THE DETERMINATION OF THE TROPHIC STATUS OF FOUR DIMICTIC TEMPERATE ZONE LAKES IN NEW YORK STATE. (U.S.A.) *

[Handwritten addition to title] With No Particular Reference to Any Factors of Eutrophication

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* with an introduction describing the crystallization of eutrophication concepts over the last 70 years.

The terms eutrophy and oligotrophy first appeared in the literature in 1907. The terms were used to describe the quantity of nutrients available to bog vegetation by C.A. Weber in this publication. Eutrophy referred to an abundance of nutrients, with which there occurred a characteristic flora. The natural progression of bogs is towards an elevated state with respect to the surrounding topography, making the bog more susceptible to leaching of its nutrients. The flora resulting at the end of this process was oligotrophic, or tolerant of low nutrient concentrations.

Naumann, knowing of Webers work, applied the terms eutrophy and oligotrophy to describe water types, characterized in theory by nutrient concentrations, but recognized by certain phytoplankton associations which gave the lake water its appearance (Hutchinson 1969). Eutrophic waters had poor transparency due to high densities of phytoplankton in the surface layer, and were of distinct coloration.

The classification of lakes according to conditions of the hypolimnion was set forth by August Thienemann. Lakes which had high oxygen concentrations in the hypolimnion at the end of the summer, prior to the fall mixing, as well as a diverse bottom fauna intolerant of anoxic conditions were considered to be oligotrophic. Alternately, a eutrophic lake possessed benthic animals tolerant of low oxygen levels along with reduced oxygen concentrations in the hypolimnion in the late summer (clinograde oxygen profile).

The approach taken by Thienemann had one obvious problem, that being the morphololgy of the lake affected its trophic status. A lake containing eutrophic waters and possessing a very large hypolimnion may not experience a decrease in oxygen levels in the bottom waters, nor will it have anaerobic bottom fauna, Thienemann and Naumann would classify a lake of this nature differently. For this purpose, Lundbeck proposed another scheme whereby a lake of the above type would be considered secondarily or morphometrically oligotrophic.

Another aspect of eutrophic lakes is their high productivity in the surface waters compared to less well nourished lakes. Naumann considered nutrient concentration synonymous with productivity, although this relationship was not defined quantitatively (Vollenweider 1971).

Presently, the concept of eutrophication is considered as any process “which plays a part in accelerating nutrient loading and increasing the nutrient level, and is directly involved in increasing water productivity.” (Vollenweider 1971). Associated with the increase in autochthonous matter are characteristic algal blooms (blue-green algae), depletion of oxygen in the hypolimnion during summer stratification causing changes in the benthic fauna and. changes in nutrient cycling, in addition to an increase in the rate of sedimentation.

An effort was made to determine the relative trophic status of four lakes in lower N.Y.S. during the fall of 1976, based upon some of the criteria discussed above. The samples were collected at the following lakes: Bowman I & Bowman II, 25 Sept; Calder Lake, 2 Oct.; and Lake Waccabuc was sampled twice, once on 9 Oct., and once on 25 Oct.

Sampling consisted of making oxygen profiles and temperature profiles with a Yellow Springs oxygen meter. Water was collected from various depths by means of a Van Dorn bottle, Part of this water was placed in BOD bottles for oxygen determination by the Winkler method later that day in the lab. The water remaining in the Van Dorn bottle was brought back to the lab in plastic containers for determining the pH, conductivity and alkalinity. The potentiometric method of determining alkalinity was employed, with the endpoints of 4.8 and 4.5 determined with a pH meter. A Lund sampler was used to obtain an integrated water sample through the water column, but this was only used at some of the lakes. Measurements of conductivity were obtained from the lund samples. A secchi disk was used at the beginning of each sampling period to determine the transparency of the water.

Chlorophyll a concentration and pheopigment concentration were determined from 500 ml. samples of lake water. This water was first filtered through a 250 micron screen to remove large seston. The water was subsequently filtered through a 1 micron filter. When approximately 400 ml of the water had been filtered through the millipore filter, several milliliters of a saturated solution of $MgCO_3$ was added to prevent lowering of the pH, thereby reducing the amount of chlorophyll degraded to phyophytin. The millipore filter was then left in the vacumn pump to air dry for a short period of time, after which it was folded in aluminum foil, placed on Dri Rite and frozen until 20 Nov. On this date, the filters were thawed, cut into small pieces and macerated in acetone. This was quantitatively transferred to a centrifuge tube and 90% acetone was added until the total volume was 10 ml. The centrifuge tubes were then placed in a dark refrigerator for 30 minutes, after which they were centrifuged for 20 minutes. The supernatant was collected, and absorption readings obtained in a Spectronic 20 at 665 nm before and after acidification with HCl. A turbidity correction reading, taken at 750 nm was applied.

Plankton was collected with a net sampler at Calder Lake on 2 Oct and at Lake Waccabuc on 9 Oct. Lugol solution was added to a 15 ml subsample upon return to the lab. Whole water samples were looked at for Bowman I. Dominant genera were determined from these samples.

RESULTS

The data for secchi disk readings, alkalinities, conductivities chlorophyll a and pheophytin content are contained in Table 1. The lakes are listed in trophic order according to that parameter with the most oligotrophic lake at the top, proceeding downward to the most eutrophic lake. It is immediately obvious that the same order is not followed under each parameter. The secchi disk readings indicate that Calder Lake had the greatest transparency, followed by Lake Waccabuc, Bowman II and Bowman I. The alkalinities and conductivities both have the same order, with Calder Lake having the lowest values, Lake Waccabuc somewhat higher, Bowman I and Bowman II with the highest values. Bowman II was found to have the lowest chlorophyll a concentration with this parameter increasing in Bowman I, Calder Lake and Lake Waccabuc. The concentration of pheophytin was also lowest in Bowman II, and increased in Bowman I and Lake Waccabuc to the highest value in Calder Lake. Profiles of both alkalinity versus depth and conductivity versus depth are included in Graph 3 and Graph 4.

The profiles of oxygen concentration for the lakes are plotted in Graph 1. The oxygen meter was used to obtain the data producing the curves in this graph. The oxygen concentration was also determined at several depths by means of the Winkler method. The plot of this data is not shown due to the lack of data points,. The data obtained from the two methods show similar patterns except for Calder Lake and Lake Waccabuc on 9 Oct. The profile in Graph 1 indicates a sharp drop in oxygen content in Calder Lake at a depth of four meters. The oxygen concentrations obtained through use of the Winkler method at Calder, although generally 0.5 ppm lower, do not show any change in oxygen concentration with depth (Orthograde curve). The temperature profile for Lake Waccabuc (taken 9 Oct)(Graph 2) roughly follows a clinograde as does the oxygen profile, but oxygen determination by the Winkler method did not. The Winkler determination exhibited higher oxygen concentrations in the bottom than at 7 meters. This was dismissed as incorrect labeling of depth on the water samples, although it is possible that the hypolimnetic aerator actually caused this phenomenon. Bowman II shows a rapidly declining oxygen concentration in its waters, until anoxic conditions are reached in the bottom waters. A secondary thermocline appears in the Bowman II temperature profile (Graph 2). Due to the shallowness of Bowman I (1.5 m), an accurate estimate of both the oxygen profile and temperature profile was not obtained. The important aspects of out Bowman I data is that the lake appears to thermally stratified and is well oxygenated through the water column.

The dominant phytoplankton from Bowman I (25 Sept), Calder Lake (2 Oct.) and Lake Waccabuc (9 Oct.) are listed in Table 2. A diatom and a colonial blue green algae were identified from the whole water samples from Bowman I. The collection and treatment of plankton from Lake Waccabuc and Calder Lake was described in the methods section. Coelosphserium was the dominant algae in Calder Lake, while three species of filamentous blue green Anabaena were found most frequently in Lake Waccabuc. Oscillatoria was also prominent in Lake Waccabuc.

DISCUSSION

The concept of eutrophy has many aspects associated with it, therefore it is not surprising that the ordering of the lakes cannot be done by any individual measurement as shown in Table 1. The fact that both alkalinity and conductivity are in agreement reflects that both these measurements are indications of the nutrient status of the water. Alkalinity is the measure of total titratable base, being expressed as mg. $CaCO_3$/l. The total amount of dissolved ions in the water is represented by the conductivity. The amount of $CaCO_3$ and total ions are much greater in the two Bowman Lakes than the amount present in either Lake Waccabuc or Calder Lake (Graphs 3 & 4). The nutrients increase greatly with depth in Bowman II. This indicates a depletion of $CaCO_3$ and other dissolved nutrients in the surface waters of Bowman II, and is probably due to algae. It was noted that an algal bloom was present at the time of sampling, thus the dramatic decrease of nutrients in the surface waters. The depletion of oxygen in the hypolimnion and relatively poor transparency of the water are all indications that Bowman II is eutrophic. The excessively high oxygen concentration in the surface water of Bowman II in comparison to the other lakes is probably due to the high rate of photosynthesis occurring near the surface. The rapid decline in oxygen with depth results from the small trophogenic zone typical of eutrophic lakes. The depletion of oxygen is caused by the combination of respiration of the algae and the decomposition of the large amounts of algae which have entered the aphotic zone. The transparency, as measured by the secchi disk was low in Bowman II. The secchi reading is indicative of the amount of suspended material in the water (Ruttner 1963), The phytoplankton is a significant portion of the suspended material in Bowman II. The chlorophyll content of this lake was determined to be the least in the lakes sampled. This was determined for a sample collected at the surface on 9 Oct., at which time there was no algal bloom. This measurement cannot be easily related to the others collected at Bowman II.

Vollenweider (1971) p. 40 cites a study which classified lakes according to the chlorophyll a content of the water. The concentration of chlorophyll a for eutrophic lakes was given as 5-140 mg/m^3, mesotrophic 1-15 mg/m^3 and oligotrophic 0.3-2.5 mg/m^3. These values overlap a. good deal and were for comparisons with lakes which were sampled during late summer. According to our data both Bowman lakes could be classified as either mesotrophic or oligotrophic, while Lake Waccabuc and Calder Lake could be of any trophic state.

Lake Waccabuc is an interesting lake, and is unique within the range of lakes we sampled. Presumably, it has a large influx of nutrients from the septic tanks of houses surrounding the lake (Fast 1975). Prior to 1973, Lake Waccabuc was described as a moderately eutrophic lake (Fast 1975). Algal blooms and depletion of oxygen in the hypolimnion characterized the lake at this time. In 1973, a system designed to aerate the hypolimnion was placed in the lake. This aerator was in operation at the time of our sampling. The average alkalinity was approximately 29 ppm $CaCO_3$ on both sampling dates (Graph 3). Fast (1975) reports average alkalinities of 29 mg/l (equivalent to 29 ppm). The aeration system has had no apparent effect upon alkalinities, as is probably true of other nutrients. The aeration system therefore is not treating the cause of the problems which were encountered in Lake Waccabuc prior to 1973. The lower half (6.5 m) of the water column was found to have oxygen concentrations less than 4 ppm, with the bottom four meters containing less than 2.5 ppm (Graph 1). While this is not an anerobic condition, it does represent a fairly low oxygen concentration. Lake Sebasticoak in Maine is considered eutrophic with oxygen concentrations of 3.9 mg/l (Edmonson 1969, p. 143).

The transparency of Lake Waccabuc is greater than that of both the Bowman Lakes, but the chlorophyll a content is greatest in Lake Waccabuc. This data is contradictory. The fault appears to lie in the chlorophyll measurements, The measurement of 5.75 micro g/l chlorophyll a was obtained at Lake Waccabuc on 23 Oct. at a depth of one meter. The chlorophyll measurements for the Bowman Lakes were both from surface water samples taken on 9 Oct. It is well known that maximum photosynthesis rates occur below the surface due to inhibition by the strong light intensities at the surface. Algae able to regulate their vertical movements would most probably stratify below the surface. At any rate, Ruttner (1965, pg 129) has evidence that most phytoplankton are between 1 and 5 meters below the surface of the water, with the least generally at the surface. Even if the assumption that the depth difference in the samples were not a significant factor, the chlorophyll data for Waccabuc was obtained on 23 Oct., at which time the lake was isothermal (Graph 2). The alkalinity and conductivity were orthograde at the time (Graph 3 & 4). While the average alkalinities appear to be very similar for both samples taken at Waccabuc, the total conductivity is lower on the later sampling date (Graph 4). There are two possibilities for this: The lower temperature of 23 Oct. reduced solubilities of chemicals in the water, or an increase in algal production exhausted some of the nutrients in the solution. The latter explanation is more likely, since the bottom waters of Bowman II were colder than the water of Lake Waccabuc on 23 Oct., yet Bowman had conductivities four times as great as those encountered at Waccabuc. If there were a temporary increase in phytoplankton on 23 Oct., this could account for the high chlorophyll values obtained as well as the decrease of nutrients. This hypothesis can be critized in that the secchi disk readings were identical for both days Waccabuc was visited.

Although the comparisons between lakes seem futile, the relative values of the one meter sample and the Lund sample for chlorophyll and pheopigments taken at Lake Waccabuc on 25 Oct. are intuitively pleasing. The chlorophyll a content of the water from one meter is more than twice the measured chlorophyll in the Lund sample. This is likely due to the stratification of plankton in the photic zone. Since the Lund sample is representative of the entire water column, less chlorophyll is expected while a larger amount of degraded chlorophyll, or pheophytin, should be present. This is exactly what was found, the pheophytin content of the Lund sample being much more than the amount measured at one meter. The extremely low value of pheophytin at one meter in Lake Waccabuc by comparison to the pheophytin concentration in the other lakes, suggests that grazing of the phytoplankton was low at this time. Since the zooplankton population is dependent in part upon the algae population it is likely that we were present at a time when phytoplankton had recently increased their densities. The zooplankton population was probably still low, thus the low pheophyton values obtained.

The algae which predominated in Lake Waccabuc on 9 Oct. were three species of Anabaena , and Oscillatoria (Table 2). These genera of phytoplankton are blue green algae and are often associated with eutrophic lakes (Boney 1975; Lund 1969). Oscillatoria rubescens has even been suggested for use as an indicator species in lakes where rapid eutrophication is proceeding, although the validity of this is questionable (Boney 1975, pg. 97). This should be one species of Oscillatoria which should be looked for.

Lake Waccabuc can be classified as a eutrophic lake according to its depleted hypolimnetic oxygen concentration, the dominant phytoplankton and the suspected high nutrient content of the water. The absence of algal blooms, lack of anaerobic bottom waters and reduced alkalinities from those found at Bowman II would indicate that Lake Waccabuc was at an earlier stage of eutrophy than Bowman II.

The chlorophyll data for the two Bowman Lakes was collected on the same day (9 Oct.) and should, therefore, be directly comparable. Bowman I was found to have 3.56 micro grams /l chlorophyll a; Bowman II 2.85 micro grams/l. No other data was collected along with the chlorophyll on this date. It was observed on 25 Sept. that Bowman II had a noticable algal bloom, while Bowman I did not. The chlorophyll a content of the water taken from Bowman II would most probably have been greater on 25 Sept., yet two weeks later Bowman I had higher chlorophyll a concentrations. This reflects the sensitivity of algae to changes in the lakes in addition to their rapid change in densities. For this reason, the chlorophyll data should be compared between lakes which were sampled in a short period of time.

Bowman I is a difficult lake to assess the trophic status of because there is a paucity of data points. The lake was thermally stratified on 25 Sept. (Graph 2). The difference between the temperature of the surface water and the bottom water was 1.5°C. at 10a.m. and 1.8°C. at 10:50 a.m.. it is likely that Bowman I becomes thermally stratified during the day and isothermal at night during the autumn (and possibly the spring) due to the shallowness of the lake. The high oxygen content throughout the water column is partially due to the shallowness of Bowman I and partly to its turning over. The low transparency of the lake is primarily due to the large quantity of suspended sediment in the water, as evidenced by the muddy color of the water. The fairly large alkalinity and very high conductivities can both be attributed to the high degree of loading which Bowman I is confronted with. . This lake serves as a flood control catch basin for the Blind Brook watershed, and is subjected to large inputs of both suspended and dissolved materials.

The two algae identified from Bowman I whole water samples were Diatoma and Coelosphaerium. For purposes of this study, these algae will be considered as the dominant ones. The presence of a diatom in large numbers signifies an abundance of silica. The origin of this silica could be from the sediments (indicating overturn) or from Blind Brook. Coelosphaerium, as with other blue greens, indicate eutrophic waters (Hasler; Edmonson 1969).

Bowman I is eutrophic, probably between Lake Waccabuc and Bowman II. It is well oxygenated through the entire water column due to overturn, but it has high nutrient concentrations, low transparency and blue green algae which are indicative of eutrophic lakes. This lake needs to be studied earlier in the season since it is probable that mixing had occurred prior to sampling.

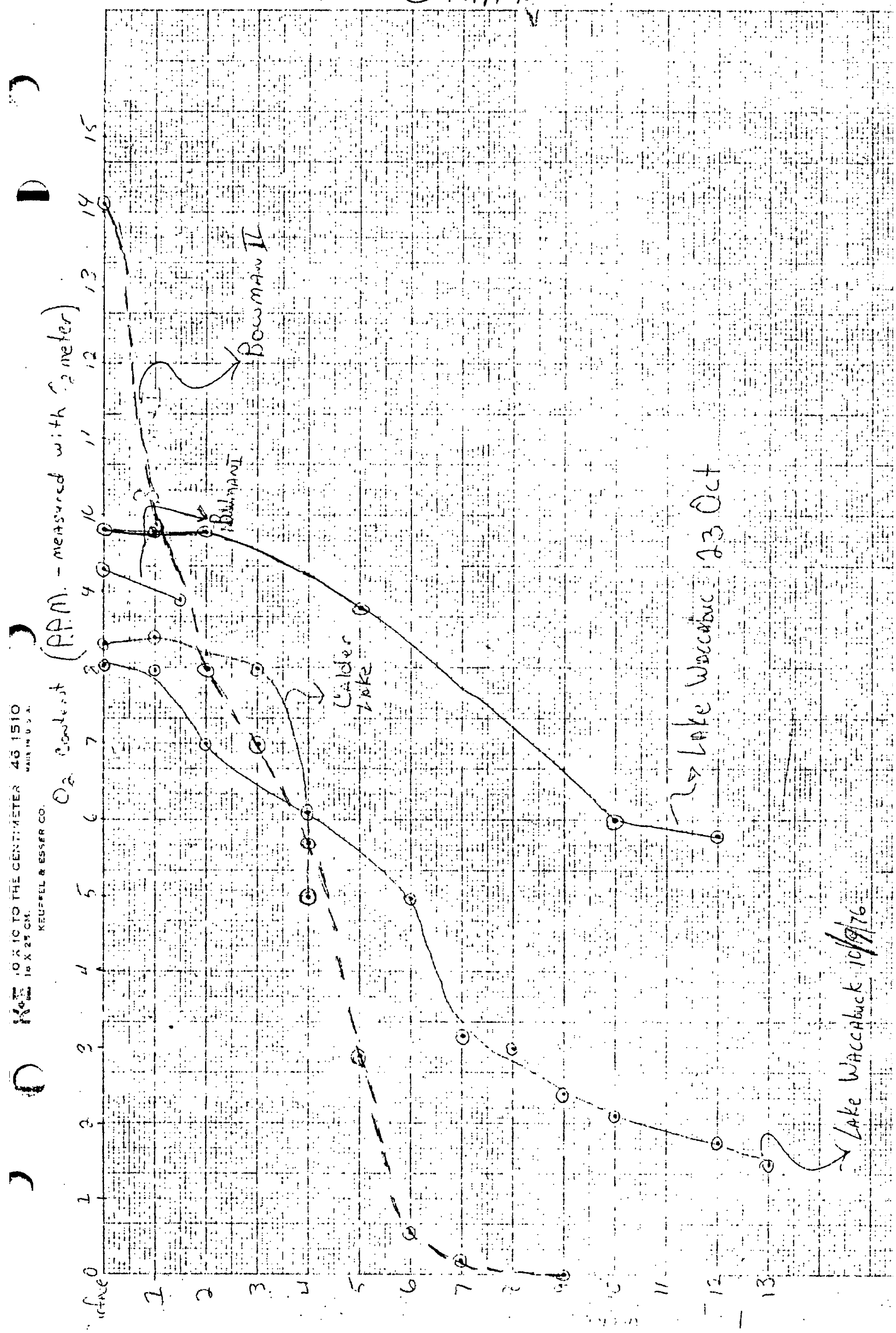
Calder Lake is considered to be the lake of lowest trophic level of the lakes studied. The secchi disk reading from this lake is the largest obtained, ranging from 2.5 to 3.7 meters. Unfortunately, it is believed that Calder Lake had almost reached autumnal overturn as indicated by the temperature profile in Graph 2. The decrease in temperature from the surface to one meter is partly due to residual warm water of the summer, and partly from the influx of solar energy during the morning. Surface water had been cooling and then sinking, supplying the bottom water with oxygen and forcing the thermocline towards the surface The apparent drop in oxygen shown in Graph 1 is thought to be the result of the oxygen meter hitting the bottom sediments. The Winkler oxygen determinations show no drop in oxygen concentrations. Both the alkalinity and conductivity are isoplethal, partially due to the breaking down of the thermocline and the resulting mixing.

The chlorophyll and the pheophytin data from Calder Lake were not marked as to the depth from which they were obtained. It is likely that the chlorophyll a concentration of 3.92 micro grams/l was taken from nearer the surface than was the sample having 0.52 micrograms/l. it is expected that chlorophyll concentration would increase with depth to a maximum slightly below the surface, and then decrease until the bottom. Pheopigments should generally increase with depth. Stratification by either phytoplankton or zooplankton would disrupt this general pattern. If the sample with the highest chlorophyll a concentration were the one taken from nearer the surface, than the pheophytin concentration did increase with depth.

Coelosphaerium, Melosira, Ceratium and Anabaena were identified from the plankton net samples collected at Calder Lake. The dominant algae was Coelosphaerium. The significance of the presence of blue greens has already been discussed. Melosira was also fairly common, and is reported to almost disappear with stratification (Boney 1975). The optimal conditions for Melosira occur during the turbulent conditions of autumn and spring (Boney 1975). The presence of Melosira can then be taken as an indication that thermal stratification is minimal.

Determining the trophic status of lakes with the amount of data we collected and the spread of time over which this data was collected allows room for much conjecture. Ideally, the lakes to be compared would all be sampled on one day. The determination nitrogen and phosphorous concentrations in the waters would also be extremely useful. According to the interpertation of our data, the states of these lakes from the most eutrophic to the least is Bowman II, Bowman I, Lake Waccabuc and Calder Lake.

GRAPH 1



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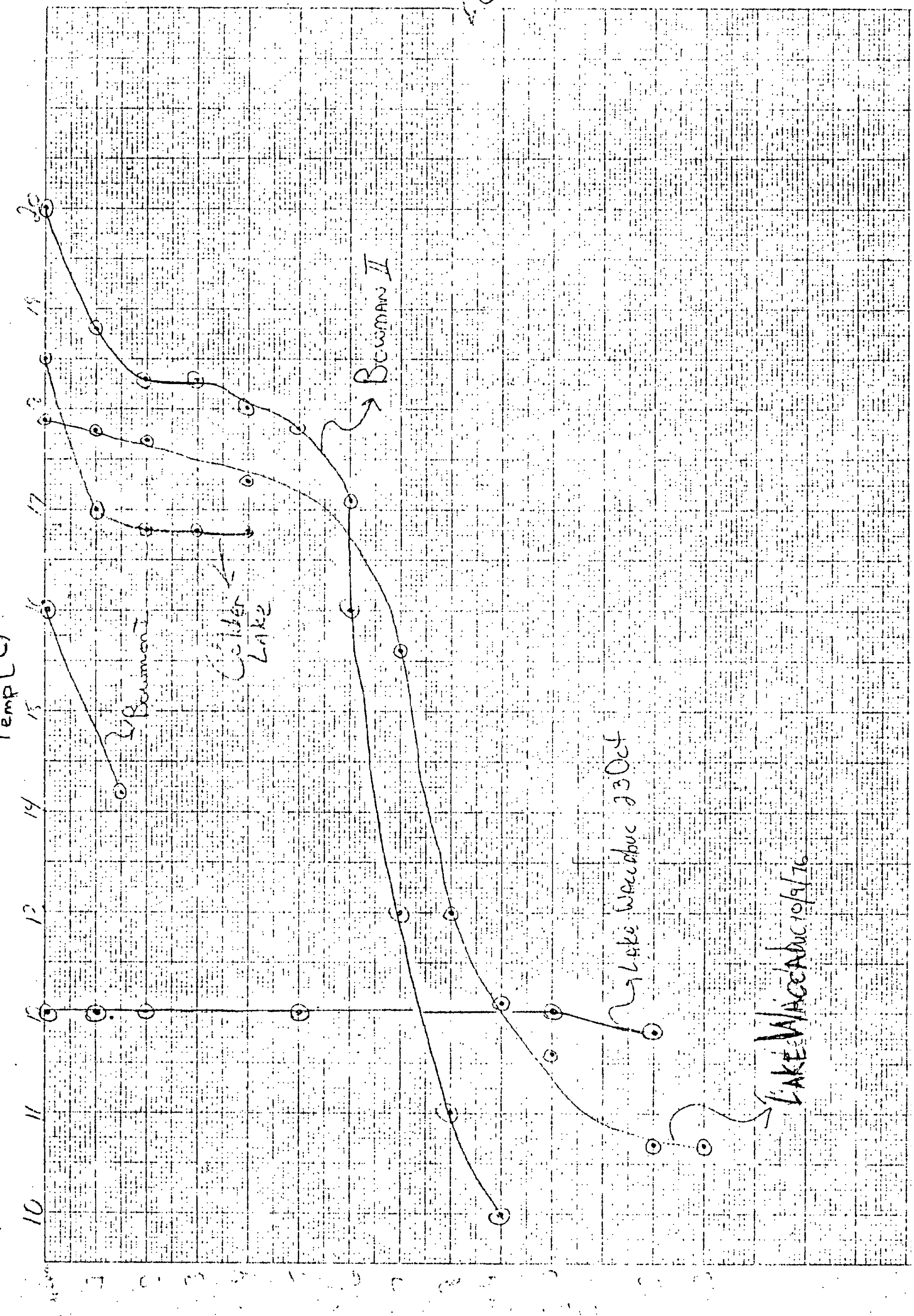
GRAPH 2



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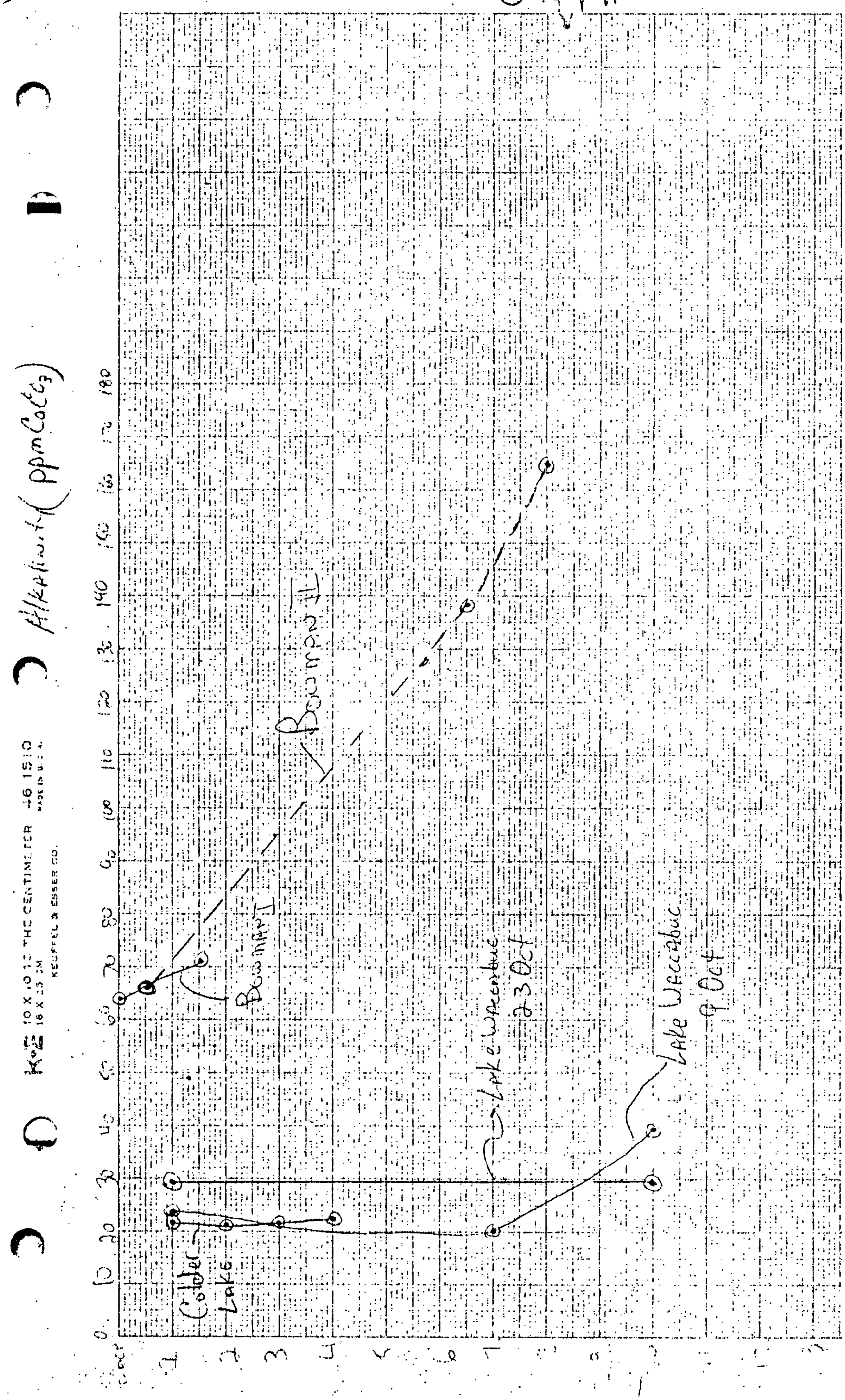
GRAPH 3



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GRAPH 4

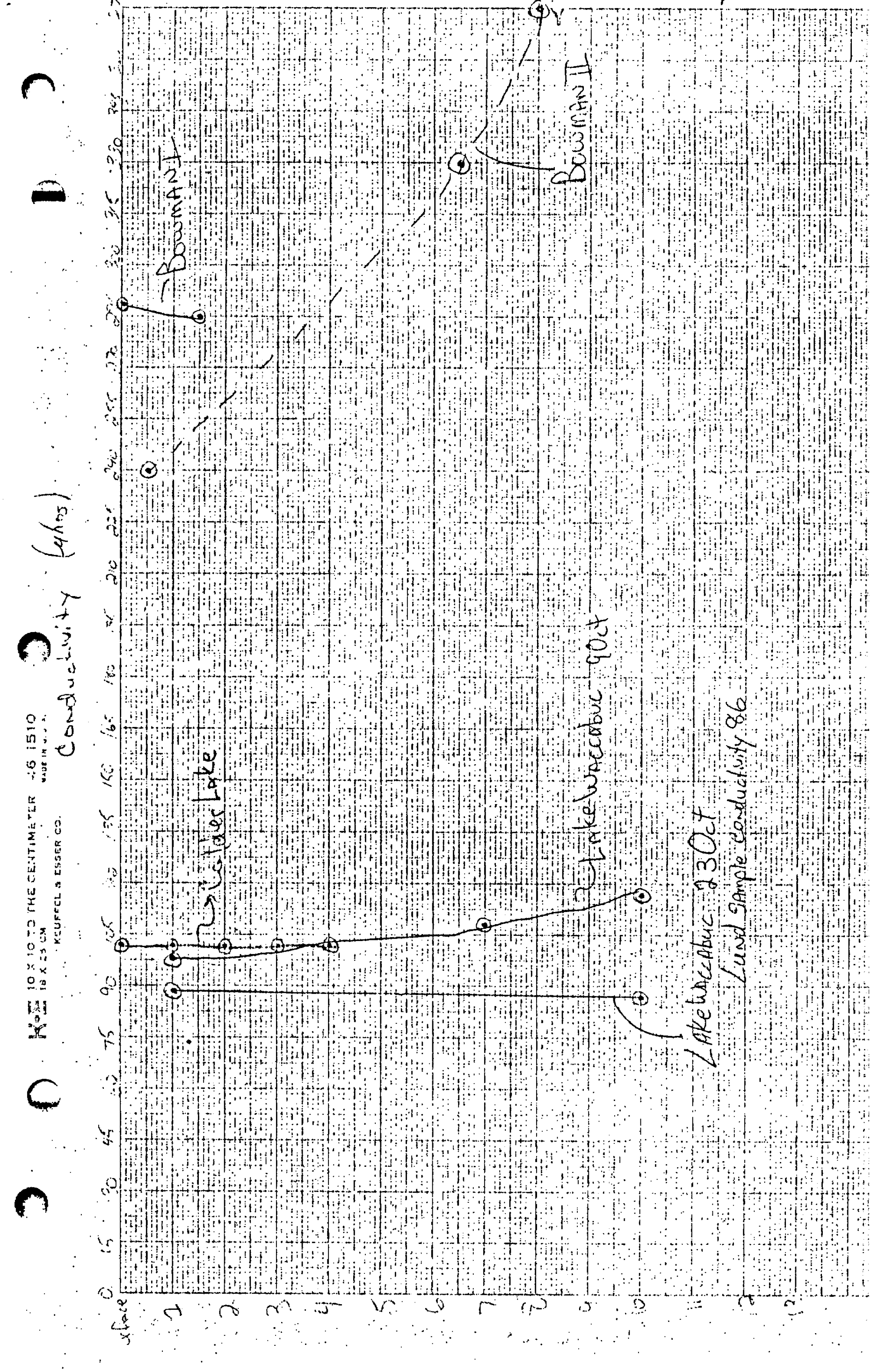

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TABLE 1

ALKALINITY	ppm $CaCO_3$
Calder Lake	22
Lake Waccabuc	24-39
Bowman I	64-71
Bowman II	66-164

CONDUCTIVITY	MHOS
Calder Lake	103
Lake Waccabuc	86-117
Bowman I	285-289
Bowman II	240-375

SECCHI	(meters)
Calder Lake	2.5-3.7
Lake Waccabuc	1.75
Bowman II	1.0
Bowman I	0.75

CHLOROPHYLL a	micro grams / liter
Bowman II	2.85
Bowman I	3.65
Calder Lake	3.92
Lake Waccabuc	5.75

PHEOPHTIN	micro grams / liter
Bowman II	0.25
Bowman I	1.43
Lake Waccabuc	2.37
Calder Lake	2.48

TABLE 2

Calder Lake	2 Oct.	
Coelosphaerium	dominant	blue green
Melosira		diatom
Ceratium		dinoflagelate
Anabaena		filamentous blue green

Lake Waccabuc	9 Oct.		
Anabena	dominant		
Oscillatoria		blue green	
Fragilars		diatom	
Ceratium			
Aphanizomenon		blue green	
Staurastrum		desmid	green
Coelosphaerium			
Microcystis		blue green	
Nauiculd		diatom	

<u>Bowman I</u> whole water sample

Diatoms
Coelosphaerium

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