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SUMMARY AND ANALYSIS OF THE WATER QUALITY MONITORING PROGRAM FROM 1973 to 1978

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Division of Fish and Wildlife
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SUMMARY AND ANALYSIS OF THE WATER QUALITY MONITORING PROGRAM FROM 1973 to 1978

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Summary

Mean summer surface values in hardwater lakes ampled were pH-8.4, total alkalinity-141.1 ppm, sulfates-11.3 ppm, chlorides-34.4 ppm, secchi disc-4.8 ft., total phosphorus-0.08 ppm and nitrogen-1.11 ppm. Mean summer surface values in the softwater lakes sampled were pH-7.3, total alkalinity-25.6 ppm, sulfates-4.2 ppm, chlorides-4.6 ppm, secchi disc-9.5 ft., total phosphorus-0.04 ppm and total nitrogen-0.88.

From spring to summer in the study lakes the pH increases about 0.2 to 0.3 units in the surface waters. In the hardwater lakes there was a 8.5 ppm loss of carbonates in the surface waters from spring to summer and a gain of 3.8 ppm in the surface waters of the softwater lakes. The gain of carbonates in the bottom waters from spring to summer was 1.6 (softwater lakes) and 2.0 ppm hardwater lakes. Hardwater lakes lose sulfates. Chlorides decreased slightly and increased slightly in the hardwater and softwater lakes respectively.

There was little change in the secchi disc transparency in the softwater lakes (9.5 ft. summer average) and a 1.8 decrease from spring to summer in the hardwater lakes (4.8 ft. summer average). There was a gain of phosphorus in the softwater (0.01 ppm) and hardwater lakes (0.06 ppm) from spring to summer. The amount of nitrogen in the surface waters was about the same in the softwater lakes (0.88 ppm - summer surface) and hardwater lakes (1.11 ppm) but the proportion of organic nitrogen was higher in the surface waters and lower in the bottom waters.

The relative age of a lake can be set on a scale of zero to 100 (trophic state index number or TSI) with low numbers, less than 40, showing that a lake is young (oligotrophic). Numbers ranging from 40 to 60 mean that a lake is middle aged (mesotrophic), and high numbers indicate advanced age (eutrophic). Most walleye and panfish lakes are middle aged, lake trout lakes have young basins, and rough fish lakes have old basins. It has been determined that Carlson's trophic state index (TSI) which summarizes chemical parameters into expected water transparency values is useful to assess interrelationships between variables and visualize the effect of a change on a lake.

The amount of rooted plant life present in the hardwater mesotrophic (middle aged) lakes was about 4 times higher than it was in the hardwater eutrophic and softwater oligotrophic lakes and 5 times higher than it was in the softwater mesotrophic lakes.

From 1973 to 1978 the range of secchi disc values show the relative ages (trophic state or TSI) of the study lakes to range from 36 to 66 which is similar to the 37 to 61 range calculated for the background data, but the 55 to 77 range for total phosphorus is 10 to 11 TSI units higher than the background data. This difference is larger than is usually found from year to year in a lake (Table 3).

Tables 1 and 2 summarize the results of the summer sampling. The trophic state of the softwater oligotrophic study lakes was 41.7, 49.6 in softwater mesotrophic lakes, 50.8 in hardwater mesotrophic lakes, and 71.5 in the hardwater eutrophic lakes. The TSI values for phosphorus was higher than the values for the other sample parameters. This suggests that many lakes have an excess of phosphorus. See Table 16 for list of lakes.

Table 1. Trophic State Index of the Study Lakes Parameters (Secchi disc, Plant Density/T. Alkalinity, Chlorophyll, T. Phosphorus, Total Nitrogen) from 1973 thru 1978 and from July and August sampling

Lake Type	Parameter					
	Mean $\overline{X}$	Secchi Disc	Plant Density/ T. Alk.	Chlorophyll	Total Phosphorus	Total Nitrogen
Softwater Oligotrophic	41.7	35.7	38.2	43.7	53.3	37.8
Softwater Mesotrophic	49.6	50.0	49.7	45.9	56.6	45.8
Hardwater Mesotrophic	50.8	48.5	50.6	52.5	57.5	44.7
Hardwater Eutrophic	71.5	63.9	63.9	73.5	75.2	81.0

Table 2. Average Amount of Water Transparency, Plant Density, Total Alkalinity, Chlorophyll, Phosphorus, and Nitrogen in the Study Lakes from 1973 to 1978 in the July and August Sampling

Lake Type	Water Transp. ft. (Meters)	Plant Density Units	Total Alkalinity (p.p.m.)	Chlorophyll (p.p.b.)	Total Phosphorus (p.p.m.)	Nitrogen (p.p.m.) Total (org.)
Softwater Oligotrophic	17.7 (5.3)	860.1	19.5	3.82	0.030	0.39 (0.28)
Softwater Mesotrophic	6.6 (2.0)	523.5	27.7	4.75	0.038	0.89 (0.75)
Hardwater Mesotrophic	7.7 (2.3)	2677.2	149.1	9.4	0.041	0.84 (0.72)
Hardwater Eutrophic	2.5 (0.8)	754.9	150.1	79.3	0.138	1.52 (1.33)

Table 3. Comparison of the Trophic Status of Minnesota Lakes Before 1951 and from 1973-1976

Item	Total Phosphorus			Secchi Disc		
	Before	After	Difference	Before	After	Difference
Softwater Lakes						
Oligotrophic	45.6	53.2	+ 7.6	37.0	35.7	- 1.3
Mesotrophic	47.4	56.6	+ 9.2*	48.6	50.0	+ 1.4
Hardwater Lakes						
Mesotrophic	53.9	58.4	+ 4.5	44.1	51.8	+ 7.7*
Eutrophic	65.4	76.8	+11.4*	61.2	66.2	+ 5.0*
Average Between years in a lake	--	--	8.7	--	--	3.8

*Higher than average

INTRODUCTION

Since the water quality monitoring program was initiated in 1973, 15 lakes have been sampled twice (5 each year on a three year rotation). The objective of the program was to detect any long term trends and to determine how much short term variation is characteristic of the parameters monitored. Some background data is available to be used as a reference when the sample values are being evaluated. The objective of this report is to determine the status of the lakes sampled, how much variation might be expected between yearly samples, between spring and summer samples, and between the surface and bottom samples.

Moyle (1952) summarized much of the water chemistry data, Peterson (1972) summarized the water transparency data. Carlson (1977) presented a trophic state index that can be used as a guide for evaluating data. Moyle (1968) presents values useful for determining whether a lake is eutrophic or mesotrophic. Eddy (1966) summarized much of the early limnological work. Tables 3 and 4 summarize the background data available (Moyle 1968, Eddy 1966, Peterson 1972). Moyle (1968) notes that in lakes with algal blooms the average and median amounts of water transparency, total phosphorus, and total nitrogen were 3.0 and 2.5 ft., 0.15 and 0.07 ppm, and 1.40 and 0.93 ppm respectively. Using Carlson's trophic state index (TSI), the median and average TSI values from water transparency were 61.3 and 63.9 respectively and for total phosphorus were 76.4 and 65.4 respectively. The mean and median nitrogen and phosphorus ratios were 15.3 and 10.9 respectively. The average and maximum depths were 10.6 and 24 feet. Surface temperatures were about 76^{o}F (range 65-83^{o}F) and bottom temperatures were 14 degrees lower in lakes with a thermocline and 1.9 degrees lower than the surface temperature in lakes without a thermocline. In the surface waters the average amount of dissolved oxygen was 9.0 ppm (range 5.5-15.6), and was 3.5 ppm (range 0 to 10.8) in the deepest part of the lake. (In lakes with a thermocline the dissolved oxygen at the bottom was 8.3 ppm (range 5.8 to 10.9) lower than the surface oxygen). In lakes without a thermocline the dissolved oxygen was 4.8 ppm (range 0 to 15.6) lower in the deepest part of the lake.

Eddy (1966) notes that stratified eutrophic lakes have little or no dissolved oxygen below the thermocline late in the summer and that good oligotrophic lakes have ample dissolved oxygen for fish life below the thermocline late in the summer. Lake trout commonly use the colder water below the thermocline. Peterson notes that the lower estimated transparency values in Minnesota's lake trout lakes were 10.5 to 14.5 feet which is a trophic state index range of 38.5 to 43.2 (average 37.1). Eightly percent of the walleye and centrarchid lakes have a transparency range of 3.5 to 14.5 feet, trophic state index values of 38.6 to 59.1 respectively. The recorded range of transparencies in Minnesota is 0.25 to 30 feet or a trophic state index value of 28.1 to 97.1 respectively.

Table 4 is a compilation of data from several sources and comprises a best estimate of conditions in various types of lakes, mostly before 1953. Carlson's trophic state index was calculated for the secchi disc transparency and the total phosphorus. This shows that the lake trout lakes border on being oligotrophic, plankton bloom (rough fish) lakes are eutrophic, and the other lakes (panfish and walleye) are mesotrophic. In Carlson's paper, the mesotrophic range is 40-60, approximately the 38.6 to 59.1 range for walleye and centrarchid lakes.

METHODS

For many years it has been difficult to make any real estimate of the amount of rooted aquatic plant life in an ordinary lake. As a substitute we use the current dual methods of estimating average density (presence/no sample) at the stations where a species is present and the percent occurrence of a species at all the stations investigated. This does not give any estimate of the total amount of plant life (all species) at all the sampling stations. However, if the density rating for each species is multiplied by the percentage of occurrence and the products are added, a useable composite figure (the sum of the weighted densities) is obtained. Since the samples are separated by depth, the results for each depth table must be summed to obtain a total sum of the densities. To be useful, this year to year data must be analyzed to determine if there has been a change. This can be done by comparing the sum of the densities with expected densities. When several species are present a regression line can be calculated for a lakes data to determine if there is a correlation between years. The slope of the line is one if there is no change (values significantly different than one indicate a decrease or increase in biomass).

Water quality data were tabulated from water quality monitoring reports for 1973-78. T-test and correlation values were calculated to compare changes in surface and bottom from spring to summer. These tests were also used to compare differences between surface and bottom in spring and summer.

Table 11 lists t-test and correlation values for this set of water quality data. Table 10 gives the means for all water quality parameters monitored except total nitrogen and its combined forms. Means and medians for the various nitrogen concentrations are listed separately in Table 8.

Mean values in Table 10 were calculated only from data where there were values for both spring and summer in one year. This was to offset any large differences between means of spring and summer values that might have occurred if values from lakes sampled only in spring or summer were to be included. The maximum number of pairs for any test was only 18 for hardwater lakes and 12 for the softwater lakes.

Means for total nitrogen and its combined forms were calculated from all detectable values in spring and summer. For some nitrogen compounds, there were very few paired data for both spring and summer which were detectable values (less than 3 pairs in some cases).

To determine if Carlson's index was a useful tool, Carlson's basic equations were recalculated using the study lake data. Table 15 shows that similar equations were obtained. Therefore, the index for chlorophyll, water transparency, and total phosphorous was calculated as proposed.

RESULTS

Temperature and Oxygen Characteristics

Average surface water temperatures corrected to the same date ranged from 7^o to 13^o C on May 19 and 17^o to 24^o on July 31 in the various study lakes. The oligotrophic lakes were coldest and the mesotrophic and eutrophic lakes were warmest. Some thermal stratification was present by May 19 and the average temperature at 10 meters ranged from 6^o to 9^o degrees C. Most lakes can warm to 6^o C (43^o F) before there is any evidence of thermal stratification. The average surface temperature when there was 1^o C difference between the surface and bottom was 7.8^o C (46^o F). The average date was about April 30 in the hard-water lakes and May 19 in the softwater lakes (Table 6).

In the spring the average amount of dissolved oxygen in the surface waters of the various types of lakes ranged from 10 to 13 ppm and from 9 to 10 ppm in the summer. At 10 meters the dissolved oxygen ranged from 7 to 11 ppm in the spring and 2 to 10 ppm in the summer.

A wide range of temperature and dissolved oxygen characteristics is present in the water quality study lakes. Some lakes have a small range (poorly stratified) of surface to bottom temperatures while well stratified waters have a relatively large surface to bottom range. The surface to bottom temperature difference in well stratified waters is usually more than 25 percent of surface temperature, and the difference is less than 18 percent of surface temperature in poorly stratified lakes. While water surface temperatures approximate air temperature, in May they are 1 to 2 degrees cooler (excepting softwater mesotrophic lakes) and by late July they are 2 to 4 degrees warmer, but in July the temperatures in clear oligotrophic lakes are less than air temperatures.

Increasing water temperatures are likely to be associated with decreasing water transparency. In the data there was a significant but low negative correlation between water temperature and water transparency; $y = 8.37 - 0.14x$ ($r = -0.37$) where y = the transparency in feet and x = the surface water temperature in degrees C. Since the equation only covers a small range of transparencies it has a limited usefulness unless it is modified. It does indicate temperatures influence a lakes trophic state. Since lake temperatures increase, the data suggests an interrelationship between spring and summer water temperatures and transparency. A result of a comparison of the possible combination of temperatures and transparencies suggests the following formula: (r - 0.90) expresses the interrelationships y_2 = 7.496 + 0.882 (y_1) - 0.253 (x) - 0.340 (z) where y_2 = the summer water water transparency in feet, y_1 = the spring water transparency in feet, x = the summer surface water temperature (^{o}C) at 10 meters, and z = the spring water temperature (^{o}C) at the surface. It appears that the water transparency decreases about one foot for every 4^{o} C of temperature rise from 0^{o} C at 10 meters. While the foregoing equation illustrates the effect of spring water temperatures, spring water transparency, and lake basin water circulation (temperature at 10 meters) its predictive value is limited.

The amount of dissolved oxygen in the surface waters is at or somewhat above saturation in most lakes, coefficient of variation (average/standard deviation x 100) about 15 percent, but in the eutrophic lakes the amount of dissolved oxygen in the surface waters is more variable, coefficient of variation 42 percent. In the bottom waters, the dissolved oxygen decreases from the spring to summer, but the change varied from small to large, being lowest in the clear lakes and highest in the well stratified lakes with low transparencies. The effect of stratification or the lack of it in the summer on the amount of dissolved oxygen at 10 meters can be expressed by the equation y = 7.47 - 0.44x at r = 0.63 where y = the dissolved oxygen at 10 meters and x = the temperature difference from the surface to the bottom. When the temperature surface to bottom difference is small the dissolved oxygen at 10 meters is high and when there is a large difference there is little oxygen.

As the water transparency decreases the amount of dissolved oxygen present at 10 meters also decreases so the amount of dissolved oxygen present at 10 meters is also related to the trophic state of a lake. There was a moderate amount of correlation r = 0.533 between the secchi disc transparency and the amount of dissolved oxygen present at 10 meters. One reason for the low correlation was that there was no oxygen at 10 meters and the magnitude of the decline was not accurately determined. By deleting the observations where the dissolved oxygen was less than one and where the temperature difference was large, it was found that the degree of correlation at a temperature difference of 1.3 degrees increased to r = 0.85 and at 8.75 degrees r = 0.95. The equations were combined into a three variable equation, y = 1.33x + (0.51Z - 3.15), where y = secchi disc in feet, x = dissolved oxygen at 10 meters, and Z - the surface to 10 meter temperature difference. NOTE: Retesting showed this equation was only efficient at r = 0.88 where the dissolved oxygen was one part per million or more.

The former equation was only helpful where the surface to 10 meter temperature difference was small so an attempt was made to correlate the slope of the dissolved oxygen curve with the secchi disc transparency. The slope was defined as starting at the depth where the temperature was 2 or 3 degrees below surface temperature to the depth where the dissolved oxygen had declined to one ppm. The result was a correlation of $r = 0.61$ (equation $y = 13.4 - 6.79x$ where y = secchi disc transparency in feet and x = the oxygen decline in ppm per foot). While a relationship obviously existed, the variations between lakes limited the usefulness of the equation.

By dividing the rate of oxygen decline (ppm per foot of depth) by the amount of homothermous water (within one degree of surface temperature) and separating the data into two parts (strongly and poorly stratified) the degree of correlation was improved $r = 0.79$ and $r = 0.88$ for the strongly and poorly stratified lakes respectively. In the poorly stratified lakes, where the surface to bottom temperature difference less than is 18 percent of surface temperature, the slope of the line was nearly zero, and the decline of oxygen was approximately 0.0142 ppm per foot per foot of homothermous water. In the strongly stratified lakes (surface to bottom temperature difference was 25 percent or more of the surface temperature) where y = the oxygen decline in ppm per foot per foot of homothermous water and where x = the secchi disc transparency in feet, the equation is $y = 0.1121 - 0.0061x$.

Plant Density

The plant mean density in hardwater mesotrophic lakes, 2931.7 units, was more ($t = 3.94$) than was found in the softwater mesotrophic lakes (523.5 units), and was more ($t = 3.08$) than was found in the hardwater eutrophic lakes (755 units). There was more vegetation in the clear softwater oligotrophic lakes (770 units) than in the bog stained mesotrophic lakes (523.5 units) but the difference was not significant ($t = 0.76$) in these samples, see Table 9.

Water Chemistry

Mean summer surface values in hardwater lakes sampled were pH-8.4m total alkalinity-141.1 ppm, sulfates-11.3 ppm, chlorides-34.4 ppm, secchi disc 4.8 ft., total phosphorus-0.08 ppm and nitrogen-1.11 ppm. Mean summer surface values in the softwater lakes sampled were pH-7.3, total alkalinity-25.6 ppm, sulfates-4.2 ppm, chlorides-4.6 ppm, secchi disc-9.5 ft., total phosphorus-0.04 ppm and total nitrogen-0.88 ppm.

Surface to Bottom and Spring to Summer Changes

pH

pH values for summer surface waters were about 8.4 for hardwater lakes (range 7.9 - 8.9) and 7.3 for softwater lakes (range 7.0 - 8.4). Surface and bottom water pH values of hardwater lakes were about 1 pH unit higher than the corresponding values for softwater lakes.

The pattern of pH changes from spring to summer is approximately the same for both hardwater and softwater lakes. In the spring the surface water pH is about 0.2 to 0.3 units higher than that of bottom waters. From spring to summer there is a small, but significant increase of 0.2 - 0.3 pH units in surface waters. Bottom water pH remains stable from spring to summer, with a mean of 6.8 - 6.9 for softwater lakes and 7.9 for hardwater lakes.

The following differences were found to be significant (t values listed for softwater and hardwater lakes, respectively): 1) higher pH of surface waters in spring (t = 2.3, 5.1); 2) increase of pH of surface waters from spring to summer (t = 2.9, +2.3); and 3) higher pH of surface waters in summer (t = 3.9, 8.4). Low correlation values between pairs indicate that the pH fluctuates in both surface and bottom waters from spring to summer.

ALKALINITY

The summer surface total alkalinity was about 141.1 ppm (range 109.2 - 186.5) in hardwater lakes and 25.6 ppm (range 15.6 - 43.3) in softwater lakes. In hardwater lakes, the surface water alkalinity decreased from spring to summer, while there was only a slight increase in the bottom waters. The softwater lakes showed an increase in alkalinity in both surface and bottom waters from spring to summer, with a larger increase in the bottom waters than in the surface waters.

There was a net gain of about 9.5 ppm alkalinity in the softwater lakes from spring to summer, as compared to a net loss of about 6.5 ppm in the hardwater lakes (not correcting for volume above and below the thermocline or variations in the surface waters). The lower correlation coefficient of softwater lakes for surface water total alkalinity from spring to summer indicates that surface water alkalinities of softwater lakes are more variable than in hardwater lakes.

Total alkalinity in the bottom waters of hardwater lakes was significantly higher than surface waters in both spring and summer ($t = -2.4, -6.8$, respectively). In spring the surface water alkalinity was 2.0 ppm less than in the bottom waters. From spring to summer the surface waters lost 8.5 ppm alkalinity, while the bottom waters showed an increase of 2.0 ppm. The decrease in the surface waters was significant ($t = 3.4$, $n = 14$).

Bottom water alkalinity of softwater lakes was about 0.6 ppm lower than surface waters in spring, and 1.6 ppm higher than surface waters in summer. From spring to summer, surface and bottom water total alkalinity increased 3.8 to 5.8 ppm, respectively. The increase in the bottom waters was significant ($t = -2.3$).

SULFATE

The summer surface concentration of sulfates was about 11.3 ppm in hardwater lakes (range 1.0 - 23.3) and 4.2 ppm (range 2.0 - 7.4) in softwater lakes.

Hardwater lakes tend to lose sulfates in both surface and bottom waters from spring to summer (-0.2 and -0.6 ppm, respectively), with a greater loss in the bottom waters than in the surface waters. Sulfate concentration in softwater lakes tended to increase in both surface and the bottom waters (+0.1 and +1.1 respectively). However, none of these changes was significant. Low correlation values in softwater lakes for surface and bottom concentrations from spring to summer indicate there is more fluctuation in softwater than in hardwater lakes.

There were no significant differences between surface and bottom concentrations in spring and summer for either lake type. Summer bottom water concentrations in midsummer were about 0.7 ppm higher than surface waters in softwater lakes and 0.6 ppm lower than surface waters in hardwater lakes.

CHLORIDE

The chloride concentration of spring surface waters was about 35.8 ppm (range 1.0 - 187) in hardwater lakes and 3.3 ppm (range 0.6 - 5.6) in softwater lakes. The chloride content in surface waters remained relatively constant from spring to summer. Summer surface chloride values were 34.3 ppm (range 0.8 - 152) and 4.6 ppm (range 0.05 - 7.5) in hardwater and softwater lakes, respectively.

Chloride concentrations were highest in Long Lake and Lake Johanna, which are located in the Twin Cities metropolitan region. The mean summer surface chloride concentration of hardwater lakes excluding the values from those two lakes was only 11.8 ppm (range 0.8 - 33).

Mean chloride concentrations of spring surface waters of both lake types were slightly higher than in bottom waters. From spring to summer, the hardwater lakes showed a decrease of about 1.5 and 1.2 ppm in the surface and bottom waters, respectively. Softwater lakes showed an increase of 1.3 ppm in the surface waters and 1.4 ppm in the bottom waters. The increase in the bottom waters of softwater lakes was significant ($t = 2.6$, $n = 9$).

SECCHI DISC

The average secchi disc reading in summer was 4.8 feet (range 1.0 - 10.9) in hardwater lakes and 9.5 feet (range 1.7 - 21.0) for softwater lakes.

The values for softwater lakes did not change significantly from spring to summer, showing a slight average increase of 0.1 feet. Secchi disc readings for hardwater lakes showed a significant decrease of 1.8 feet ($t = 3.6$) from spring to summer.

PHOSPHORUS

The phosphorus content of summer surface waters was about 0.07 ppm (range 0.01 - 0.29) in hardwater lakes and 0.04 ppm (range 0.02 - 0.07) in softwater lakes. The ratio of midsummer surface to bottom phosphorus concentration was 0.8:1 in both hardwater and softwater lakes.

There was a net gain of 0.01 ppm phosphorus in softwater lakes, and a net gain of 0.08 ppm phosphorus in the hardwater lakes from spring to summer. Spring surface phosphorus concentrations in softwater lakes were 0.02 ppm higher than bottom water concentrations, and from spring to summer the surface and bottom did not show any significant changes. In hardwater lakes the spring waters were well mixed, and from spring to summer the surface and bottom phosphorus content had increased by a factor of 1.6 and 2.0, respectively. The increase in the bottom waters was significant ($t = -2.45$, $n = 11$).

The low correlation values for surface and bottom waters from spring to summer indicate there was fluctuation in phosphorus content in both hardwater and softwater lakes, although there was a significant correlation between spring and summer surface concentrations in hardwater lakes (r = 0.74, n = 11). However, by midsummer the phosphorus concentration in the bottom waters was significantly higher than that of surface waters in both hardwater (t = -2.21, n = 14) and softwater lakes (t = -2.28, n = 10).

NITROGEN

Both the hardwater and softwater lakes contained about the same amount of total nitrogen (surface and bottom) in the summer as they did in the spring. T-tests for total nitrogen of surface and bottom waters combined showed no significant differences from spring to summer.

However, the proportion of organic and inorganic (ammonia, nitrate, and nitrite) forms showed some changes from spring to summer and there were differences between the hardwater and softwater lakes. Even though the proportions varied considerably from lake to lake and even from year to year within the same lake, some general differences between hardwater and softwater lakes are presented (see Figure 1). Table 7 lists the ranges of nitrogen compounds in summer surface waters.

Figure 1 was constructed using median concentrations of the four forms of combined nitrogen. Concentrations of ammonia, nitrate, and nitrite nitrogen were frequently present in undetectable amounts and could not be assigned a value. Correlation coefficients, t values, and means were calculated using only detectable values. Thus, the tests for ammonia, nitrate, and nitrite nitrogen were not always reliable, since the number of N pairs was frequently very low.

Arithmetic means of these three forms of nitrogen were also over estimated. Therefore, when stating average concentrations of ammonia, nitrate, and nitrite nitrogen, the median is given instead of the arithmetic mean. For comparison, mean vs. median concentrations of nitrogen compounds are listed in Table 8.

NITROGEN IN SOFTWATER LAKES

The mean surface concentration of total nitrogen in midsummer was 0.88 ppm, ranging from 0.12 - 1.83 ppm. There were no significant changes in either surface or bottom waters from spring to summer.

Proportions of organic and inorganic nitrogen compounds did not change much from spring to summer in either surface or bottom. However, there was a small but significant increase in the concentration of organic nitrogen in the surface waters (t = -2.60, n = 9), with a mean of 0.57 ppm in summer surface waters.

The median concentration of ammonia in spring was an undetectable amount (less than 0.005 ppm) in both surface and bottom waters, and by summer the median concentration increased to 0.060 and 0.026 ppm in surface and bottom waters, respectively.

Nitrate tended to decrease in the surface waters from spring to summer. The median summer surface concentration was 0.013 ppm, about 1/5 of the median concentration in the spring surface waters. Nitrate concentrations in the bottom waters remained about the same from spring to summer.

The median concentration of nitrite in surface and bottom waters was less than 0.001 ppm in both spring and summer.

NITROGEN IN HARDWATER LAKES

Concentrations of total nitrogen in summer surface waters ranged from .27 - 2.62 ppm (mean - 1.11 ppm). In contrast to the softwater lakes, the summer surface concentration of total nitrogen was significantly lower than in the bottom waters (t = -2.15, n = 15).

The amount of organic nitrogen in the surface and bottom waters tended to increase from spring to summer, but the increases were not significant. The mean summer surface concentration was 0.97 ppm (range 0.08 - 1.52).

From spring to summer, the proportions of inorganic forms of nitrogen showed greater change in the hardwater lakes than in the softwater lakes. Nitrate and nitrite decreased in both surface and bottom waters, and there was a fourfold increase in the amount of ammonia in the bottom waters.

The increase of ammonia in the bottom waters from spring to summer was significant (t = -2.52, n = 11). The median concentration of ammonia in summer was 0.04 ppm in the surface waters and 0.340 ppm in the bottom waters, and the concentration of the bottom waters in summer was significantly higher than in surface waters (t = -3.17, n = 10).

In the surface water in the summer, the median concentration of nitrate was about one tenth of the amount present in the spring. The median summer surface concentration of nitrite was less than 0.005 ppm.

CHLOROPHYLL

Ranking the lakes by the least amount of chlorophyll present produced the following list; 1-Trout, 2-Pokegama, 3-Wilson, 4-Bear Island, 5-Snowbank, 6-Colby, 7-White Iron, 8-Nokay, 9-Frances, 10-Johanna, 11-Detroit, 12-Minnewaska, 13-Big Pine, 14-Shields, and 15-Long. Of these lake; Trout, Pokegama, and Wilson had the least phosphorus and Big Pine, Shields and Long Lakes had the most phosphorus. At an average transparency of 7.4 to 9.4 feet a lake should have 3.4 to 7.6 p.p.b. of chlorophyll and a total phosphorus concentration of 0.03 to 0.044 ppm or about the amounts reported for walleye and centrarchid lakes in the background data.

Variation Between Yearly Samples

Between yearly midsummer observations some parameters such as total alkalinity, secchi disc, pH, and plant density varied less than others (chlorophyll, nitrogen, chlorides, sulfates, and phosphorus). Both the correlation coefficients and the slopes of the lines indicate a small amount of variation (r over 0.90 and the slope of the regression lines between 0.65 of 1.01) for total alkalinity, secchi disc, pH, and plant density. Of the second group of parameters the overall amount of total nitrogen in the lakes was about the same (slope 0.94 indicates little overall change), but there was considerable variation from lake to lake (r = 0.65).

There was a good year to year correlation for phosphorus (r = 0.97), chlorides (r = 0.90), and chlorophyll (r = 0.80) samples, but the amount of phosphorus and chlorides was higher in the second set of samples (span of 3 years) than it was first set, slopes of the lines 2.2 and 2.5 respectively. In the second set of yearly samples the chlorophyll levels were low (slope of the line 0.16) and quite variable from lake to lake. The degree of correlation (r - 0.40) between sulfates between the two sets of summer samples was fairly low and the slope of the line was high (2.1) which indicates a tendency towards variable and frequently high inputs of sulfates.

In the metropolitan lakes in the late winter 1971 - 1972 the only parameters showing a fairly high correlation from year to year were total alkalinity, turbidity, chlorides, and total nitrogen. The various forms of nitrogen (ammonia, nitrates, and organic) and total phosphorus were not correlated.

Its simpler to visualize the magnitude of changes by dividing a minimum value by the maximum observed. Then an average variation can be determined for all lakes (example - secchi disc observations 4.5/5.0 = 0.90). Then the means for each parameters can be ranked in order of their stability as follows (100 indicates no change): 1-pH 96%, 2-total alkalinity 89%, 3-secchi disc 75%, 4-aquatic plant density 72%, 5-total nitrogen 63%, 6-sulfates 63%, 7-total phosphorus 62%, 8-chlorophyll 54%, 9-organic nitrogen 54%, 10-chlorides 45%, 11-inorganic nitrogen 15% (Table 14).

Note that the two most commonly used parameters - total alkalinity and secchi disc transparency - are the second and third most stable and fir directly into our classification systems of hardwater-softwater lakes and turbid plankton bloom eutrophic and very clear oligotrophic lakes.

Note that in Table 13 the degree of variation between yearly sample values for total alkalinity, total phosphorus and total nitrogen was the same in the northern basin of Shady Oak Lake as it was in the Study Lakes and that the variation within a year was less than the year to year variations. The year to year variation was 57 to 88 percent and the weekly sample to sample variation was 72 to 98 percent in the northern basin of Shady Oak Lake. Note that the weekly variation in phytoplankton volume was more than the year to year variation.

Analysis of Results

There are four distinct groups of study lakes, (1) softwater oligotrophic lakes, (2) softwater mesotrophic lakes frequently stained brown from bog and swamp drainage, (3) hardwater mesotrophic lakes, and (4) hardwater eutrophic plankton bloom lakes (one lake had very hard water).

In the softwater and hardwater study lakes the range of total alkalinity in the summer was 16 to 43 and 109 to 237 ppm respectively. The lake with very hardwater (Minnewaska) had a sulfate content ranging from 55 to 101 ppm and a total alkalinity of 227 to 237 ppm.

The softwater oligotrophic lakes frequently have a good supply of oxygen in the hypolimnion (bottom waters) which is also associated with the presence of lake trout. Softwater and hardwater mesotrophic lakes have no oxygen or a more limited supply of oxygen in the bottom waters (hypolimnion) and have populations of northern pike, walleye, and/or centrarchids. Hardwater eutrophic lakes have no oxygen below the thermocline, large populations of rough fish auch as bullhead and carp, and variable populations of game fish and centrarchids.

In the lakes sampled the TSI (Trophic State Index) for secchi transparency was 35.7 for softwater lake trout (oligotrophic) lakes, 50.0 for softwater walleye (mesotrophic) lakes, 51.8 for hardwater mesotrophic walleye and centrarchid lakes and 66.2 in the eutrophic lakes. The TSI for chlorophyll was 43.7 for lake trout lakes, 55.3 for hardwater walleye and centrarchid lakes, and 66.3 in the most eutrophic lakes. The total phosphorus was 53.2 in the softwater lake trout lakes, 56.6 in the softwater walleye lakes, 58.4 in the hardwater walleye and centrarchid lakes, and 76.8 in the most eutrophic lakes. Note that the total phosphorus was high compared to the secchi disc transparency, a difference of 17.5 TSI units in oligotrophic lakes, 6.6 TSI units in mesotrophic lakes and 10.6 TSI units in eutrophic lakes.

The hardwater mesotrophic lakes had more phytoplankton than was present in the softwater lakes, but the phosphorus levels were lower in the hardwater lakes, In the mesotrophic softwater lakes the secchi disc transparency ranged from 1.7 to 13.5 feet, and the chlorophyll ranged from 2.5 to 8.9 p.p.b. In the mesotrophic hardwater lakes the secchi disc transparency ranged from 4.0 to 10.9 feet, and the chlorophyll ranged from 2.2 to 19.8 p.p.b. The range of phosphorus in the softwater and hardwater mesotrophic lakes was 0.024 to 0.07 ppm and 0.011 to 0.06 ppm respectively.

From the foregoing its obvious that the carbonate content of the water is related to the chlorophyll levels. Since many studies have also indicated that phosphorus levels are related to plankton levels, both parameters must be related to chlorophyll levels. By dividing the chlorophyll by the total alkalinity, and then comparing the result with the phosphorus level for each lake, it was determined that there was a correlation (r = 0.92) between them, equation y = 0.1688x + 0.0247 where y = total phosphorus (ppm) and x = chlorophyll/total alkalinity (ppm). This equation can be rewritten as follows:

$$\text{Expected chlorophyll (P.P.B.)} = \frac{\text{Total Alkalinity (Tot. phos. - 0.0247)}}{0.1688}$$

The concept was to determine the number of units of chlorophyll per unit of total alkalinity, and then compare the result with the total phosphorus concentration.

In a preliminary laboratory experiment, where duckweeds were grown in a nutrient solution containing ample nitrogen, it was noted that the optical density of the chlorophyll in the duckweeds remained the same (about 0.45) when the sodium carbonate was increased in the test jars at rates of 0, 50, 100, and 200 ppm, but the algae on the walls of the jars increased. The optical density of the algae chlorophyll was 0.65 at 50 ppm, 0.95 at 100 ppm, and 1.8 at 200 ppm. These results were obtained using Hutners growing medium. Optical densities of 0.45, 0.65, 0.95, and 1.8 have the following light transmission values respectively: 35.5, 22, 11, and 2 percent. About 0.0031 grams of duckweeds per jar were used in the experiment. Later it was observed that duckweeds respond to changes in total alkalinity when the carbonate levels were below 30 ppm where sulfates levels were below 90 ppm.

By dividing the sum of the plant density ratings for each lake by the total alkalinity and then comparing the result with the secchi disc transparency it was determined there was a positive correlation (r = 0.84). The equation is y = 0.30067x + 1.04954 where y = the secchi disc transparency in feet and x = the plant density divided by the total alkalinity. This equation can be rewritten as follows:

$$\text{Expected plant density} = \frac{\text{Total Alkalinity (Secchi transp. - 1.049)}}{0.30067}$$

The foregoing equation suggests that few or no aquatic plants are present when the transparency is lower than one foot. Note that a trophic state index for plant density can be calculated using the expected water transparency.

Carlson's trophic state index equations can be used with the water quality monitoring data since similar equations were derived using the water quality monitoring data. See Table 15 comparing Carlson's results with the study lake data. Additional equations were derived from a trophic state index for total nitrogen, and total plant density, and a predictive equation for expected chlorophyll using the total phosphorus and total alkalinity. A correlation secchi disc transparency and the plant density was derived by dividing the plant density by the total alkalinity.

Where secchi disc transparency = y the following correlations and equations were derived from the data:

$y = 20.35 - 12.88$ (T. Nitrogen as ppm) $r = -0.92$

$y = 19.40 - 13.99$ (org. Nitrogen as ppm) $r = -0.93$

$\ln y = 2.693 - 1.340$ (ln Chlorophyll as ppb) $r = 0.706$

$y = 46.65$ (1/T. Phosphorus as ppb) $r = 0.56$

$y = 0.301$ (Plant density/ppm T. alkalinity) $r = 0.84$

The correlation between phosphorus and secchi disc was low ($r = 0.56$), and the correlation between chlorophyll and total phosphorus was good ($r = 0.81$). The correlation between secchi disc and chlorophyll was 0.71 so the total phosphorus is only indirectly related to the secchi disc transparency. Apparently the trophic state index (TSI) as calculated for total phosphorus indicates potential rather than existing conditions. The differences between the TSI for the secchi disc and total phosphorus might indicate how effectively the phosphorus is being utilized. The data suggests phosphorus is accumulating in softwater lakes.

Most of the variation in water transparency between yearly observations in the study lakes appears to be caused by the variation in water temperatures. The secchi disc transparency of 7.7 feet increased to 8.93 feet with a 2.5 and 1.5 decrease in the May and July water temperatures using the equation $y_2 = 7.496 + 0.882_{y1} - 0.253x - 0.340_Z$ where the average Y_2 = water transparency in the summer, y_1 = 8.08 feet of water transparency in May, x = a temperature of 15^o C in May decreased 2.5^o to 9.5^o C, the 7.7 average transparency is 86.2 percent of the higher transparency and within the 64.3 to 86.5 range of variation calculated for the observation from the study lakes. The average variation in May and July air temperatures is about 1.5^o C and 2.5^o C respectively.

NOTE: The temperature changes were determined from the average year to year air temperatures in May and July.

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Figure 1. MEDIAN CONCENTRATIONS (ppm) OF TOTAL AMMONIA (NH_3), NITRATE (NO_3), AND ORGANIC NITROGEN IN THE SOFTWATER AND HARDWATER LAKES IN THE SPRING AND SUMMER

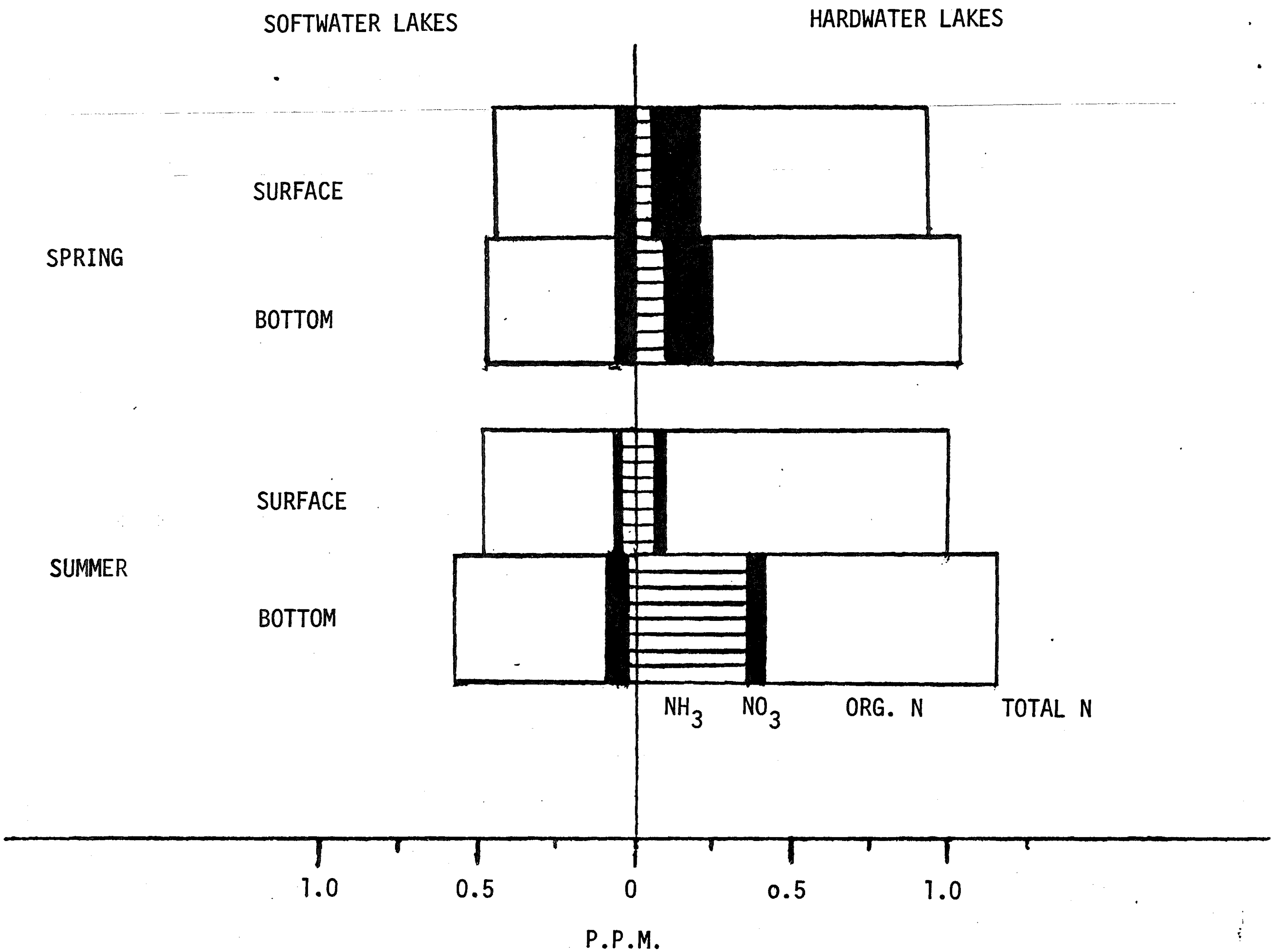

Table 4

Trophic State Index (TSI) in various types of Fish Lakes as Determined by the Secchi Disc (SD) and Total Phosphorus (TP) from background data.

	Secchi Disc (Ft.)	Plankton gm/m^3	Total Phosphorus (ppm)	TSI (Trophic Status)	
				SD	TP
Lake Trout	16.1	0.201	0.018*	37.00 (O)	45.55 (M)
Softwater Walleye	7.8	0.203	0.020	48.61 (M)	47.37 (M)
Centrarchid	9.0	0.313	0.030	44.19 (M)	53.21 (M)
Hardwater Walleye	9.0	0.471	0.033	44.19 (M)	54.59 (M)
Rough Fish	3.0	--	0.070	61.24 (E)	65.44 (E)
Alkaline Prairie	1.1	5.426	--	75.71 (E)	--

*Lakes become Mesotrophic when TP over 0.012 p.p.m. on the phosphorus scale.

Table 5. Average spring water temperatures, dissolved oxygen and sampling date for the various lake types, and the amount of change per 100 days to midsummer.

Trophic State	Ave. Date	Spring						Ave. Change per 100 days 1/ to Midsummer					
		Temperature °C			Dissolved Oxygen			Temperature °C			Dissolved Oxygen		
		Surface	10M	20M	Surface	10M	20M	Surface	10M	20M	Surface	10M	20M
Eutrophic	5-4	10.4	7.3	7.8	12.8	10.6	6.8	15.2	14.2	9.6	-2.53	-9.45	-9.70
Hardwater Mesotrophic	5-3	9.6	7.2	5.3	10.9	8.8	6.9	16.5	9.3	2.8	-1.64	-6.73	-2.80
Softwater Mesotrophic (Dystrophic)	5-19	13.1	7.9	-	10.1	9.0	-	11.8	8.0	-	-1.39	-8.71	-
Oligotrophic	5-13	6.5	5.5	5.2	10.9	10.9	10.9	13.9	9.3	1.7	-1.80	-1.63	-4.37

1/ Average difference between the spring and summer sampling dates equals 86 days.

Table 6. Water temperatures and dissolved oxygen at the surface and 10 meters for the various lake types adjusted to same spring and summer sampling date.

Trophic State	Index No.	Surface				10 Meters			
		Temp. °C		Dis. Oxygen		Temp. °C		Dis. Oxygen	
		5-19	7-31	5-19	7-31	5-19	7-31	5-19	7-31
Eutrophic	71.5	12.7	23.8	12.4	10.6	9.4	19.7	9.2	2.3
Hardwater Mesotrophic	50.8	12.2	24.2	10.6	9.4	8.6	15.4	7.7	2.8
Softwater Mesotrophic	49.6	13.1	21.7	10.1	9.1	7.9	13.7	9.0	2.6
Oligotrophic	41.7	7.3	17.5	10.8	9.6	6.3	12.8	10.8	9.6

Table 7. Ranges of Summer Surface Concentrations of Organic, Ammonia, Nitrite and Nitrate Nitrogen (ppm).

	Hardwater	Softwater
Organic	0.16-2.13	0.08-1.52
Ammonia	<0.005-0.615	<0.005-0.12
Nitrate	<0.005-0.12	<0.005-0.281
Nitrite	<0.0005-0.0025	<0.0005-0.015

Table 8. Median and Mean Values for the Concentrations of Nitrogen Compounds in Hardwater and Softwater Lakes

Hardwater Lakes

Form of Nitrogen	Spring Surface		Spring Bottom		Summer Surface		Summer Bottom	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Organic	0.84	0.74	0.83	0.79	0.97	0.91	0.97	0.76
Ammonia	0.22	0.052	0.24	0.09	0.10	0.04	0.44	0.340
Nitrate	0.212	0.148	0.21	0.137	0.04	0.014	0.08	0.036
Nitrite	0.005	0.004	0.005	0.003	0.001	<0.0005	0.002	<0.0005
TOTAL	1.25	1.28	1.28	1.32	1.19	0.98	1.54	1.41

Softwater Lakes

Form of Nitrogen	Spring Surface		Spring Bottom		Summer Surface		Summer Bottom	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Organic	0.48	0.38	0.54	0.42	0.57	0.41	0.54	0.48
Ammonia	0.10	<0.005	0.11	<0.005	0.05	0.060	0.07	0.026
Nitrate	0.14	0.06	0.11	0.06	0.12	0.013	0.10	0.05
Nitrite	0.002	<0.0005	0.002	<0.0005	0.004	0.0006	0.004	0.0008
TOTAL	0.75	0.56	0.79	0.60	0.88	0.44	0.80	0.57

Table 9. Total Plant Density in the Study Lakes

Mesotrophic	Hardwater 1st yr.	Hardwater 2nd yr.	Mesotrophic	Softwater 1st yr.	Softwater 2nd yr.
Pokegama	4167	2974	Bear Island	532	332
Johanna	2078	2307	Wilson	975	775
Frances	3890	1879	Colby	406	811
Detroit	3396	3131	White Iron	135	222
Nokay	2825	2670			
$\bar{x}$ (all years)	2931.7 (Sx = 746.0)			523.5 (Sx = 302.87)	

Eutrophic	Hardwater 1st yr.	Hardwater 2nd yr.	Oligotrophic	Softwater 1st yr.	Softwater 2nd yr.
Big Pine	1387	1616	Snowbank	514	894
Shields	677	807	Trout	775	897
Long	14	29			
$\bar{x}$ (all years)	755.0 (Sx = 667.2)			770.0 (Sx = 179.9)	

Mesotrophic (very hard water)		
Minnewaska	1496	1326

Hardwater
Eutrophic vs Mesotrophic
t ind = 3.08

Softwater
Mesotrophic vs Oligotrophic
t ind = 0.76

Hardwater Mesotrophic vs Softwater Mesotrophic
t ind = 3.94

Table 10.

WATER QUALITY PARAMETERS
(SUMMARY)

Parameter		Softwater Lakes Surface	Softwater Lakes Bottom	Hardwater Lakes Surface	Hardwater Lakes Bottom
pH	spring	7.0	6.8	8.2	7.9
	summer	7.3	6.9	8.4	7.9
Total Alkalinity	spring	21.8	21.2	149.6	151.6
	summer	25.6	26.9	141.1	153.6
Sulfate	spring	4.2	4.2	11.5	11.2
	summer	4.3	5.3	11.3	10.6
Chloride	spring	3.3	2.8	35.8	35.7
	summer	4.6	4.2	34.3	34.5
Secchi disc	spring	9.4		6.6	
	summer	9.5		4.8	
Total phosphorus	spring	0.03	0.05	0.05	0.05
	summer	0.04	0.05	0.08	0.10

Table 11. Results of Comparisons Between Surface to Bottom and Spring to Summer Samples.

Parameter		Softwater Lakes N	r	t	Hardwater Lakes N	r	t
pH	spring vs summer						
	surface	10	0.3	-2.9*	14	0.3	-2.3*
	bottom	10	0.5	-0.9	14	0.07	-0.07
	surface vs bottom						
	spring	10	0.5	2.3*	18	0.6*	5.1*
	summer	12	0.4	3.9*	16	0.6*	8.4*
Total Alkalinity	spring vs summer						
	surface	10	0.4	-1.5	14	0.9*	3.4*
	bottom	10	0.7*	-2.3*	14	0.9*	-0.8
	surface vs bottom						
	spring	10	0.9*	1.4	18	0.9*	-2.4*
	summer	12	0.7*	-0.7	16	0.9*	-6.8*
Sulfate	spring vs summer						
	surface	9	-0.2	-0.1	14	0.8*	0.1
	bottom	10	0.3	-0.8	14	0.7*	0.4
	surface vs bottom						
	spring	9	0.9*	-0.8	18	0.9*	0.1
	summer	12	0.7*	-1.0	15	0.9*	0.9
Chloride	spring vs summer						
	surface	8	0.07	-1.1	14	0.9*	0.4
	bottom	9	0.7*	-2.6*	14	0.9*	0.4
	surface vs bottom						
	spring	8	0.9*	-0.6	18	0.9*	1.1
	summer	11	0.8*	0.6	16	0.9*	-0.03
Secchi disc	spring vs summer	10	0.9*	-0.1	14	0.8*	3.6*
Total phosphorus	spring vs summer						
	surface	8	-0.58	-1.21	11	0.74*	-1.22
	bottom	8	-0.38	-0.06	11	0.47	-2.45*
	surface vs bottom						
	spring	8	-0.45	-1.64	14	0.86*	1.30
	summer	10	0.89*	-2.28*	14	0.60*	-2.21*

Table 11 Continued

Parameter		Softwater Lakes N	r	t	Hardwater Lakes N	r	t
Total nitrogen	spring vs summer						
	surface	8	0.89*	-1.62	14	0.60*	0.40
	bottom	8	0.79*	-0.12	13	0.38	-1.09
	surface vs bottom						
	spring	9	0.91*	-0.70	18	0.95*	-0.09
	summer	10	0.93*	0.39	15	0.71*	-2.15*
Organic nitrogen	spring vs summer						
	surface	9	0.90*	-2.60*	12	0.77*	-1.97
	bottom	9	0.73*	-0.56	12	0.65*	-1.32
	surface vs bottom						
	spring	10	0.91*	-0.68	18	0.86*	0.23
	summer	11	0.93*	0.63	14	0.70*	0.43
Nitrate nitrogen	spring vs summer						
	surface	6	0.76	0.83	6	-0.49	1.16
	bottom	7	0.74	0.63	9	-0.39	1.12
	surface vs bottom						
	spring	10	0.86*	-0.25	16	0.99*	0.25
	summer	6	0.72	-0.41	9	0.67*	-1.60
Ammonia nitrogen	spring vs summer						
	surface	3	0.98	1.38	7	0.25	0.01
	bottom	2	-0.99	0.39	11	0.42	-2.52*
	surface vs bottom						
	spring	3	0.88	-0.28	13	0.64*	-0.25
	summer	8	0.13	-1.13	10	0.19	-3.17*
Nitrite nitrogen	spring vs summer						
	surface	4	0.927	0.522	5	0.674	2.801*
	bottom	5	0.918*	-0.678	6	-0.056	1.388
	surface vs bottom						
	spring	5	0.999*	0.0	14	0.967	1.793
	summer	6	0.740	-0.649	4	1.000	-0.999

* significant at .05 level

Table 12. Amount of Correlation for Various Parameters Between the Two Years Lakes were Sampled (year 1 vs. year 2) in the Study Lakes from 1973 to 1978 in the Summer and the Metro Lakes from 1971 to 1972 in Late Winter.

	Metro Lakes Winter (1971 - 1972)			Statewide July (1973 - 1978)		
Parameter	Corre.(r)	Slope	Intercept	Corre.(r)	Slope	Intercept
Total Alkalinity	0.75	+0.89	12	0.99	+0.97	1.52
pH	0.30	+0.42	4.3	0.85	+0.879	1.156
Secchi disc	--	--	--	0.94	+1.01	0.40
Turbidity	0.64	+0.63	0.5	--	--	--
Total Nitrogen	0.83	+1.04	-0.13	0.65	+0.94	0.41
Total Phosphorus	0.15	+0.02	0.034	0.97	2.20	-0.43
Aquatic Plants	--	--	--	0.90	0.65	376.21
Chlorophyll	--	--	--	0.80	0.16	7.24
Plant density	--	--	--	0.83	0.76	3.53
Organic N	0.01	+0.02	0.83	0.75	1.04	0.39
Inorganic N	--	--	--	0.30	0.45	0.04
Ammonia	0.00	None	--	--	--	--
Nitrate	-0.01	-0.74	0.21	--	--	--
Chlorides	0.80	+1.06	5.3	0.96	2.496	-0.569
Sulfates	0.42	+0.74	1.5	0.491	2.06	-0.32

Table 13. Degree of Change Between Yearly and Weekly Samples in the Study Lakes and Shady Oak Lake in Late Summer (July and August)

	Between Years				Weekly Sample Variation (Shady Oak)	
	Study Lakes		Shady Oak Lake			
Parameters	$\overline{x}$	Sx	$\overline{x}$	Sx	$\overline{x}$	Sx
Total Alkalinity	88.6	11.1	87.5	8.4	97.6	2.3
Total Phosphorus	62.2	20.1	61.2	28.0	74.2	21.1
Wet Phyto Plankton (settled volume)	--	--	67.1	82.3	88.6	108.0
Chlorophyll	54.1	25.1	--	--	--	--
Total Nitrogen	62.9	22.4	57.2	26.3	71.8	23.3

Table 14. Magnitude of Variation (Minimum/Maximum) and Degree of Correlation Between the Amounts Observed in Samples Collected in the Surface Waters of the Study Lakes in July

	Variation Between Years (Pct.)					Correlation Yr. 1 vs Yr. 2		
Parameter	Max. $\overline{X} - 21.96$	$\overline{X}$	Sx	N	Min. $\overline{X} + 21.96$	r	Slope	Intercept
pH	96.0	96.7	2.5	14	98.4	0.85	0.879	1.156
Tot. Alkalinity	83.0	88.6	11.12	15	94.2	+0.99	0.97	1.52
Secchi Disc	64.3	75.4	14.5	15	86.5	+0.94	1.01	0.40
Aquatic Plant Density	63.5	72.0	16.80	15	80.5	+0.90	0.65	376.21
Tot. Nitrogen	50.9	62.9	22.35	14	74.9	+0.65	0.94	0.41
Sulfates	50.7	62.5	22.5	14	74.4	+0.471	2.055	-0.32
Tot. Phosphorus	50.3	62.2	20.12	11	74.1	0.97	2.20	-0.43
Chlorides	45.1	45.1	29.1	15	59.9	0.96	2.50	-0.57
Organic Nitrogen	41.3	54.0	24.19	14	66.7	+0.75	1.04	0.39
Chlorophyll	38.6	54.1	25.06	10	69.6	+0.80	0.16	7.23
Inorganic Nitrogen	15.0	39.2	31.5	14	48.0	+0.30	0.45	0.042

Table 15. Comparison of Carlson's equations with equations derived from study lake data.

Correlation Between	Carlson's Equations		DNR Study Lakes	
	r =	Equation	r =	Equation
Secchi disc (Meters) and chlorophyll (p.p.b.)	.93	ln SD=2.04 - 0.68 ln Chl	.706	ln SD=2.693 - 1.34 ln Chl or ln SD=2.04 - 1.02 ln Chl
Secchi disc Meters and Total Phosphorus (p.p.b.)	*	SD = 48 (1/TP)	.56	SD=46.65 (1/TP) + 0.87
Chlorophyll (p.p.b.) and Total Phosphorus (p.p.b.)	.847	ln Chl=1.449 ln TP- 2.442	.807	ln Chl=2.103 ln TP - 6.192 or ln Chl=1.449 ln TP - 4.266

* Correlation with all data equals r = 0.89 where SD = 64.9/TP

Table 16

Status of water transparency (secchi disc), total phosphorus, and chlorophyll and the trophic state index (TSI) and the TSI difference between years within a lake in water quality monitoring lakes from 1973-1976.

Lake Name	Secchi Disc		TP		Chlorophyll	
	Feet	TSI	PPM	TSI	PPB	TSI
Softwater Lakes						
Trout	18.4 - 21.0	35.1 - 33.2	0.017 - 0.027	45.0 - 51.7	0.1	7.9
Snowbank	14.4 - 17.0	38.7 - 36.3	0.027 - 0.05	51.7 - 60.6	2.8 - 8.7	40.6 - 51.8
Wilson	10.2 - 13.5	43.6 - 39.6	0.024 - 0.029	50.0 - 52.7	3.5	42.9
Bear Island	7.3 - 9.4	48.5 - 44.8	0.03 - 0.07	53.2 - 65.4	2.5 - 6.6	39.6 - 49.1
White Iron	3.5 - 5.0	50.1 - 53.9	0.037	56.2	3.3 - 8.9	42.3 - 52.0
Colby	1.7 - 2.0	69.5 - 67.2	0.043	58.4	3.0 - 5.4	41.3 - 47.1
Hardwater Mesotrophic Lakes						
Pokegama	9.7 - 10.9	44.4 - 42.7	0.026 - 0.03	51.2 - 53.2	2.2 - 3.4	38.3 - 42.5
Nokay	5.5 - 7.4	52.6 - 48.3	0.011 - 0.044	38.7 - 58.7	7.6	50.4
Minnewaska	5.6 - 7.0	52.3 - 49.1	0.031 - .053	53.7 - 61.4	19.8	59.9
Johanna	4.5 - 5.7	55.4 - 52.1	0.05 - 0.06	60.6 - 63.2	6.6 - 15.7	49.1 - 57.6
Detroit	4.0 - 5.5	57.2 - 52.6	0.05	60.6	10.4 - 11.5	53.5 - 54.5
Frances	4.1 - 5.0	56.8 - 53.9	0.042 - 0.05	58.1 - 60.6	6.7 - 10.2	49.2 - 53.3
Hardwater Eutrophic Lakes						
Big Pine	3.0 - 3.4	61.3 - 59.5	0.072	65.8	27.0 - 28.4	62.9 - 63.4
Long	1.0 - 2.1	77.2 - 66.4	0.095 - 0.169	69.8 - 78.2x	138	78.9
Shields	1.5 - 3.9	71.3 - 57.5	0.062 - 0.29	63.7 - 85.9x	32.5 - 170.9	64.7 - 81.0

	Secchi Disc	TP	Chlorophyll
Mean	3.76	8.74	7.03
Standard Deviation	3.27	7.30	5.22
Standard Error	0.87	2.2	1.65
Sample Size	14	11	10
Significance Level	2.53	2.68	2.68

Table 17.

Status and Trophic State Index (TSI) of Lakes by Type of Fish Population as Determined from the 1973-1978 Water Quality Monitoring Data

	Total Phosphorus p.p.m.	Chlorophyll p.p.b.	Secchi Disc ft. (Meters)
Oligotrophic (Lake Trout - softwater)	$\bar{X}$ = 0.030	$\bar{X}$ = 3.82	$\bar{X}$ = 17.70 (5.39)
	SX = 0.013	SX = 4.32	SX = 2.75
	SE = 0.006	SE = 2.49	SE = 1.37
	TSI = 53.2	TSI = 43.7	TSI = 35.7
Mesotrophic (Softwater Walleye)	$\bar{X}$ = 0.038	$\bar{X}$ = 4.75	$\bar{X}$ = 6.57 (2.00)
	SX = 0.016	SX = 2.32	SX = 4.24
	SE = 0.006	SE = 0.88	SE = 1.50
	TSI = 56.6	TSI = 45.9	TSI = 50.0
Mesotrophic (Hardwater Walleye and Centrarchid)	$\bar{X}$ = 0.043	$\bar{X}$ = 12.46	$\bar{X}$ = 5.8 (1.77)
	SX = 0.016	SX = 8.62	SX = 2.28
	SE = 0.004	SE = 2.49	SE = 0.61
	TSI = 58.4	TSI = 55.3	TSI = 51.8
Eutrophic (Plankton bloom lakes	$\bar{X}$ = 0.154	$\bar{X}$ = 113.80	$\bar{X}$ = 2.13 (0.65)
	SX = 0.101	SX = 72.31	SX = 1.27
	SE = 0.050	SE = 41.75	SE = 0.63
	TSI = 76.8	TSI = 71.8	TSI = 66.2