76.9	8.2	17	18
40.4	8.2	4	19
40.9	8.3	24	20
53.4	8.3	2	21
83.8	8.3	22	22
84.3	8.3	20	23
81.9	8.4	1	24
83.8	8.5	15	25
90.8	8.5	21	26
72.5	8.6	28	27
79.9	8.9	19	28
92.0	9.0	26	29

TABLE H

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN TOTAL ALKALINITY

Light Transmission (%) Annual $\bar{X}$	Total Alkalinity (ppm) Annual $\bar{X}$	Pond Identification	Rank
24.1	24.7	8	1
63.7	26.2	29	2
0.0	28.0	16	3
81.6	35.8	6	4
0.9	36.6	10	5
17.3	41.5	12	6
19.1	44.7	27	7
16.5	62.9	25	8
27.3	66.3	13	9
94.0	70.8	23	10
41.1	75.4	9	11
68.6	82.3	18	12
83.8	82.4	22	13
12.3	82.8	3	14
52.9	85.3	7	15
76.9	93.2	17	16
84.3	98.2	20	17
40.9	100.2	24	18
90.8	103.3	21	19
44.5	110.7	14	20
79.9	112.5	19	21
50.5	115.7	11	22
14.1	121.3	5	23
40.4	125.4	4	24
81.9	135.9	1	25
83.8	142.3	15	26
92.0	151.3	26	27
53.4	153.3	2	28
72.5	197.3	28	29

TABLE I

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN BICARBONATE ALKALINITY

Light Transmission (%) Annual $\bar{X}$	Bicarbonate Alkalinity (ppm) Annual $\bar{X}$	Pond Identification	Rank										
24.1	24.7	8	1	|									
63.7	26.2	29	2	|									
0.0	28.0	16	3	|									
81.6	28.8	6	4	|									
0.9	36.6	10	5	|									
17.3	41.5	12	6	|	|								
19.1	44.7	27	7	|	|	|							
16.5	62.9	25	8		|	|	|						
27.3	64.2	13	9		|	|	|	|					
79.9	65.8	19	10			|	|	|					
94.0	67.4	23	11			|	|	|					
83.8	71.4	22	12				|	|	|				
41.1	75.4	9	13				|	|	|				
90.8	78.3	21	14				|	|	|	|			
52.9	80.4	7	15				|	|	|	|			
68.6	80.8	18	16				|	|	|	|			
12.3	81.2	3	17				|	|	|	|			
84.3	81.7	20	18				|	|	|	|			
92.0	84.3	26	19				|	|	|	|			
76.9	88.7	17	20					|	|	|	|		
40.9	95.8	24	21						|	|	|	|	
44.5	102.2	14	22							|	|	|	
83.8	109.3	15	23								|	|	
50.5	111.5	11	24								|	|	
40.4	116.9	4	25									|	
81.9	118.4	1	26									|	|
14.1	119.1	5	27									|	|
53.4	139.8	2	28										|
72.5	160.8	28	29										

TABLE J

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN CARBONATE ALKALINITY

Light Transmission (%) Annual $\overline{X}$	Carbonate Alkalinity (ppm) Annual $\overline{X}$	Pond Identification	Rank
24.1	0.0	8	1
41.1	0.0	9	2
0.9	0.0	10	3
17.3	0.0	12	4
0.0	0.0	16	5
16.5	0.0	25	6
19.1	0.0	27	7
63.7	0.0	29	8
68.6	1.5	18	9
12.3	1.7	3	10
14.1	2.2	5	11
27.3	2.2	13	12
94.0	3.3	23	13
50.5	4.2	11	14
40.9	4.3	24	15
76.9	4.5	17	16
52.9	4.8	7	17
81.6	6.8	6	18
40.5	8.5	4	19
44.5	8.5	14	20
83.8	11.0	22	21
53.4	13.5	2	22
84.3	14.5	20	23
81.9	17.5	1	24
90.8	25.0	21	25
83.8	31.2	15	26
72.5	36.5	28	27
79.9	46.7	19	28
92.0	67.0	26	29

TABLE K

DUNCAN'S MULTIPLE RANGE TEST ($\alpha = 0.05$) FOR DIFFERENCES IN CHLOROPHYLL *a*

Light Transmission (%) Annual $\bar{X}$	Chlorophyll *a* (mg/1) Annual $\bar{X}$	Pond Identification	Rank
50.5	0.069	11	1
12.3	0.069	3	2
0.0	0.070	16	3
81.6	0.078	6	4
53.4	0.084	2	5
24.1	0.088	8	6
19.1	0.088	27	7
92.0	0.089	26	8
52.9	0.092	7	9
83.8	0.094	15	10
17.3	0.096	12	11
76.9	0.097	17	12
63.7	0.098	29	13
27.3	0.099	13	14
44.5	0.099	14	15
16.5	0.101	25	16
40.4	0.102	4	17
90.8	0.103	21	18
83.8	0.105	22	19
94.0	0.107	23	20
40.9	0.110	24	21
81.9	0.110	1	22
68.6	0.110	18	23
79.9	0.114	19	24
0.9	0.114	10	25
84.3	0.116	20	26
14.1	0.119	5	27
41.1	0.120	9	28
72.5	0.153	28	29

VITA

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