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Relationship Between Trophic State and Chemical Parameters In Sediment-Water Systems of Selected Western Massachusetts Lakes

by

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Resources Commission.

Contact Number 15-51452

ENVIRONMENTAL ENGINEERING
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University of Massachusetts

Amherst, Massachusetts

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Acknowlegments

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1. Preface

Recent work at the University of Massachusetts, especially in the Environmental Engineering Division of the Civil Engineering Department, has been directed toward investigation of eutrophication in lakes and in particular, the interrelationship of bottom deposits and overlying water quality. In these studies, the rate and mechanism of nutrient transfer has been examined in laboratory simulations of field conditions. The ultimate objective however, is to provide information which is applicable to actual lake conditions. This paper presents the results of a detailed survey of lakes in Western Massachusetts carried out during the summer months of 1970. The survey will be used to select the appropriate lake or lakes for more exhaustive studies of nutrient exchange and to verify the laboratory findings. Specific chemical and biological data were collected during the summer algal bloom period which made possible the classification of the lakes into their limnological type; eutrophic, oligotrophic, or mesotrophic. These pertinent measurements along with others will be used in future lake classification studies. It is anticipated that forthcoming information will be useful in decision making steps affecting the future of lakes in Massachusetts.

II. Rationale for Lake Studies

The main objective of this project was to determine the chemical, physical, and biological classification of selected lakes in Western Massachusetts. Since it was not possible to measure all parameters, it was decided to measure or observe those which are believed to govern eutrophication. Depth and temperature, both physical parameters, were selected since these are essential for determining the degree of mixing (resulting from thermal stratification), percent saturation of dissolved oxygen, correct determination of pH (pH is a function of temperature) and, vertical variations of the other chemical parameters.

The chemical parameters of interest were orthophosphate, alkalinity, pH, ferrous iron, total iron, and dissolved oxygen. Orthophosphate was decided upon since it is an algal limiting nutrient (Sawyer, 1947), and has been shown to be directly related to algal blooms (Casper, 1965). Alkalinity and pH were determined to ascertain the relative buffering capacity and hydronium ions concentration. Ferrous and total iron analysis were also performed since iron and orthophosphate can be tied up together in the sediment as either $FePO_4$ (Morgan and Stumm, 1964) or as $Fe_3(PO_4)_2$ (Harter, 1968). Finally dissolved oxygen was determined in the lake water since it is related to biological activity as well as the relative redox (reduction - oxidation) potential.

Biological activity was not measured directly; rather, a visual description of approximate amount and type was made. This parameter was chosen since the degree of eutrophication is related to the plant or algal productivity of a lake.

The above parameters found in the various lakes are those which would be most significant in determining the degree of eutrophication. The three basic classes used were eutrophic, mesotrophic and oligotrophic. By comparing the chemical and biological parameters, it was further and more importantly hoped that each lake could be classified into one of the three categories. Further and more importantly, with a knowledge of the surrounding area, each lake's present limnological type should be related to the quantity and source of nutrients entering the lake.

Another part of the study dealt with the type of sediment in each lake, and more specifically the amount of orthophosphate in lake muds. It was of interest to study the release of phosphorous at low redox potentials, and the relationship of interstitial phosphate to the phosphate in the lake water itself. Samples were collected in core barrels and stored at 20°C for two weeks to four months to let the mud naturally reach a low redox potential and to reach an equilibrium with the overlying water. Samples were then analyzed for orthophosphate, total iron, pH, dissolved oxygen, and volatile solids content. The orthophosphate and total iron concentration as well as pH were determined on the interstitial water in the mud only since the water is presumed to be at equilibrium with the surrounding solids and would be readily available to diffuse out of the mud and into the lake water. Dissolved oxygen was measured to ascertain the relative redox potential of the system which should be in a very reducing state. Finally, the volatile solids content of the muds should give an indication of the organic content of the mud. The entire analysis should show the effect of reducing conditions on the liberation of algal nutrients from lake muds.

The results from the lake water and the sediment studies will be compared to see if a relationship exists between the degree of eutrophication and the potential of the mud, under reducing conditions, to liberate nutrients. Comparisons of the various parameters should also show from what depth in the mud the nutrients can diffuse into the lake water and what characteristics in the mud are significant in determining the chemistry and biology of the overlying water.

III Area of Investigation

The various types of lakes studied were all located in Western Massachusetts within forty miles of Amherst. All of the lakes are located either within arkosic sandstones, glacial gravels, or granitic - like igneous rocks. There are no prominent outcrops of limestone (natural source of carbonate) which explains the relatively low amounts of alkalinity and the acidic (low pH) nature of all of the lakes. In addition, the lakes studied are relatively small, between 50 and 130 acres, and are also quite shallow.

The lakes studied can be grouped into two categories based on depth; those less than 20 feet deep exhibiting no thermocline and those deeper than 20 feet (and usually not any deeper than 50 feet) with a well developed thermocline. Moreover, in the former category, there appeared to be two sub-categories; those relatively free of algae and those which showed high amounts of algae. Metacomet Lake (see Figure I)is the only one which was relatively free of algae blooms. It is located in Belchertown, Hampshire County, is 74 acres in size, and has a maximum depth of 18 feet (McCann, 1970). The lake has a large number of summer residence homes as well as swimming facilities and reasonable fishing. Water lilies and marsh-like areas are the only obvious indications that the lake contains some nutrients.

Within the same drainage basin are located two other shallow lakes, both of which were populated with high amounts of algae during the time

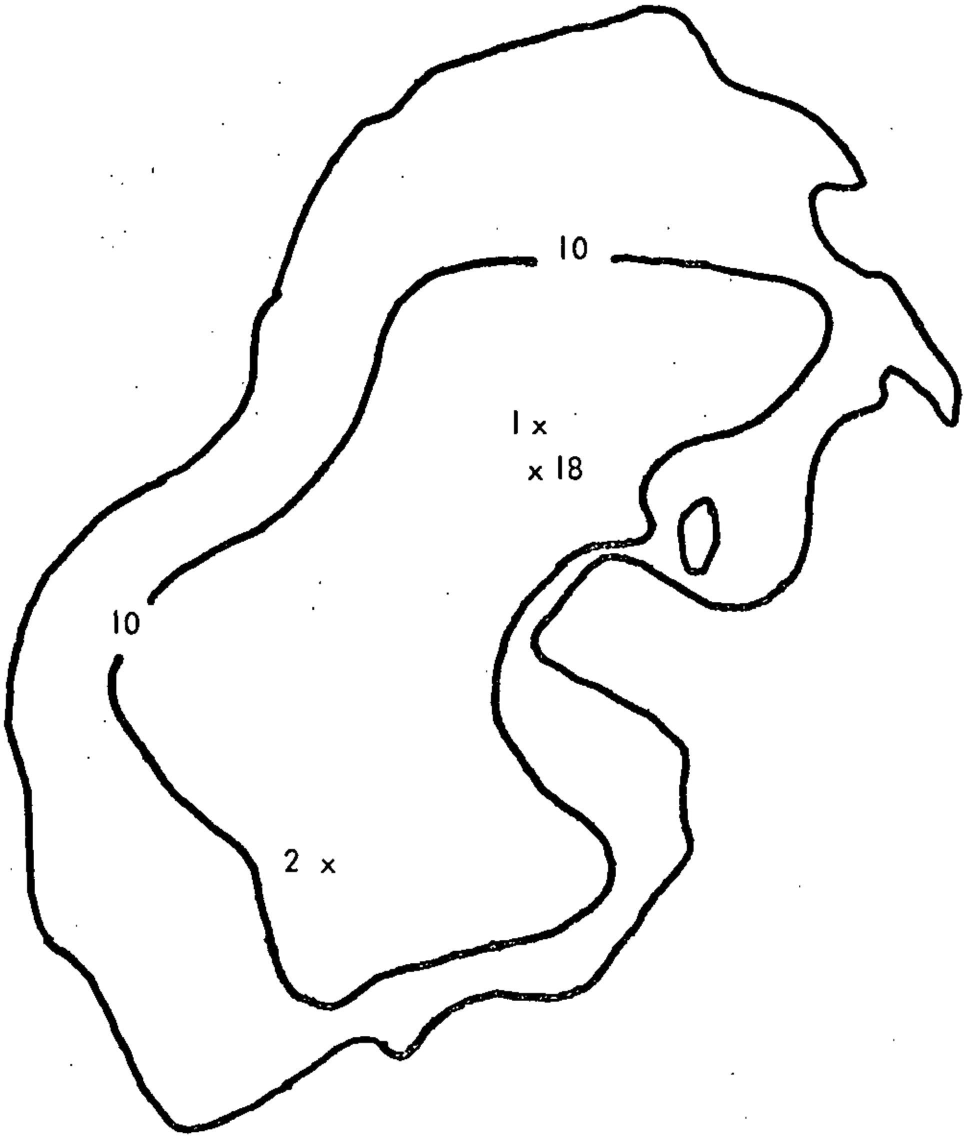

Figure 1

Metacomet Lake

Belchertown

Hampshire County

Area = 74 Acres

"x indicates sample station"

of the study. These are Aldrich Lake (see Figure 2) and Forge Pond (see Figure 3). Batchelor Brook empties into Forge Pond and then flows into Aldrich Lake. Both lakes are located in Granby, Massachusetts, and receive the effluent from the Belchertown State Hospital treatment plant via Batchelor Brook. Forge Pond, at the time of the study, had been partially drained due to a cracked dam and was only 6 feet deep. Aldrich Lake was about 13 feet and, because it was created about 1910 by the construction of a dam, has only six to ten inches of mud covering the sand and humus bottom.

The last lake to be discussed in the shallow category is Lake Warner (Figure 4), located in North Hadley, Hampshire County. It has an area of 68 acres, and a maximum depth of 10 feet (McCann, 1970). This lake was formed by construction of a mill dam on the Mill River and exhibited abundant growths of algae, mainly _Anabaena_ _sp._ and _Anacystis_ _sp._ The lake receives sporatic (?) slugs of sewage from the overflow of the Amherst Treatment Plant which eventually enters the lake via the Mill River.

In the other category, those lakes with thermal stratification, there are also two sub-categories but not as easily separated: those with depth of 30-40 feet and others with depths of greater than 50 feet. Laurel Lake (Figure 5) is located in the towns of Erving and Warwick, has an area of 51 acres, and a maximum depth of 32 feet (McCann, 1970). The lake is quite clean with bathing (Erving State Park), boating, and fishing. No algae were evident although there was abundant bottom plant growth.

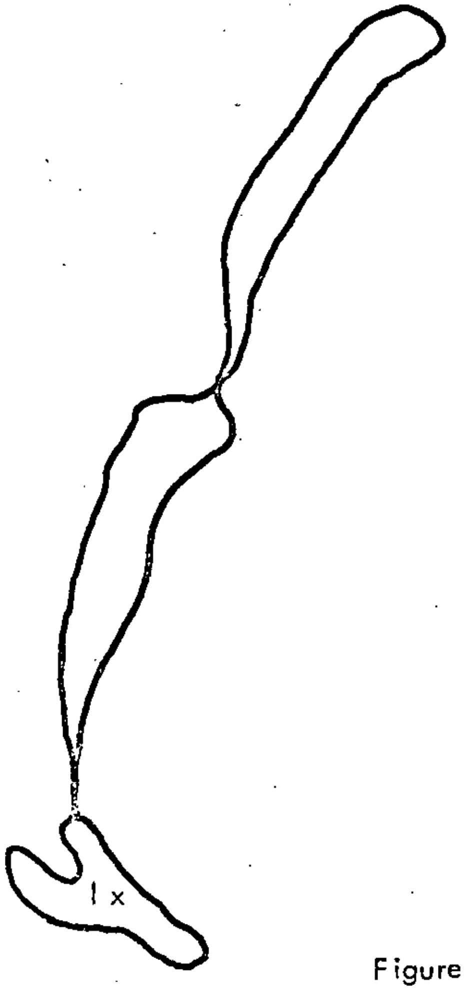

Figure 2

Aldrich Pond

Hampshire Co.

Granby, Mass.

"x indicates sample station"

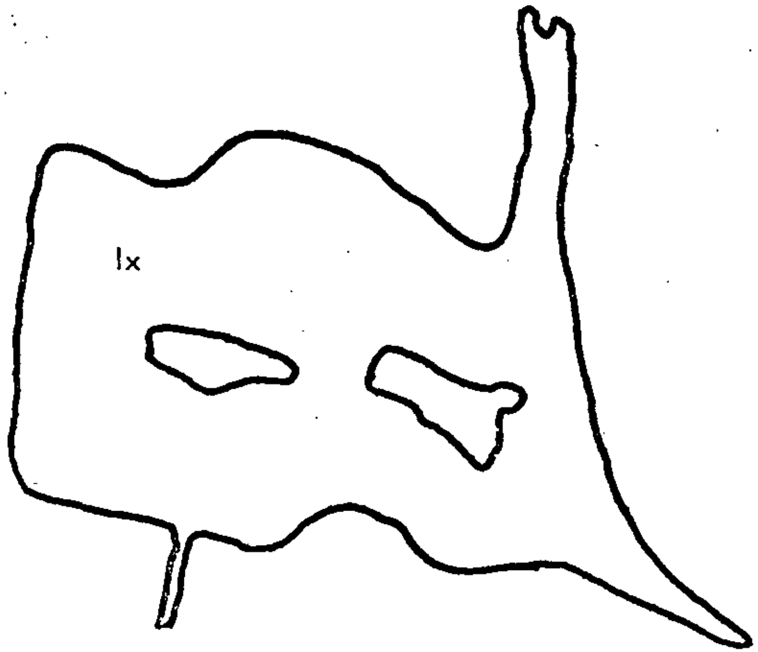

Figure 3

Forge Pond

Hampshire Co.

Granby, Mass.

"x indicates sample station"

α

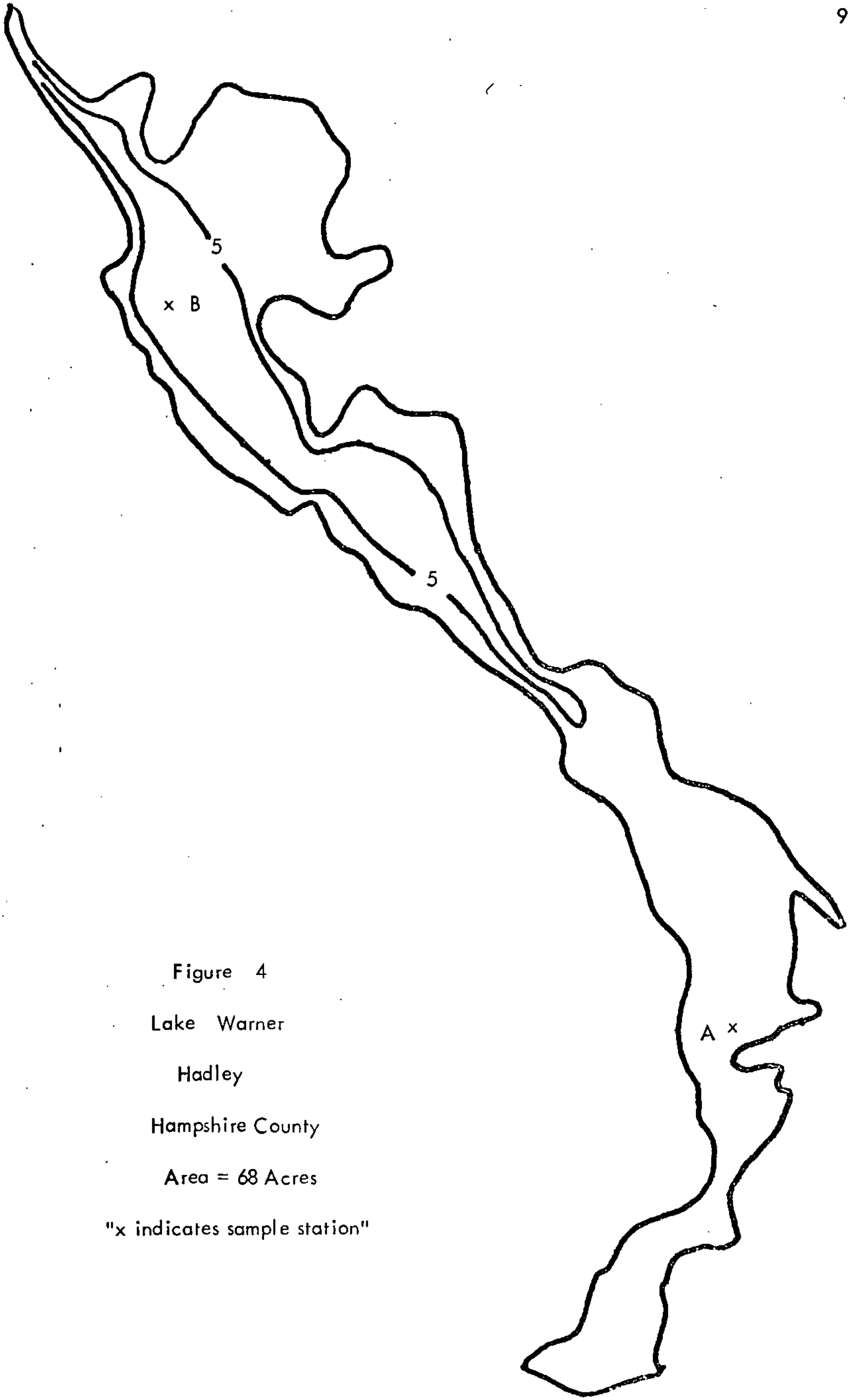

Figure 4

Lake Warner

Hadley

Hampshire County

Area = 68 Acres

"x indicates sample station"

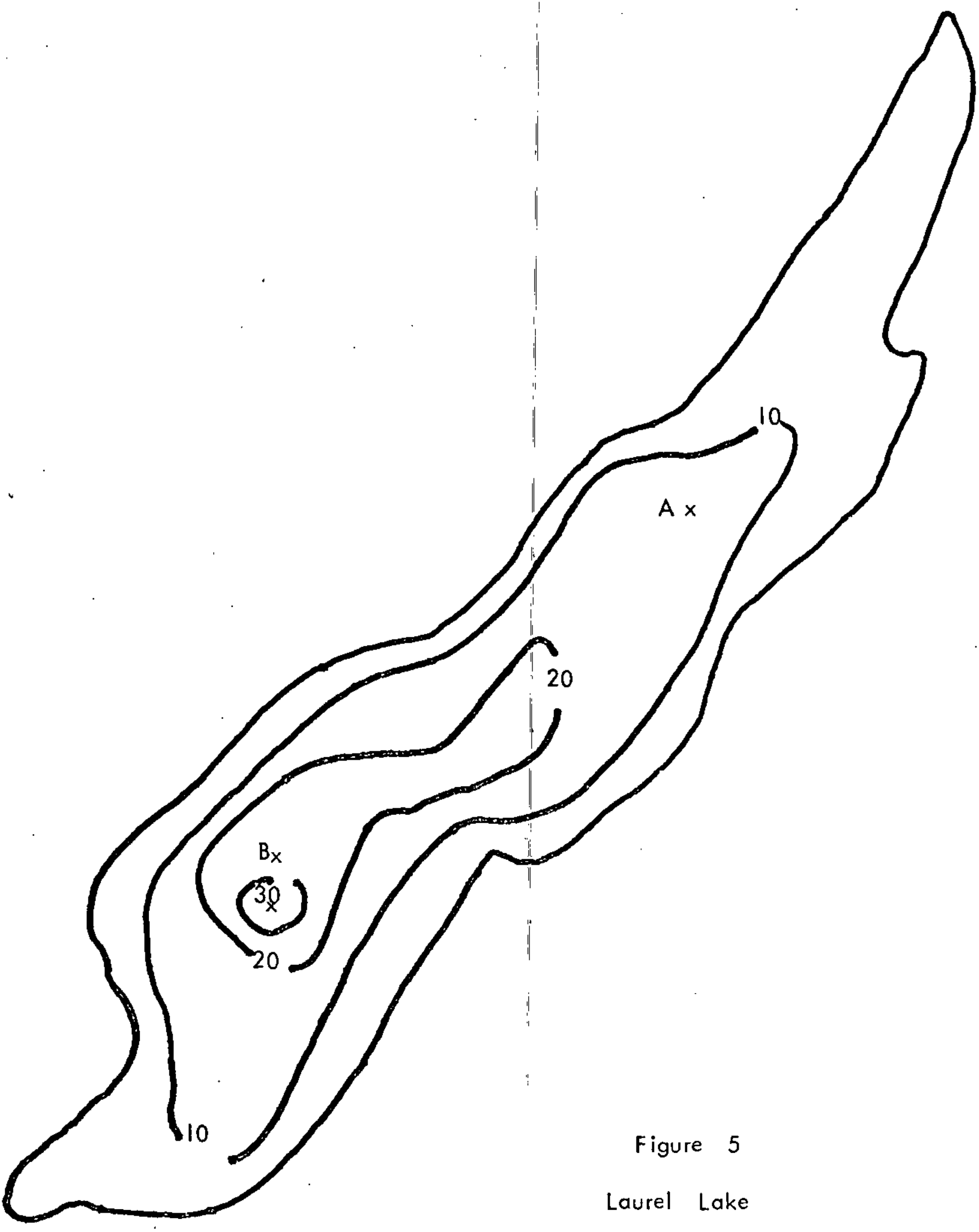

Figure 5

Laurel Lake

Erving Warwick

Area 51 Acres

"x indicates sample station"

Lake Wyola (Figure 6), located in Shutesbury, Franklin County, has an area of 129 acres, and a depth of about 34 feet (McCann, 1970). This lake also has bathing, boating, and fishing along with a large summer population of shore residents. At the eastern end of the lake (influent of two streams), a large area of marsh and underwater plant growth is evident, but little, if any floating algae are present. Lake Mattawa (Figure 7), is also in this group. Located in Orange, Mass., this lake has an area of 112 acres, and a depth of about 40 feet (McCann, 1970). Like the others, Lake Mattawa has fishing swimming, and boating as well as a large number of summer homes. Some water lilies are present in the extreme southeastern corner, but no other area has any bottom plants and no floating algae was observed.

In the category of deeper lakes with stratification are Norwich Pond and Asnacomet Pond. Norwich Pond (Figure 8), located in Huntington, Hampshire County, has an area of 122 acres, and a maximum depth of 53 feet (McCann, 1970). The water itself is very clean and accomodates fishing, boating, swimming, a summer camp, and a large summer population. There are a few underwater plants and no algae present. Asnacomet Pond (Figure 9), in Hubbardston, Massachusetts, has an area of 127 acres, a maximum depth of 55 feet, and occasionally serves as a water supply for the MDC (Metropolitan District Commission) system (McCann, 1970). Asnacomet Pond has all of the recreational facilities found in the other lakes described and is surrounded by a moderate number of summer homes. No evidence was

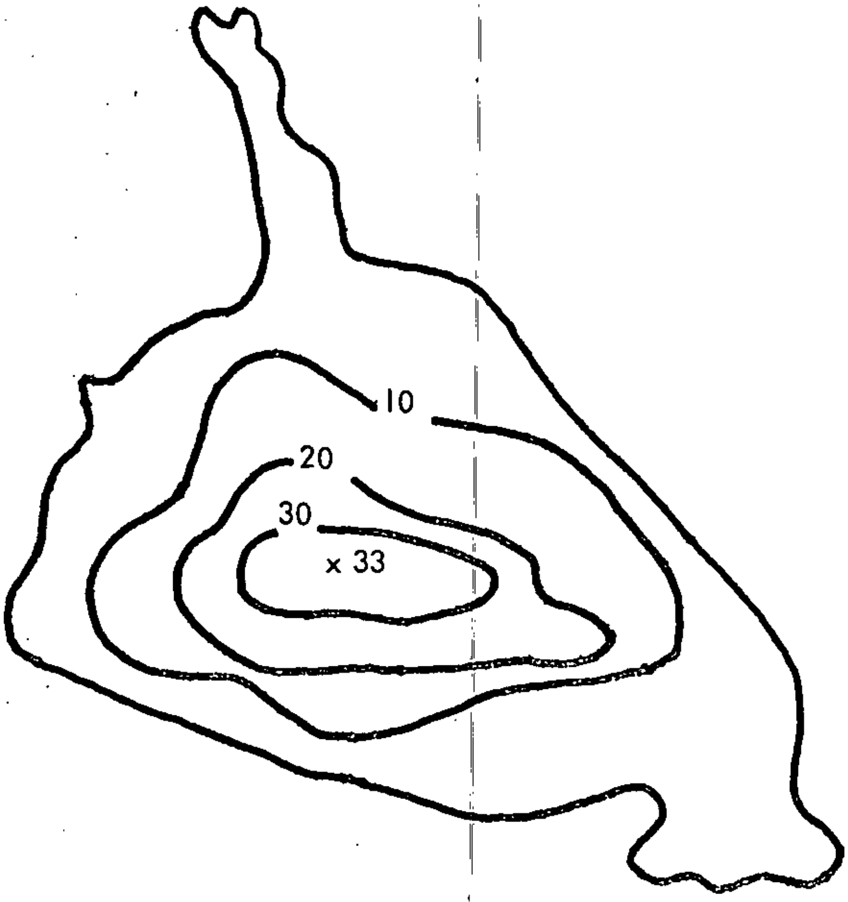

Figure 6

Lake Wyola

Shutesbury

Franklin County

Area = 129 Acres

"x indicates sample station"

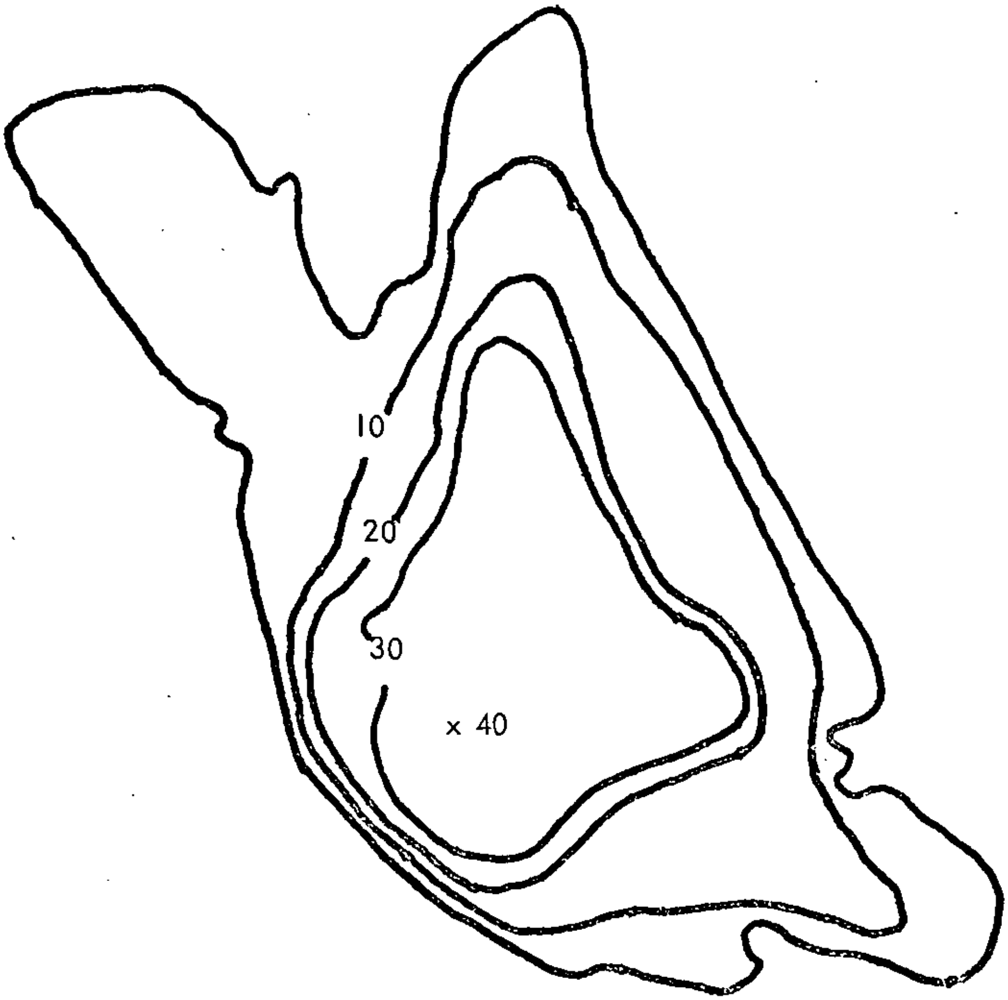

Figure 7

Lake Mattawa
Orange

Area = 112 Acres

"x indicates sample station"

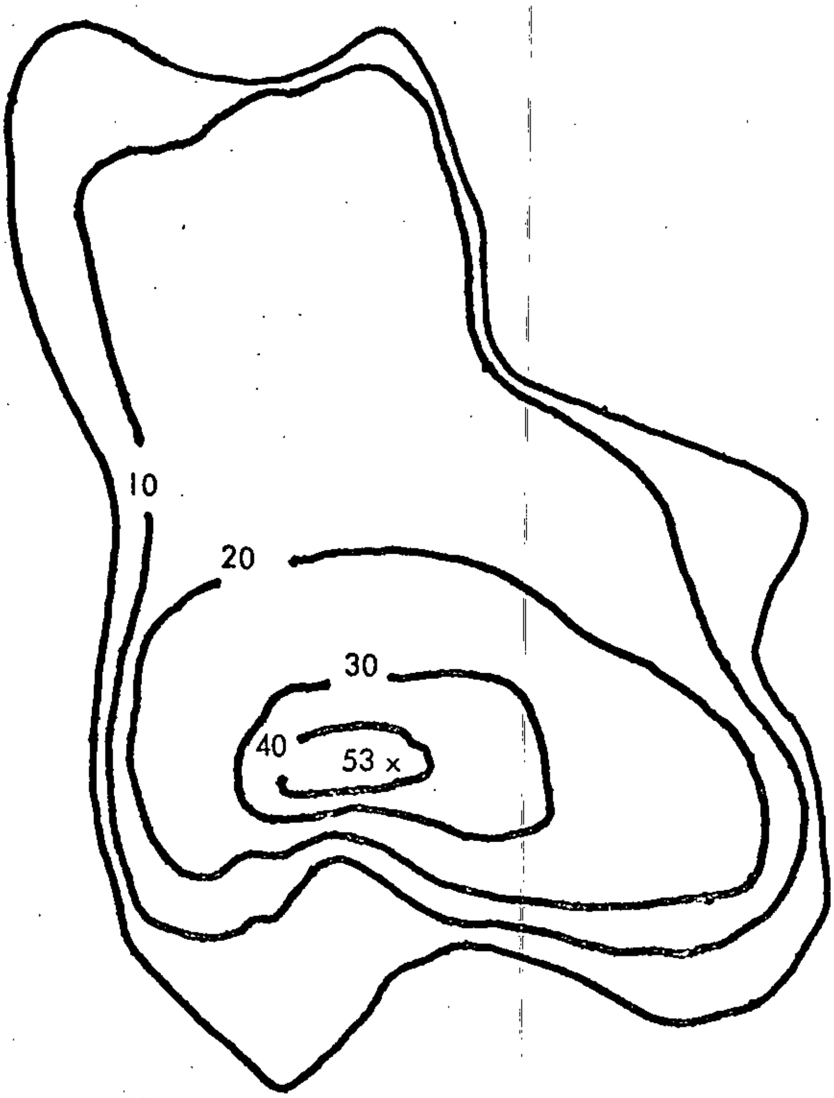

Figure 8

Norwich Pond

Huntington Hampshire Co.

Area 122 Acres

"x indicates sample station"

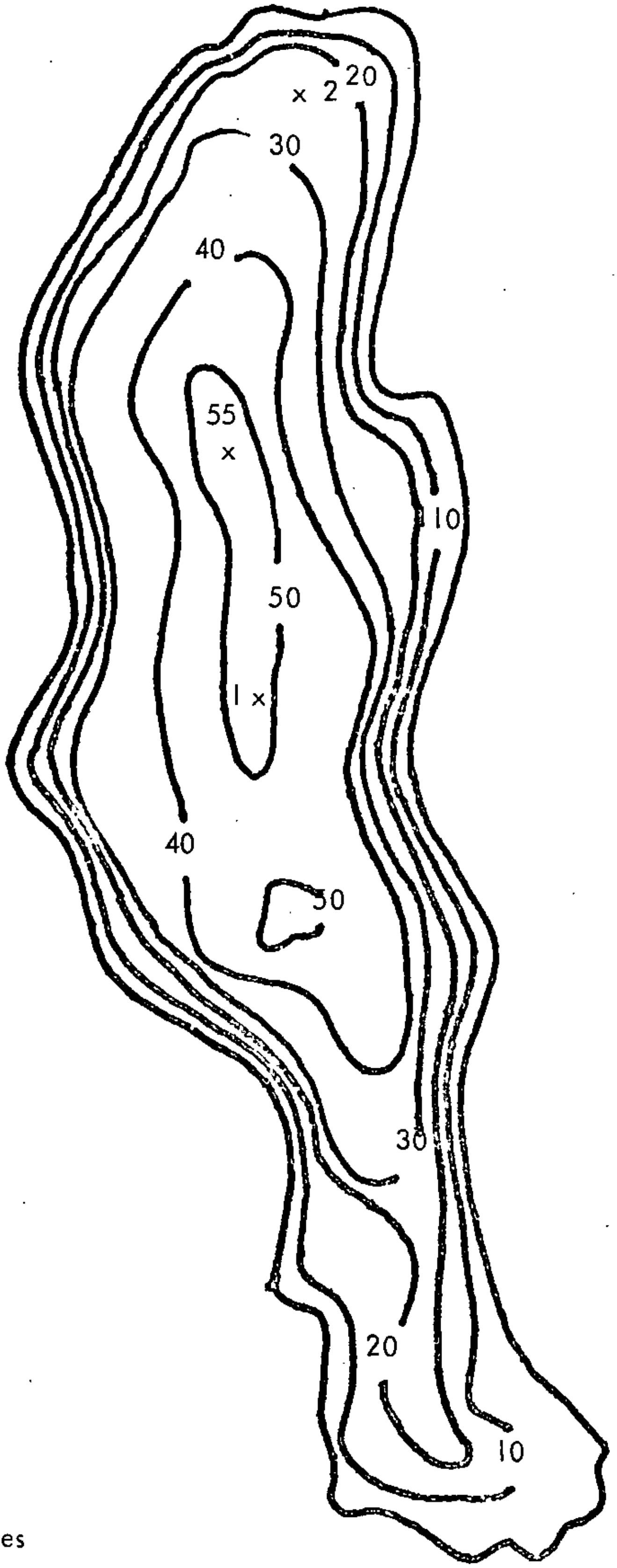

Figure 9

Asnacomet Pond

Hubbardston

Area = 127 Acres

"x indicates sample station"

found of attached plants or algae, and the water itself was very transparent.

It would appear from the forgoing that only the very shallow lakes have algae problems and only those that receive direct input of sewage suffer from algae blooms. All of the deeper lakes tested showed no algae blooms and were quite the opposite being very clean lakes. The only shallow lake, Metacomet, that did not have algae blooms had been previously treated with sodium arsenite to kill attached plants. This fact along with its greater depth and no direct sewage input may explain why it is not in the same condition as the other shallow lakes.

The following table gives a summary of the pertinent data:

Lake	Maximum Depth (feet)	Thermocline	Algae	Group
1. Metacomet Lake	18	No	few	shallow
2. Aldrich Lake	13	No	many	shallow
3. Forge Pond	6	No	many	shallow
4. Lake Warner	10	No	many	shallow
5. Laurel Lake	32	Yes	none	deep
6. Lake Wyola	34	Yes	few	deep
7. Lake Mattowa	40	Yes	none	deep
8. Norwich Pond	53	Yes	none	deep
9. Asnacomet Pond	55	Yes	none	deep

IV Method of Analysis

The study consisted of two separate series of analyses. In the lake water study, on site measurements of temperature, depth, alkalinity, pH, dissolved oxygen, ferrous iron, and total iron were preformed in order to avoid any changes in these parameters. Temperature was measured with a portable thermal probe lowered into the water in order to obtain a complete profile of temperature. Additionally, a Heathkit depth sounder was used to determine total depth and the contour profile of the lakes. Alkalinity (as determined by acidimetric titration), pH (Orion pH meter), and dissolved oxygen (Delta Portable galvanic cell) data were taken at specific depths with a 1 liter water sampler. Ferrous (Fe^{+2}) and total iron (Fe^{+2} and Fe^{+3}) were measured colorimetrically with the aid of a Hach Portable Colorimeter. In contrast to the field determinations, orthophosphate analyses were performed in the laboratory. The method adopted for low level measurments of orthophosphate (PO_4^{-3} as P) was that employing ascorbic acid and extraction (See appendix 1 for method). Readings were taken on a Spectronic 20 and values determined from the calibration curve (Appendix II). This method was also used on determining free PO_4^{-3}-P in the interstitial water of the mud after appropriate dilution (Sutherland, et.al., 1966). All of the other parameters were observed visually and recorded in the field. These include visual assessment of productivity, amount and type of attached plants, benthic organisms, appearance and character of mud and source, if any, of pollution or number of homes on the lake.

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The mud study involved some of the above parameters as well as volatile solids and water content. Samples were taken using a modified Benthos coring device lowered from a 14 foot boat by means of a winch and boom. An Echman dredge was used to determine mud type and to take samples for benthic organisms. Cores from the lake were, after storage, analyzed for dissolved oxygen, pH, and orthophosphate in the same method as previously described. Total iron was determined using the phenanthroline method (Standard Methods, 1965) and readings determined on the Spectronic 20. Actual values were determined from the calibration curve (Appendix III). Volatile solids and water content were determined on the various samples and recorded as percentages rather than in mg/gm so that comparisons between the various lakes could be easily done, (Standard Methods, 1965 and Sawyer and McCarty, 1967). All of the core analysis data was determined with respect to depth in the core so that variations of these parameters could be correlated to depth in the mud. Orthophosphate and total iron were measured by first centrifuging the mud to extract the interstitial water, while pH, volatile solids, and water content were determined on the entire sample. Data gathered in the field, especially iron and orthophosphate concentrations of the overlying water, was used as initial values against which the aged core values were compared.

V. Observations on the Lake Study

The data gathered on the lake water study has revealed many good correlations between the lakes. All of the actual data is presented in tabular form in appendix III. Graphs of the various parameters are presented in the text to show how the lakes appear to group into different categories depending on their temperature and dissolved oxygen profiles. (Sample dates are given on each figure).

Figure 10 shows that Metacomet Lake does not exhibit a thermocline but has a gradually decreasing dissolved oxygen profile with all other chemical parameters increasing in concentration with increasing depth. The increase in H^+, iron, and alkalinity can all be attributed to the decrease in the redox potential (lowering of D.O.) and increase of CO_2 from bacterial activity at the bottom. Of interest is the low amount of algae present in this lake compared to the next three lakes.

Figure 11 and 12 are the temperature - dissolved oxygen profiles for Aldrich Pond and Forge Pond, respectively. Both are similar to Metacomet Lake in that neither exhibits a thermocline; however, they differ quite markedly from Metacomet in their dissolved oxygen profile. Both lakes at the surface are supersaturated with respect to dissolved oxygen (between 1.5 and 2 times the saturation values). The gradient of the oxygen profile is quite steep. This extreme condition is explained by the presence in both lakes of high concentrations of algae which cause the supersaturated condition at the surface while the utilization of oxygen by benthic bacteria

Figure 10

Metacomet Lake 8-27-70

"Dissolved oxygen and Temperature vs. depth"

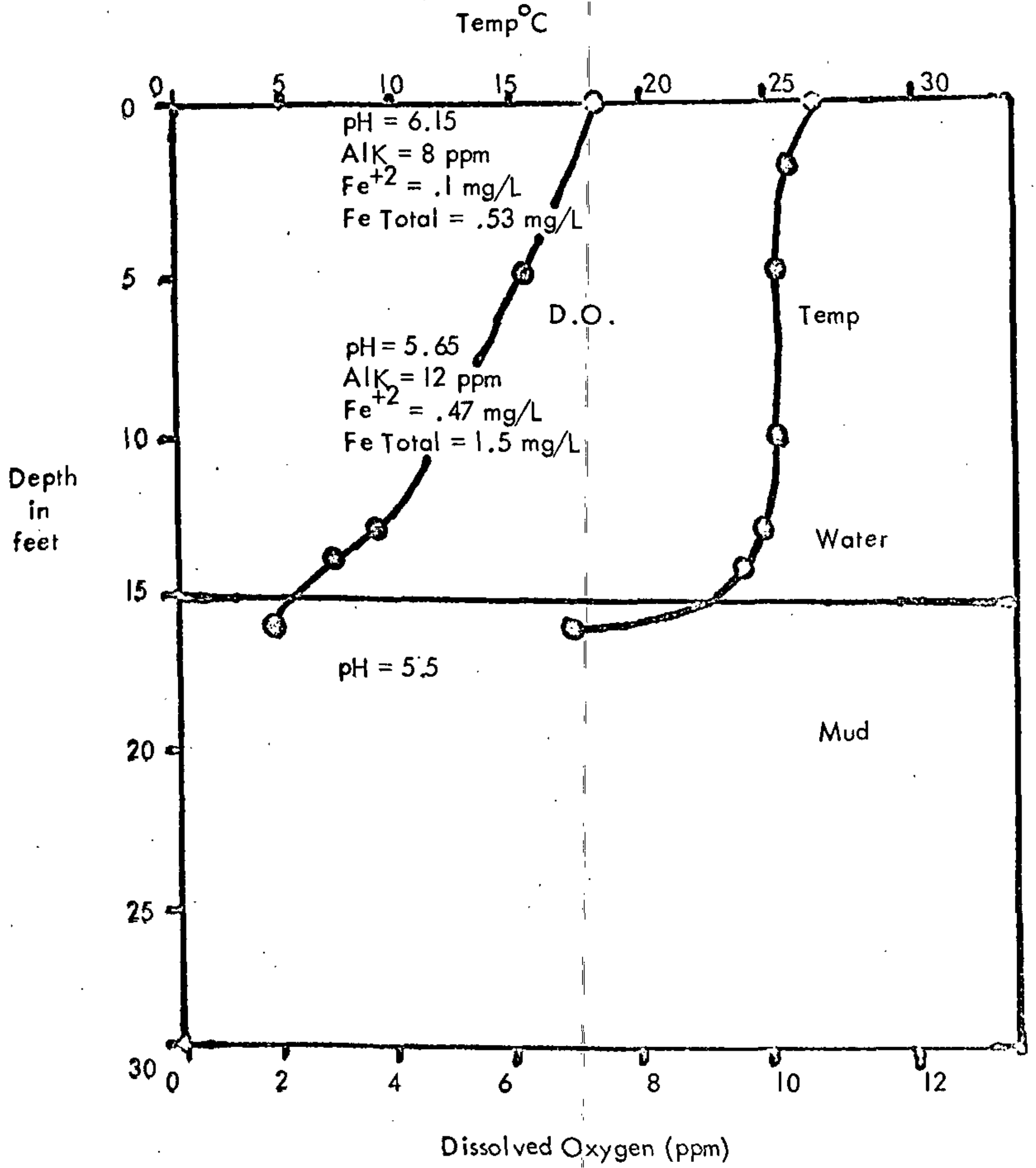


Figure 11

Aldrich Pond 9-10-70

"Dissolved oxygen and Temperature vs. depth"

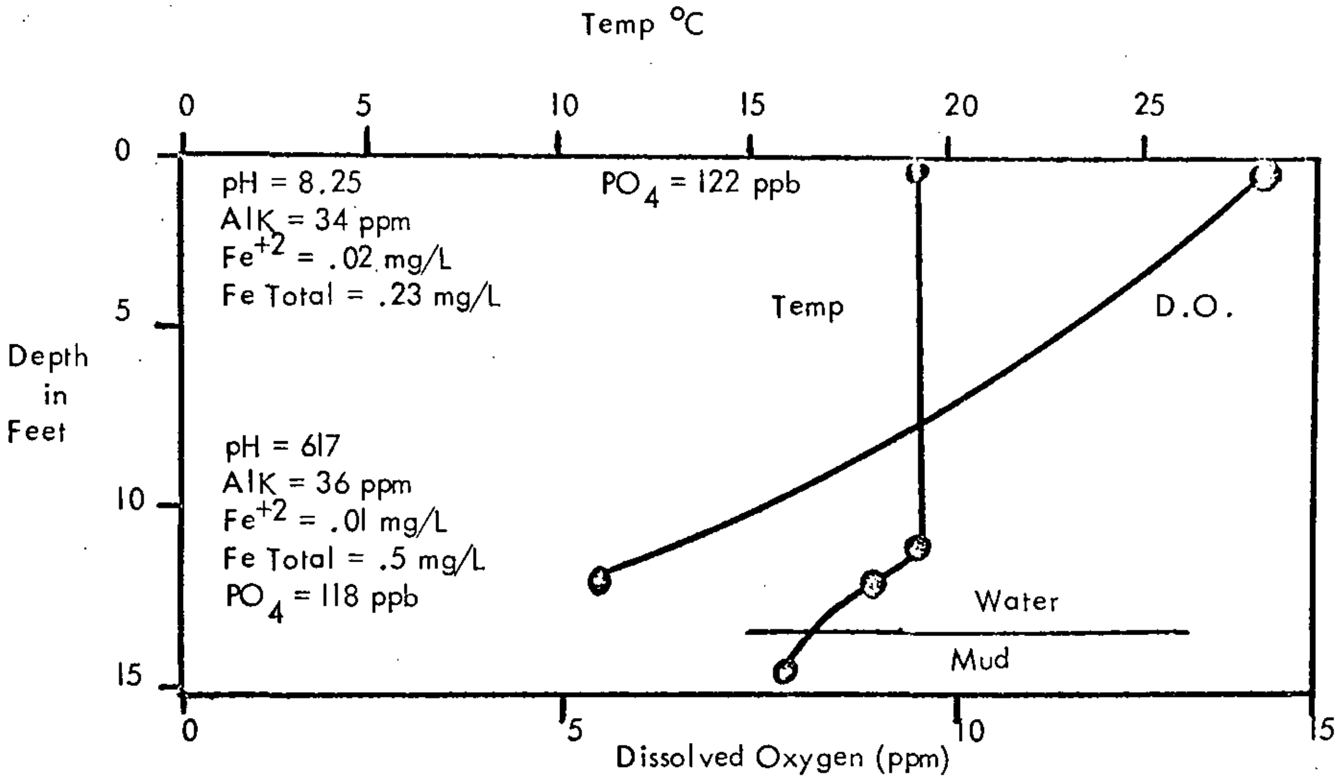
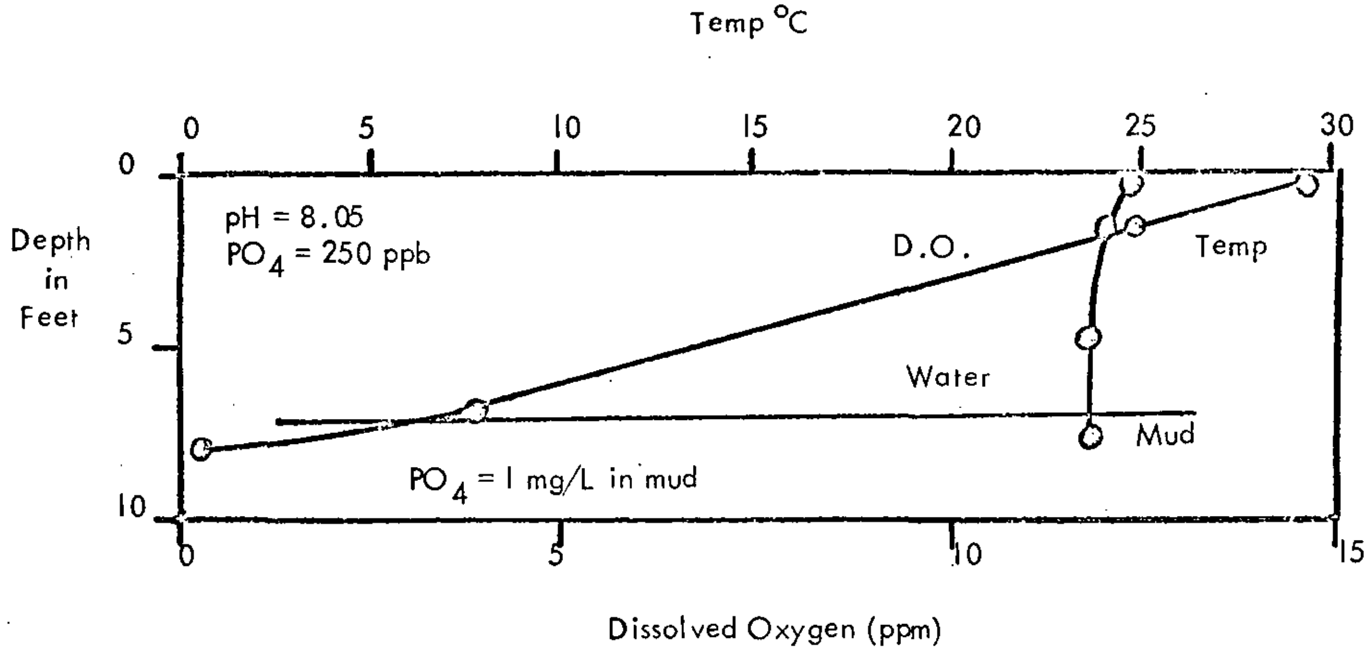


Figure 12

Forge Pond 9-10-70 and 8-18-70

" Dissolved oxygen and Temperature vs: depth"



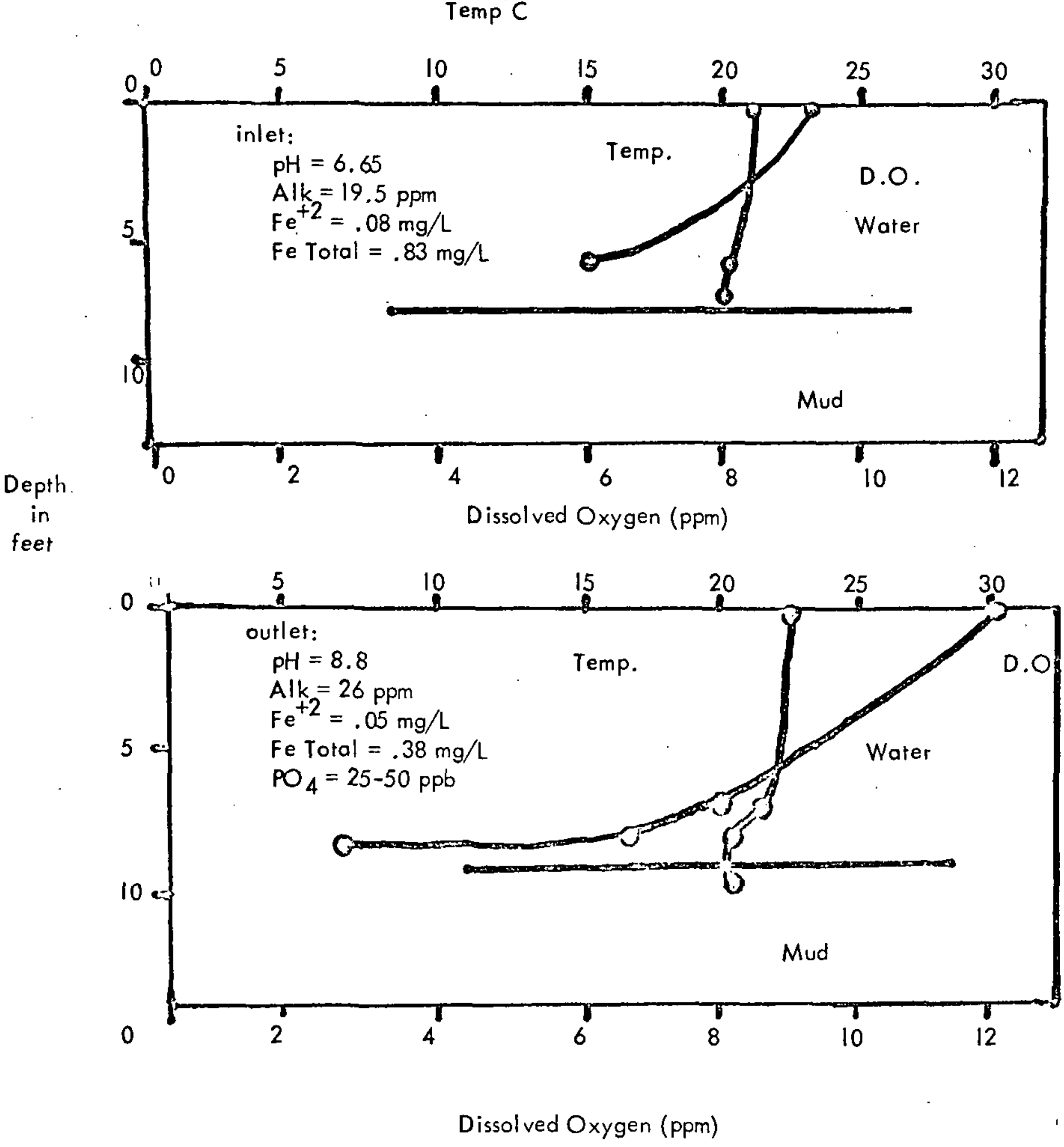
in their breakdown of dead algal cells resulted in the extremely low values of D.O. observed at the lake bottom. Both lakes show tremendous amounts of PO_4^{-3}-P in both the water (120 - 150 ppb) and mud (1000 ppb). Moreover Aldrich Pond showed a very large decrease in pH from surface to bottom. Further comparison of Aldrich Pond with Lake Metacomet reveals a three-fold increase in alkalinity. The relatively high alkalinity and rapid change in pH from top to bottom are attributed to the algal bloom present at the surface (Gahler, 1969). The lowering of D.O. and the redox potential by benthic bacteria is responsible for the shift in pH and the increase in total iron with increasing depth.

Figure 13 illustrates the temperature - dissolved oxygen data from Lake Warner for both inlet and outlet. Comparisons between the two show a similarity to the previous data for Aldrich Pond. Like Aldrich and Forge Ponds, Lake Warner has the same type of oxygen profile with supersaturation at the surface and well below saturation at the bottom (6 to 9 feet). The presence of an algal bloom is evident in the oxygen profile as well as the changes of pH and alkalinity between the inlet and outlet. PO_4^{-3}-P is also very high in the lake water (25 - 50 ppb), being much higher than the 10-15 ppb value needed to produce measurable algal blooms (Casper, 1965).

The four lakes already described fit into the category of shallow lakes and all but one show the control of algal blooms on the chemistry of the lake water. Lake Warner is quite illustrative of the rapid change from top to bottom of pH, D.O., and alkalinity due to algae blooms. Also of note is that all

Figure 13
Lake Warner 8-25-70

"Dissolved Oxygen and Temperature vs. depth"



of the lakes with algal blooms had high amounts of orthophosphate, high pH values, and fairly high alkalinities.

The other group of lakes investigated all had sufficent depth to develop a thermocline. Data collected in Laurel Lake (Figure 14) shows a typical pattern of near saturation values of D.O. at the surface and increasing vlaues of D.O. as the temperature decreases with depth. At the thermocline, the D.O. rapidly decreases due to chemical and bacterial uptake of oxygen and low rate of diffusion of oxygen across the thermocline. This lake, along with some of the others, shows the very low pH and orthophosphate in the lake water which would appear typical for this type of oligothrophic lake. Of interest here is the very low concentration of orthophosphate (40 ppb) in the mud compared to the concentration in the mud of Forge Pond (1000 ppb).

Results of studies in Lake Wyola (Figure 15) show the same chemical and physical pattern as observed in Laurel Lake. Additional information, probably typical of the chemical changes in all of the deep lakes is also evident. It appears that H^+, iron, and probably alkalinity increases tremendously with depth. The sharp increase in concentration of iron from top to bottom illustrates this trend nicely. This increase is directly due to the lower redox potential of the water below the thermocline (Mortimer, 1941). The D.O. profile for Lake Wyola, after the fall overturn with the concomitant effect of mixing the top and bottom waters is shown in Figure 16. Dissolved oxygen is near saturation for almost the entire depth with a rapid decrease near the mud interface.

Figure 14

Laurel Lake 7-30-70

"Dissolved oxygen and Temperature vs. depth"

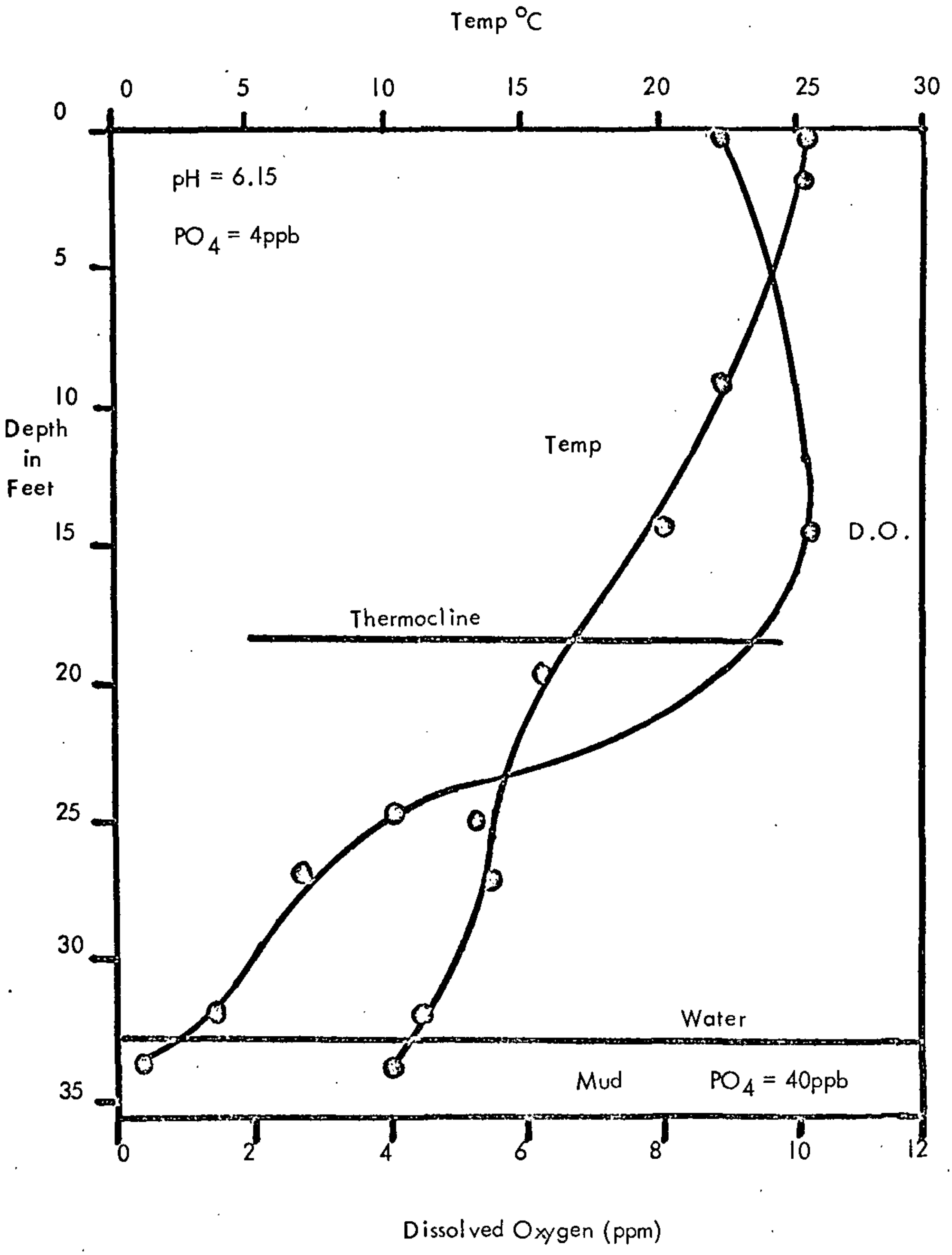


Figure 15

Lake Wyola 8-11-70 and 9-3-70

"Dissolved Oxygen and Temperature vs. depth"

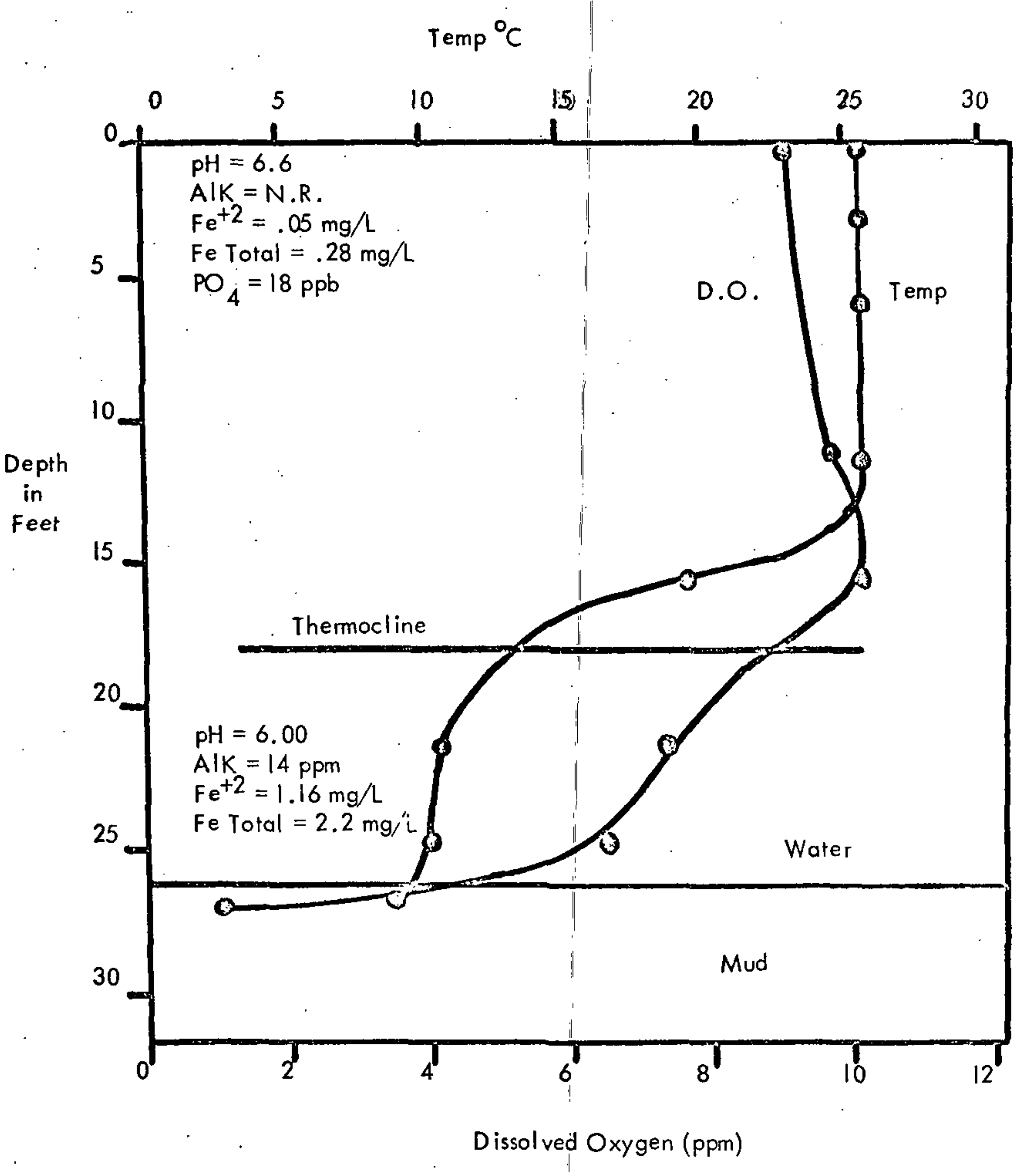
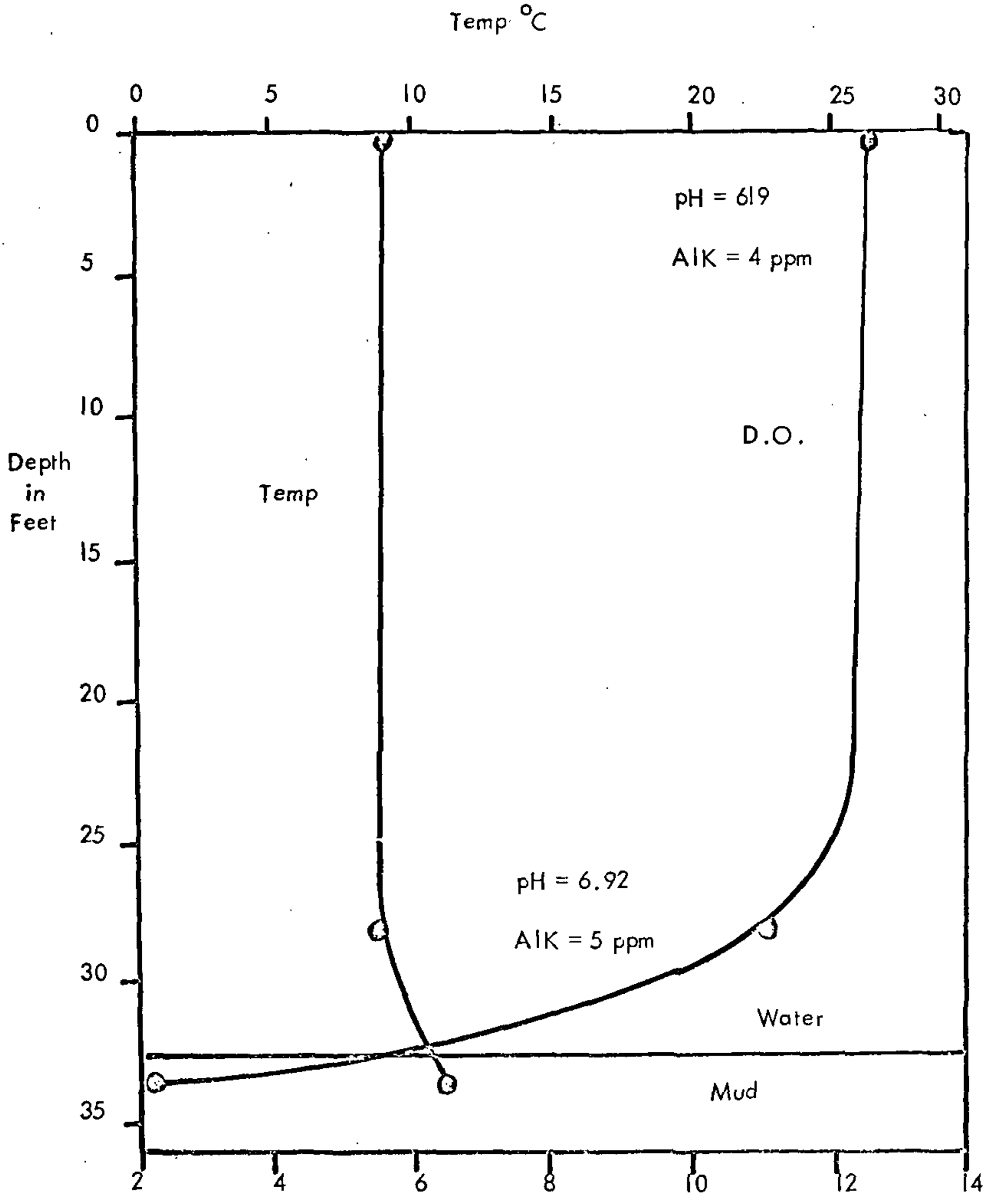


Figure 16

Lake Wyola 11-7-70

"Dissolved Oxygen and Temperature vs. depth"



Dissolved Oxygen (ppm)

The alkalinity is much lower than in the summer and is uniformly distributed as is the pH.

Lake Mattawa (Figure 17) once again exhibits the typical summer pattern for dissolved oxygen in an oligotrophic lake. The very low value of orthophosphate in the epilimnion would probably be contrasted with high values of PO_4^{-3} -P in the hypolimnion (Mortimer, 1941) due to the lower redox potential below the thermocline. Norwich Pond, (Figure 18) is also similar to Lake Mattawa and shows, like Laurel Lake, the very low concentration of orthophosphate in the mud water.

Asnacomet Pond represents the deepest lake studied and shows, perhaps better than any of the other lakes, the typical dissolved oxygen-temperature profile of a stratified lake. The profile (Figure 19) shows a rapid increase in D.O. with depth until the thermocline is reached. Reduction of D.O. below the thermocline is slow until a few feet from the bottom, where the concentration diminishes due to the uptake of oxygen by benthic bacteria.

The chemical data on the nine lakes would appear to group them into two separate categories with a few minor exceptions. All of the shallow lakes, except Metacomet, have algal blooms, high pH and alkalinity values, and very steep gradients to their D.O. profiles. Metacomet, due to its slightly greater depth and no direct input of sewage appears to fall outside of this category. Also, since it had been treated with sodium arsenite just before the sampling period, no accurate phosphate determinations could be made due to the interference of arsenite with the

Figure 17

Lake Mattawa 8-30-70

"Dissolved Oxygen and Temperature vs. depth"

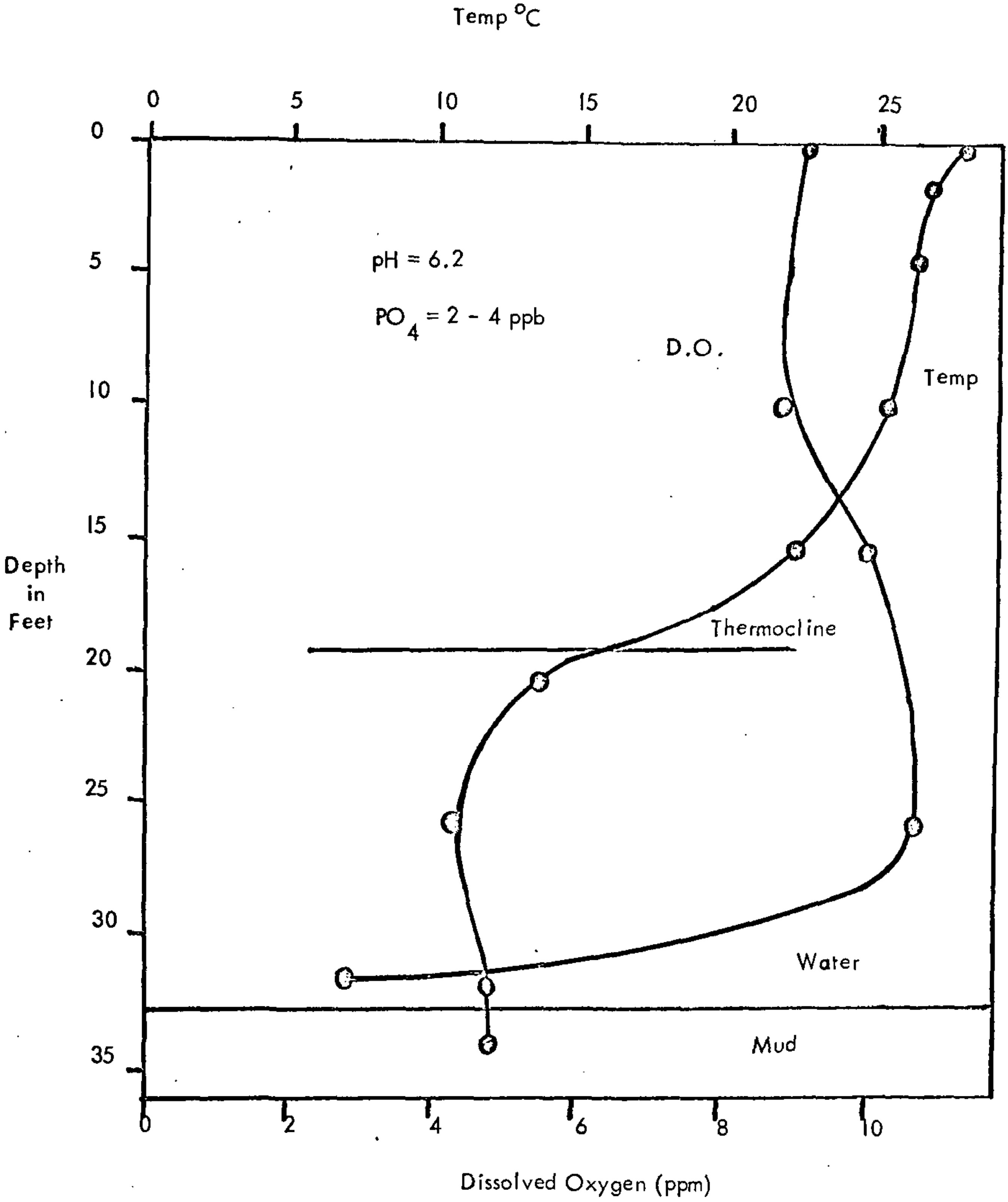


Figure 18
Norwich Pond 8-20-70

"Dissolved oxygen and Temperature vs. depth"

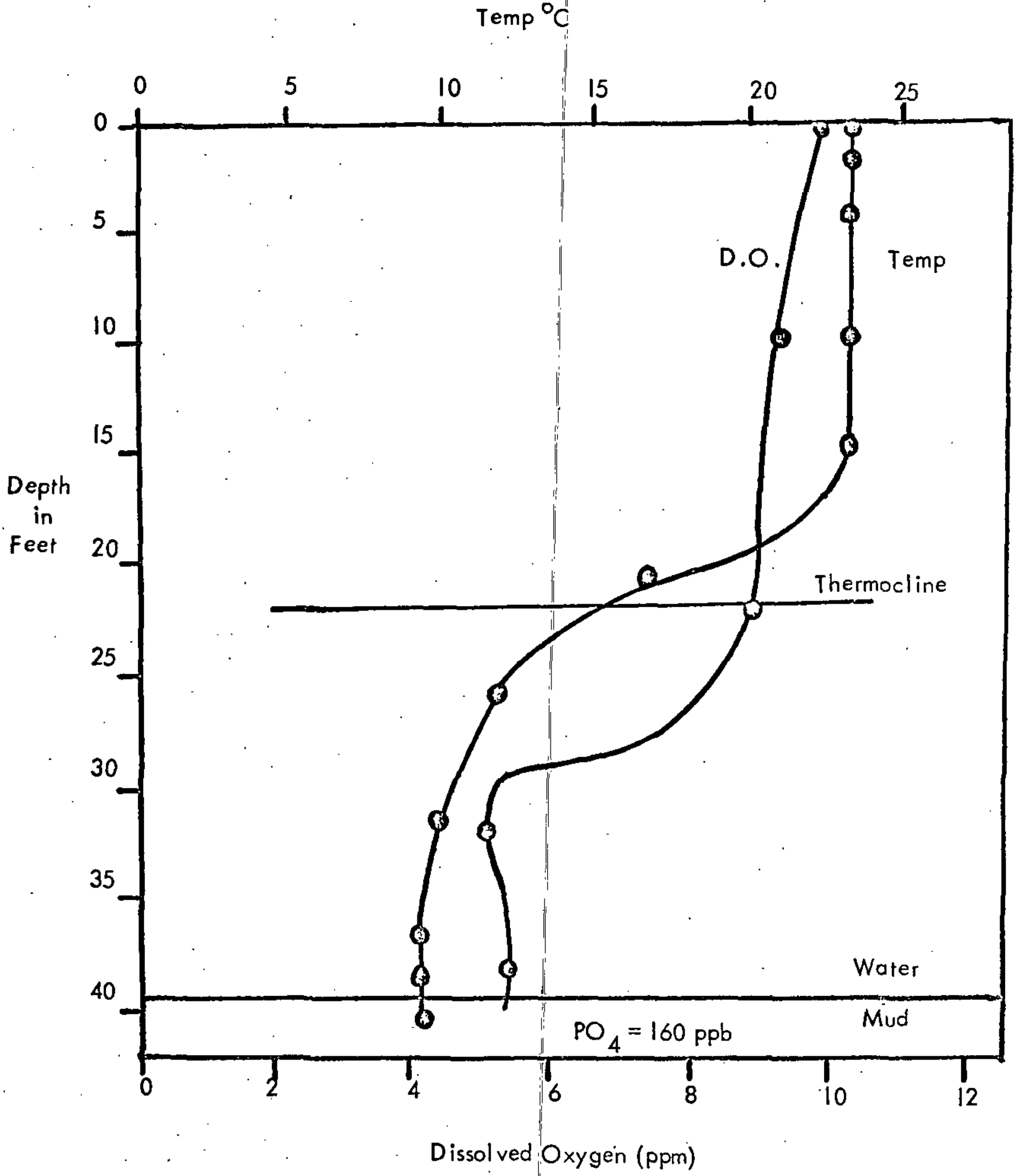
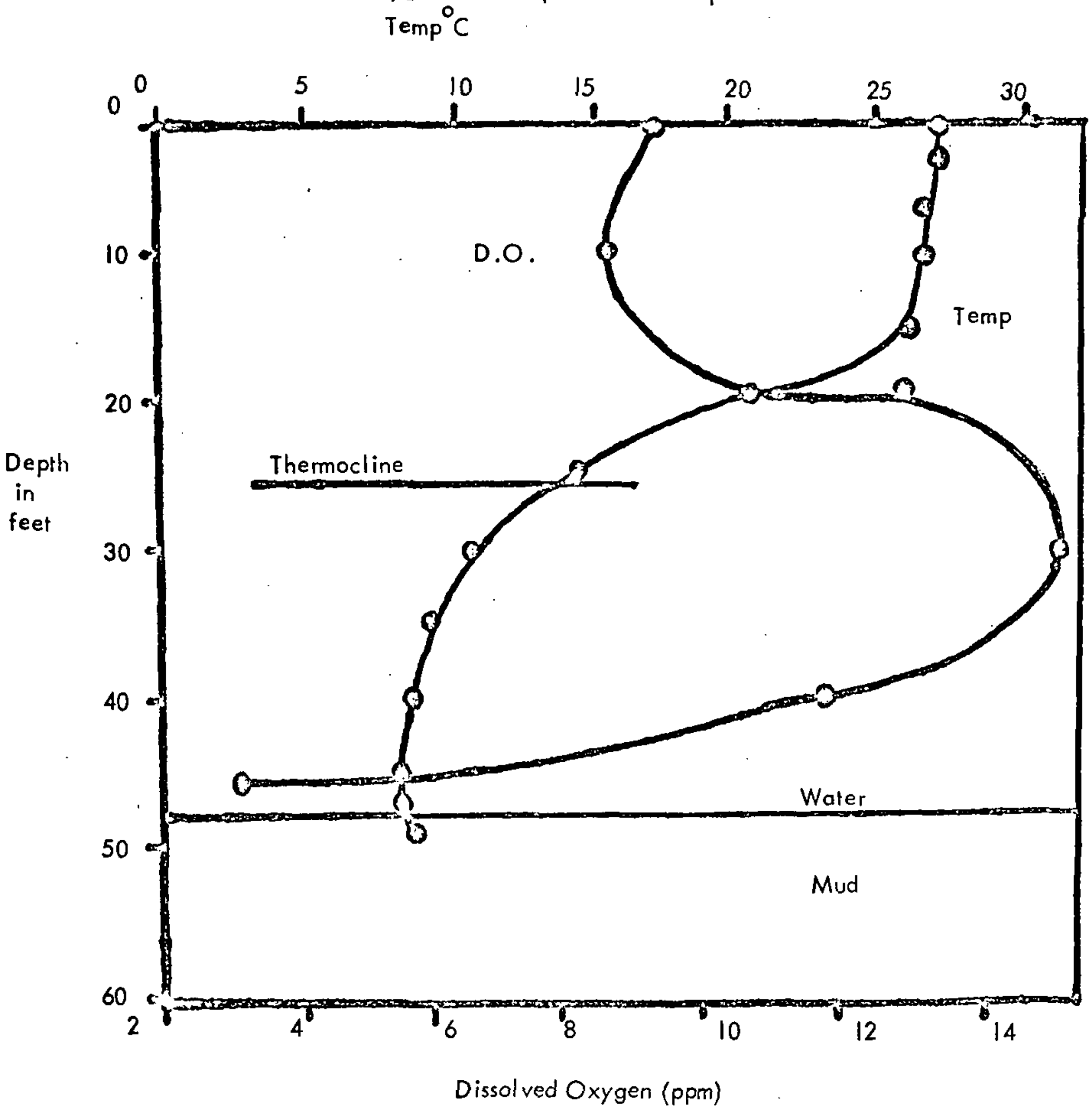


Figure 19

Asnacomet Pond 8-4-70

"Dissolved oxygen and Temperature vs. depth"



chemical analysis.

All of the stratified lakes, with the possible exception of Lake Wyola, show a very similar pattern of low orthophosphate and alkalinity values, low pH values, and well developed dissolved oxygen profiles. Lake Wyola tends to be more mesotrophic with higher alkalinity and orthophosphate values and is potentially the only deep lake studied which could eventually have algal blooms.

VI. Observations on Core Studies

A good correlation between lake water and mud core studies was obtained. All of the actual data appears in Appendix IV and graphs of iron, pH, and phosphate as a function of core depth appear in the following text. Composite graphs are presented with pH plotted on the far right and iron and phosphate on the left. In some instances, it was *necessary to plot iron and phosphate data points onto the pH graph;* simple extrapolation of the values should be used to find the correct concentration. Iron, phosphate, and pH as a function of mud depth is shown in Figure 20 for a core obtained from Metacomet Lake. Due to the low redox potential imposed on the system, the iron concentration is about 4 times greater than in the actual lake water. The pH is about the same as in the lake water with increasing acidity as one goes deeper *into the mud.* PO_4^{-3}-P *is fairly low in the sediment with values increasing* at depths greater than 10 inches.

Figure 21 shows the core data obtained from a Aldrich Pond sample. The most obvious difference here is the extremely high concentration of orthophosphate at the mud interface (400 ppb), the decline in PO_4^{-3}-P with depth until it again increases below 5 inches. The core water concentration of orthophosphate with high (55 ppb) but not as high as in the lake water (122 ppb). This difference is probably due to adsorption of the phosphate by the plastic core liners. Of note here is the decline in iron with depth to around 2 mg/L.

Figure 20

Lake Metacomet August, 1970 (3-1-71)

Iron, phosphate, and pH vs. depth in core

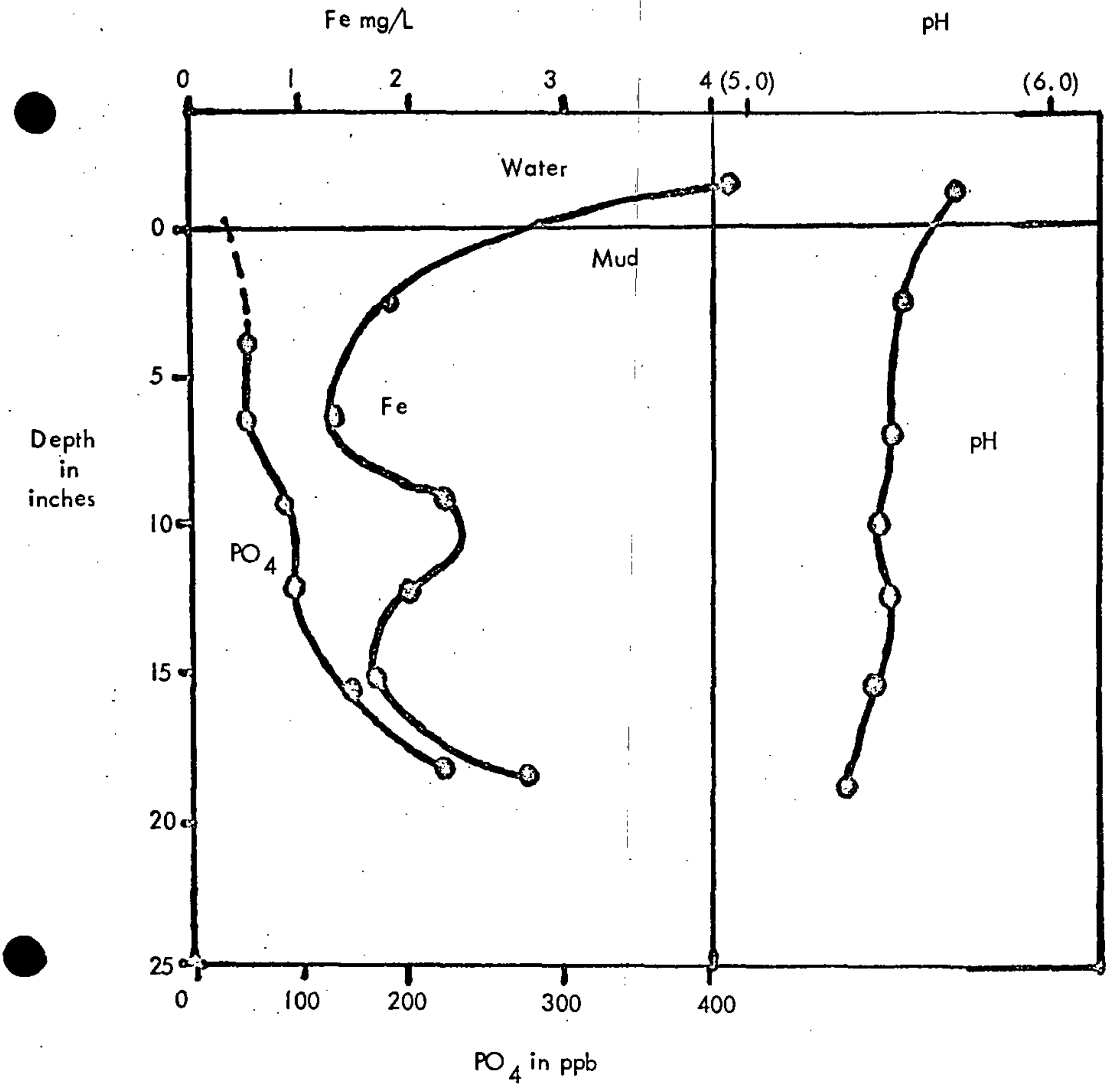
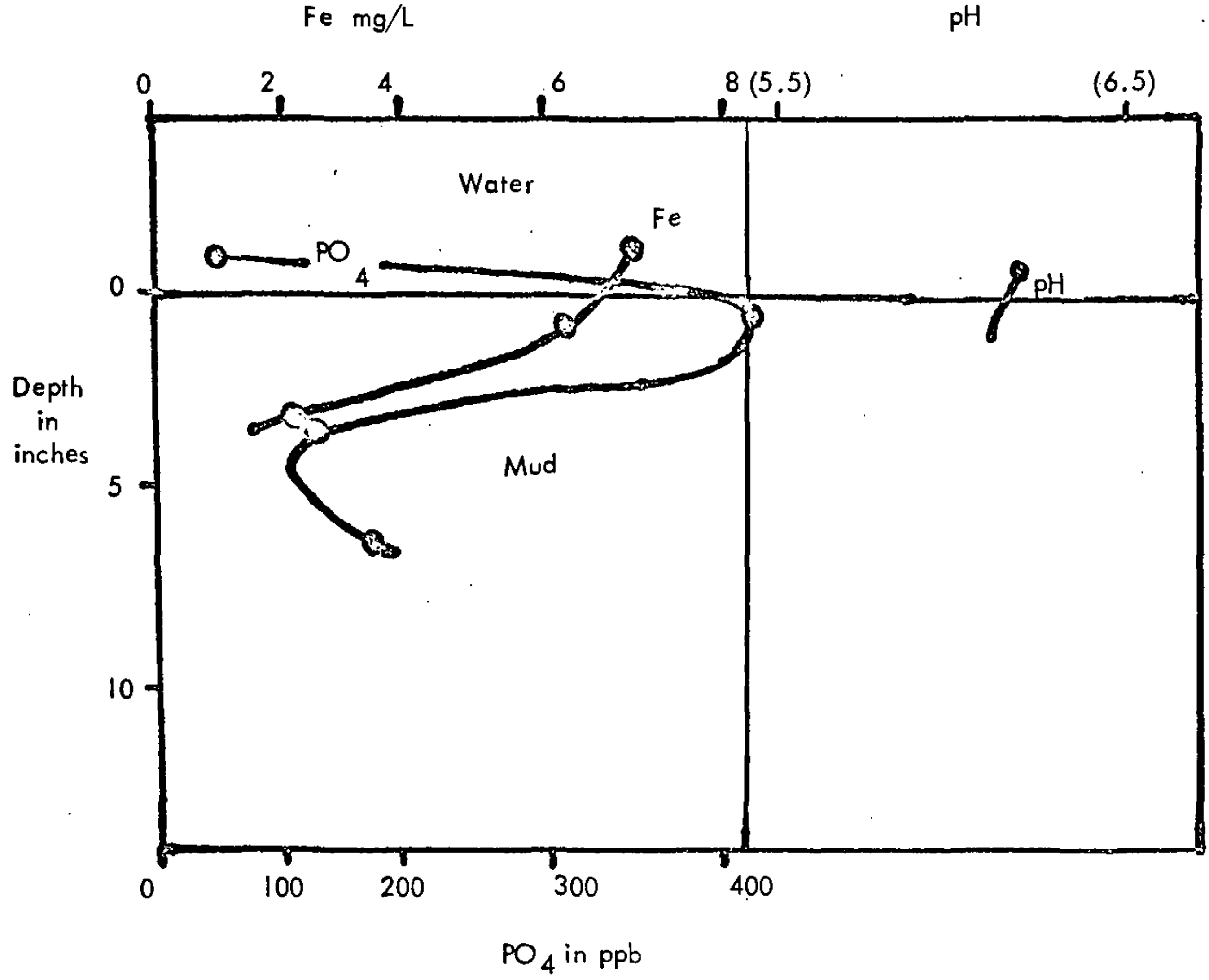


Figure 21

Aldrich Lake September, 1970 (4-12-71)

Iron, phosphate, and pH vs. depth in core



Similar data for a Lake Warner core is shown in Figure 22. The high concentration of orthophosphate in the water above the core (38 ppb) is quite similar in magnitude to that detected in the lake water study (25-50 ppb). Moreover, core samples from Lake Warner and Aldrich Pond both exhibited high phosphate concentrations above the core. Orthophosphate was present in high concentrations (460 ppb) in the mud near the interface and decreased to a depth of 10 inches after which increases were apparent. The distribution of iron here appeared to show a similar pattern with a high concentration near the interface and a decrease to a depth of 10 inches. Below this depth, the iron concentration did not again increase as did the phosphate but remained at a rather constant value.

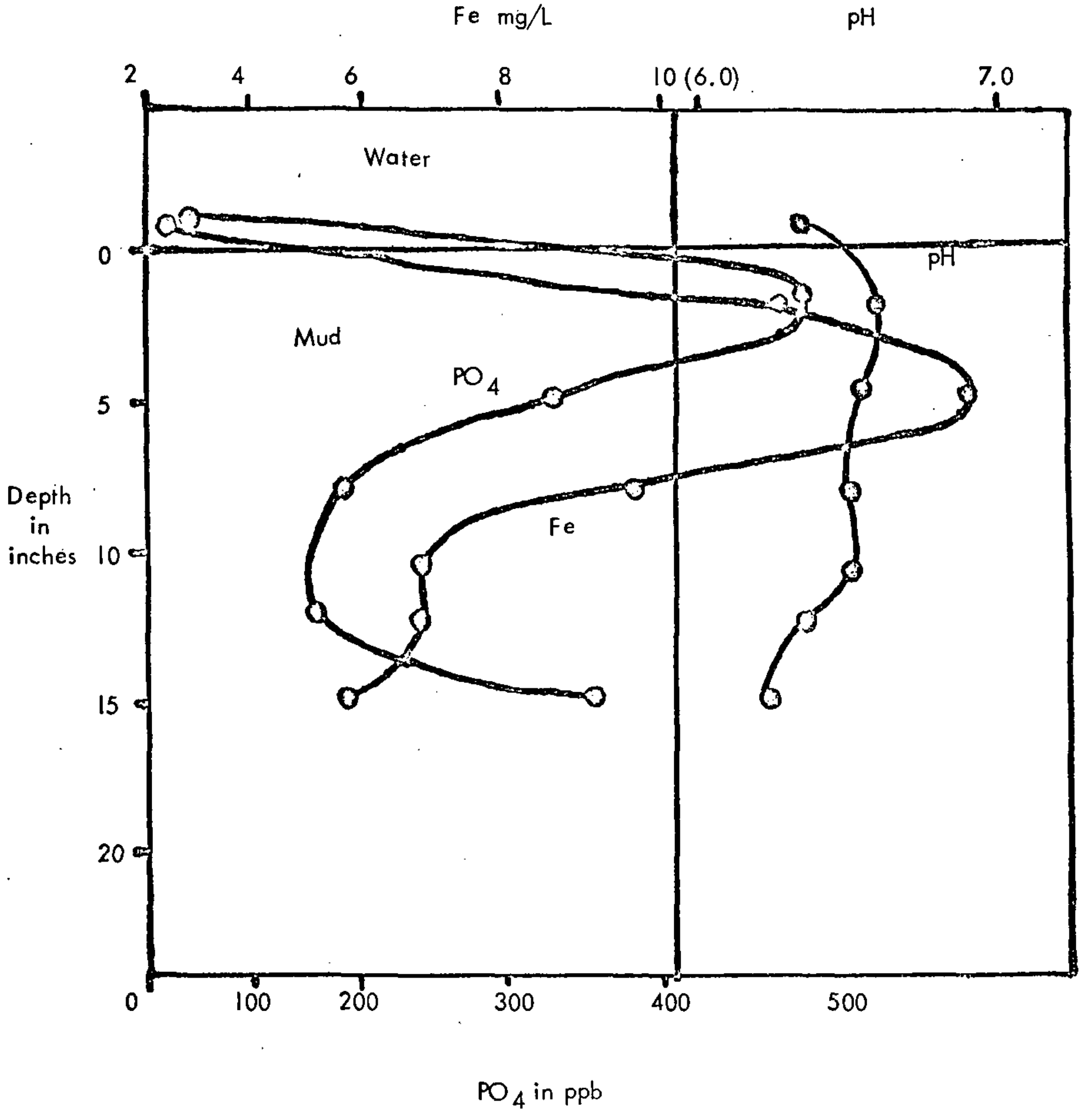
The three lakes already described are in the shallow lake category and two of them, Warner and Aldrich, both show high concentrations of phosphate at the interface and relatively high concentrations of phosphate in the water above the core. Metacomet, shows a quite different pattern with low concentrations of phosphate in the interstitial water at the interface. (Analysis of orthophosphate in the lake and core water was impossible due to the presence of residual arsenic originating from a weed control program).

In order to show uniformity or differences in the method for analysis of the muds, four separate cores from Lake Wyola were studied. The similarity in phosphate concentration patterns for two cores are illustrated

Figure 22

Lake Warner August 1970 (1-9-71)

Iron, Phosphate, and pH vs. depth in core



in Figures 23 and 24. The following observations were made: a very low concentration of PO_4^{-3}-P in the core water (5 - 7 ppb), an increasing concentration at the interface (100 - 179 ppb), a decreasing concentration to a depth of 8 inches, and finally a rapid increase with greater depth. Iron in both cores was high near the interface (3 - 4 mg/L), stabilizing at about 1.5 mg/L with increasing depth in the mud.

Figure 25 shows the results of the core analysis on a third core from Lake Wyola. Phosphate concentrations were similar to those shown in Figures 23 and 24. The distribution of iron, however, appeared different with a very high concentration of iron in the water above the core. This may be due to either lower or higher redox potentials reached in this core compared with the other cores (more ferrous iron or more ferric hydroxide respectively). It may also be noted that the iron concentration as a function of depth follows the same pattern as shown in previous graphs with stabilization below 10 inches.

Finally, Figure 26 shows the results of analysis on a Lake Wyola core that had been aerated and agitated for 15 minutes before analysis took place. Here, the pH increased considerably, as did the iron concentration. The high PO_4^{-3}-P as well as the high iron concentrations in the water are easily explained by the mixing of the water with the interface mud which tends to resuspend the mud in the water thus yielding higher concentrations of both parameters. Another possible explanation is the

Figure 23

Lake Wyola 9-4-70 (3-10-71)

Iron, phosphate, and pH vs. depth in core

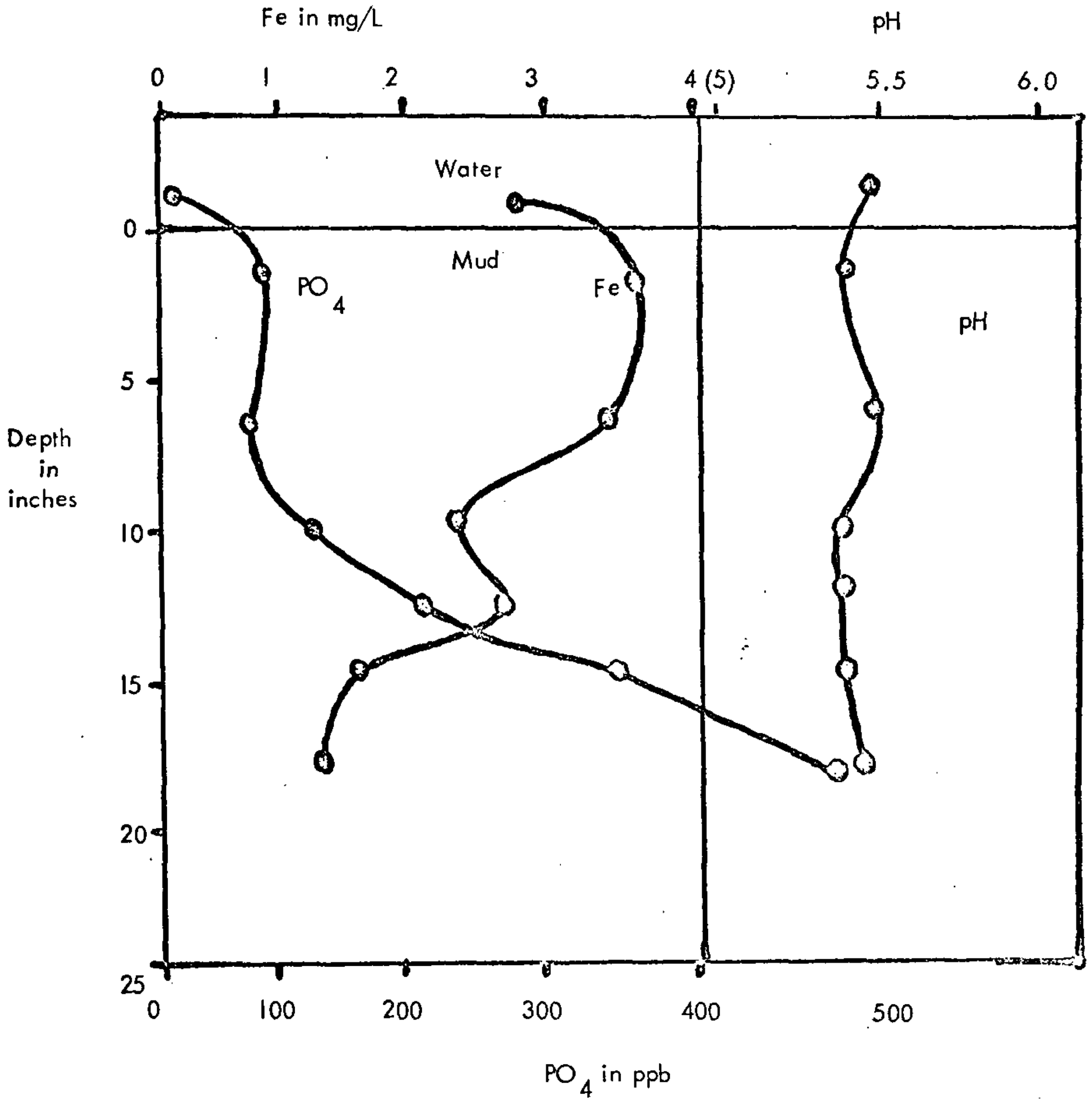


Figure 24

Lake Wyola 11-7-70 (1-25-71)

Iron, phosphate, and pH vs. depth in core

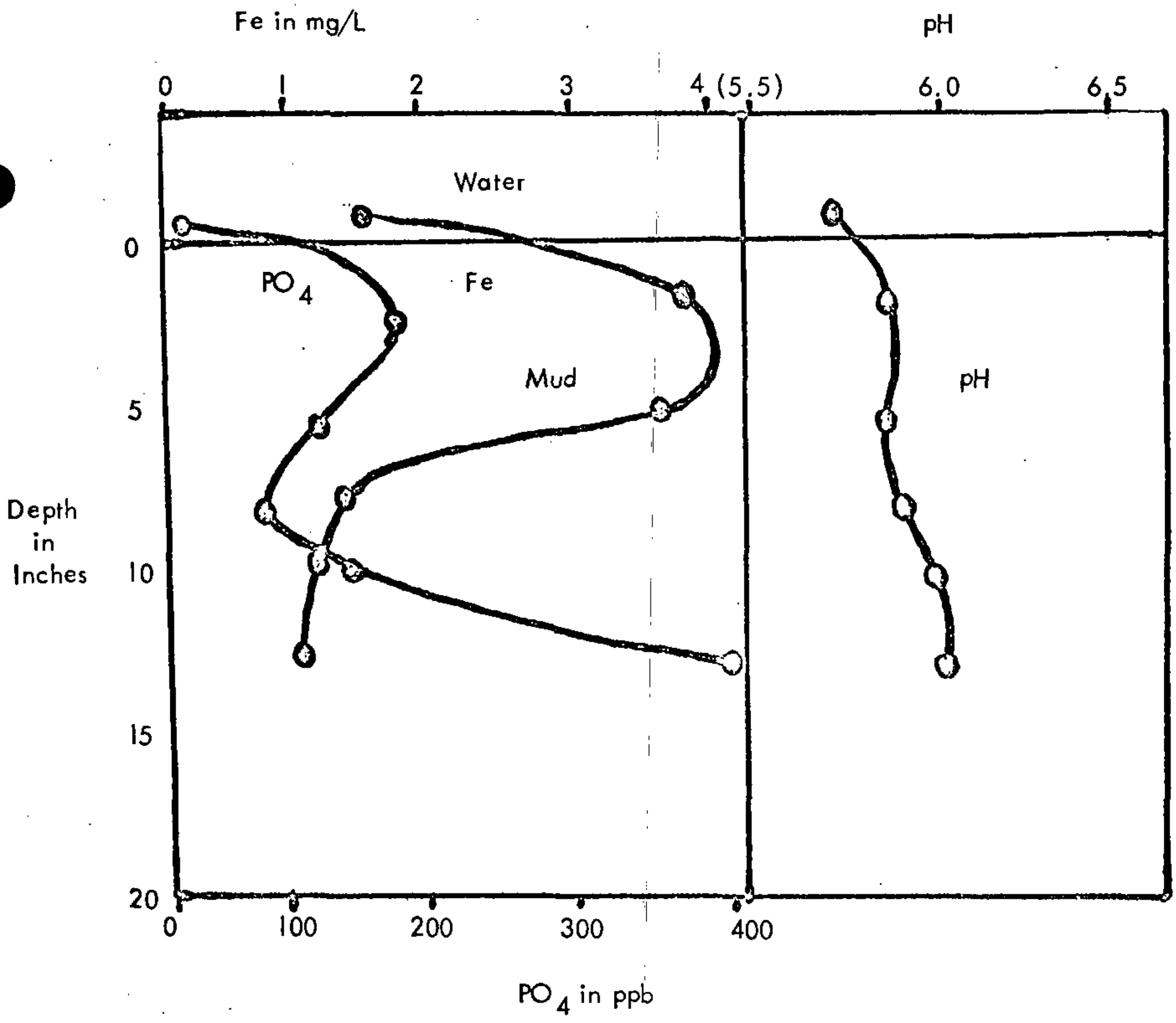


Figure 25

Lake Wyola 11-1-70 (2-22-71)

Iron, phosphate, and pH vs. depth in core

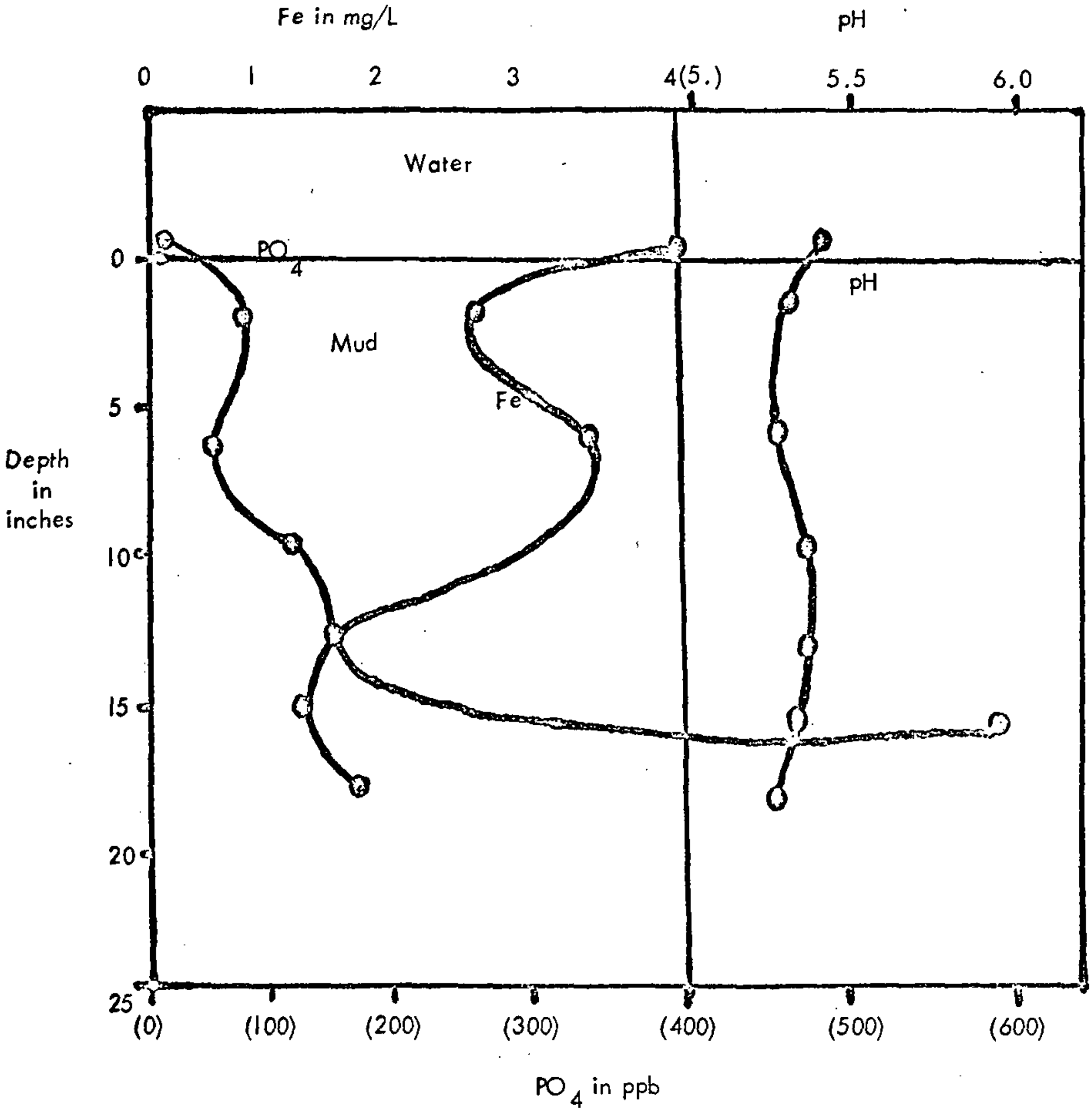
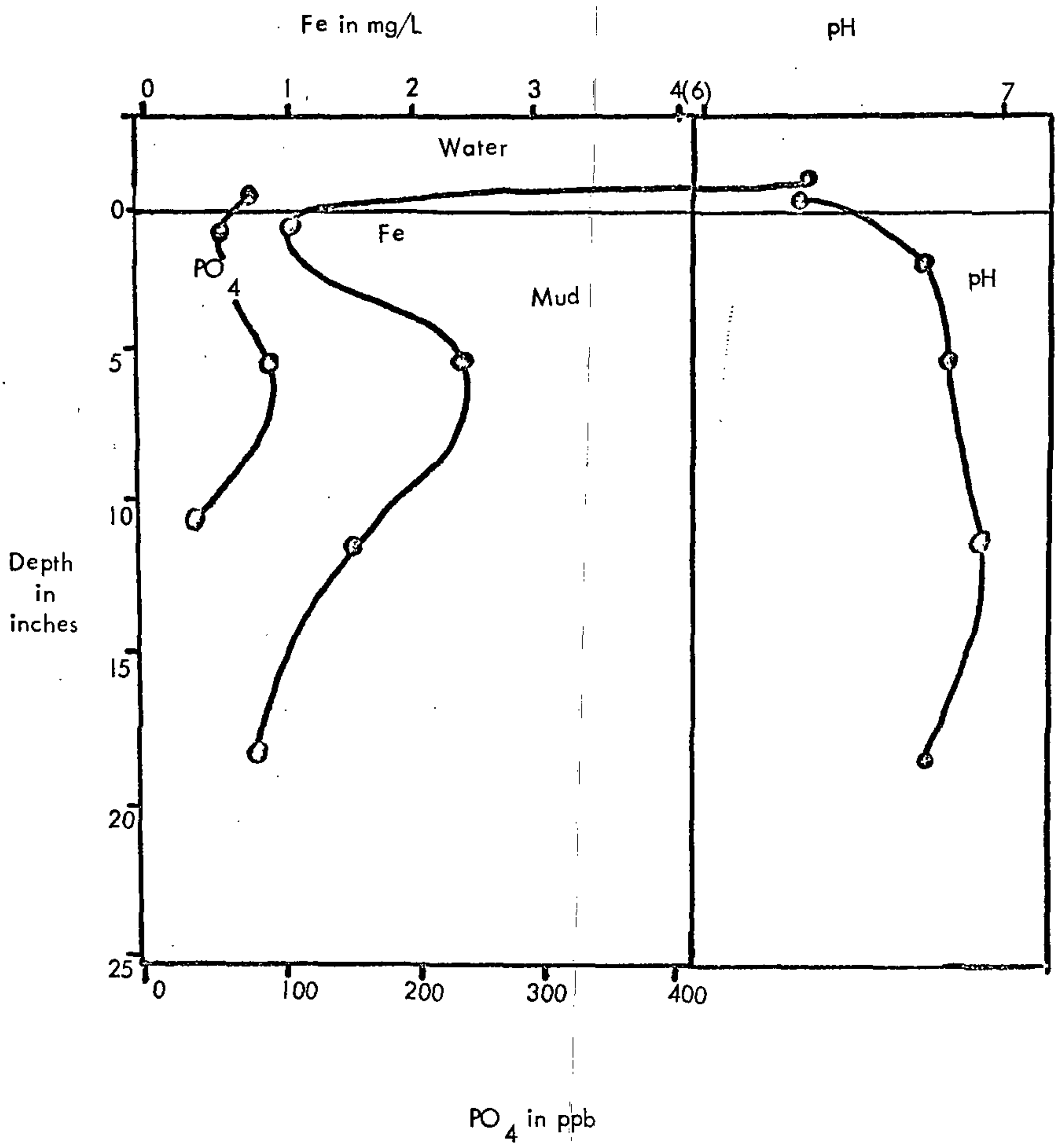


Figure 26

Lake Wyola 11-7-70 (11-21-70)

Iron, phosphate, and pH vs. depth in core



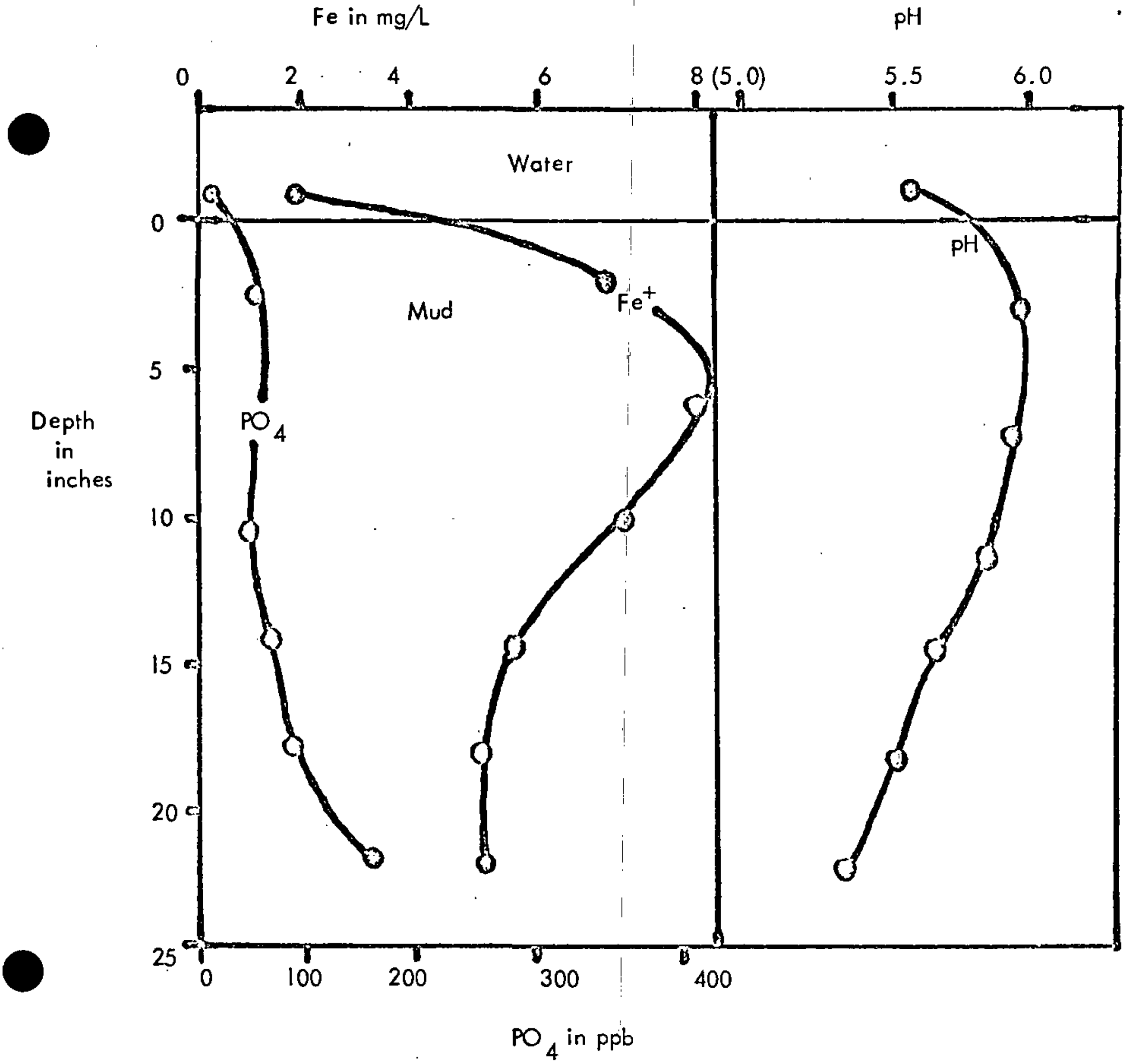
rapid migration of PO_4^{-3}-P and iron from the sediment to the overlying water due to the rapid change in redox potential. Finally, it can be seen as from the other graphs that the iron concentration stabilizes below 10 inches.

The core data for Lake Mattawa is shown in Figure 27. Here, the typical pattern shown by a clean, oligotrophic lake is evident. There is a very low concentration of PO_4^{-3}-P in the water above the core as well as in the interstitial water. A slight increase is noted below 15 inches, but, compared to the eutrophic and mesotrophic lakes, this increase is still very small. Iron also shows the same tendency to stabilize at depths below 10 inches, and the pH tends to become more acidic with depth.

Separation of each of the lakes studied appears to fall into three different groups. Lake Warner and Aldrich Pond fall into the category of eutrophic since both possess very large amounts of PO_4^{-3}-P in the sediment which is reflected in the relatively large orthophosphate concentrations in the overlying water. Both lakes therefore possess large reservoirs of PO_4^{-3}-P which may then diffuse into the lake water thereby support large blooms of algae. Metacomet Pond and perhaps Lake Wyola are mesotrophic in that each has moderate amounts of orthophosphate in the interstitial water which in turn indicates a tendency of the overlying water to contain near bloom quantities of orthophosphate. The core taken from Lake Mattawa was the only one exhibiting a definite oligotrophic character. Here, there

Figure 27
Lake Mattawa August, 1970 (1-20-71)

Iron, phosphate, and pH vs. depth in core



seems to be a very low chemical gradient between the interstitial water and the overlying water with respect to orthophosphate. It could be presumed that if diffusion of orthophosphate from the mud did occur, the actual amount would be very small, especially when compared to that occuring in Aldrich Pond or Lake Warner.

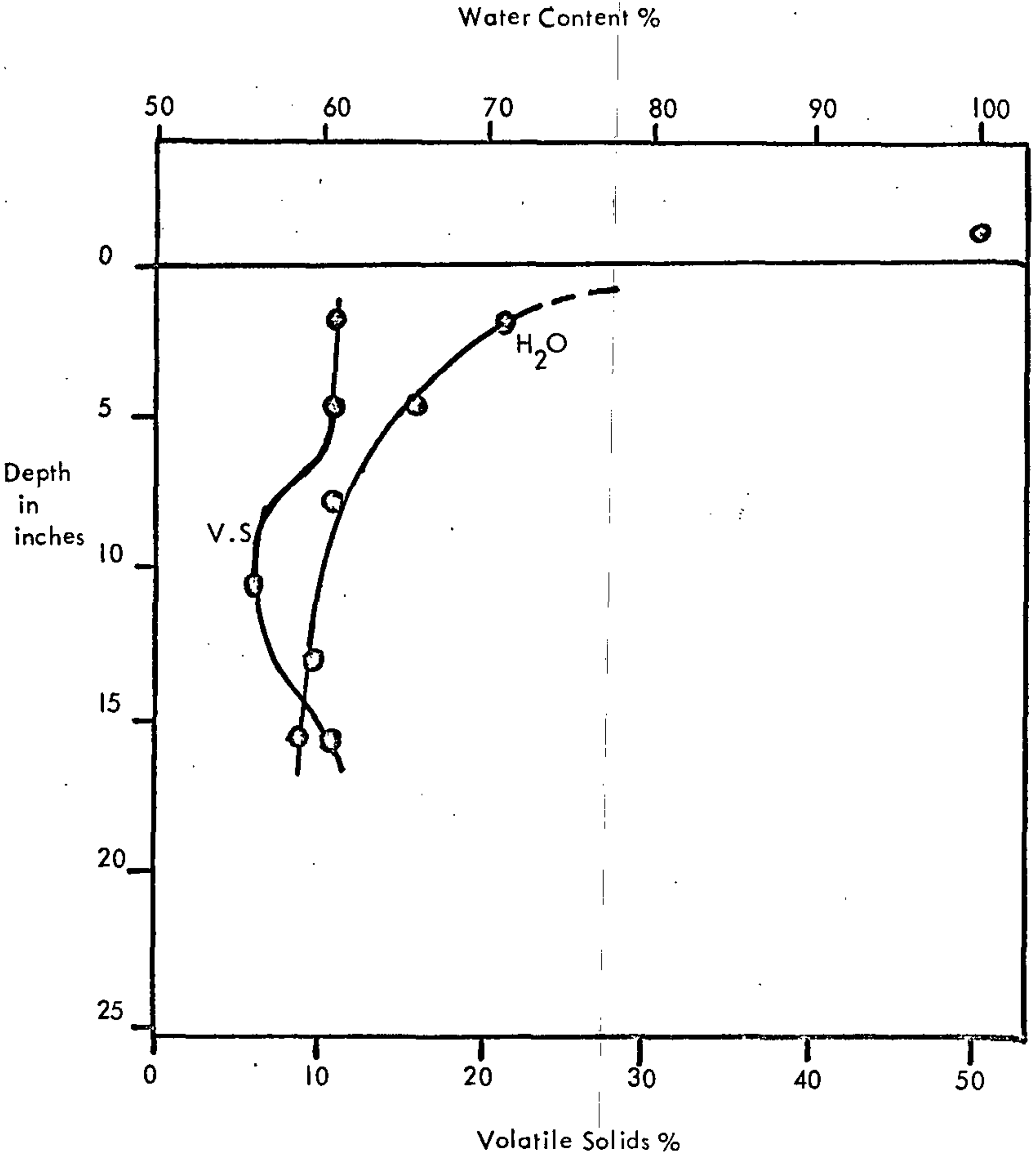
The data obtained from the water content and volatile solids analysis of the muds appears at first to be inconsistent with the previous classification based on chemical data. Lakes that have been classified as being eutrophic actually appear to have very low water and volatile solids content. Eutrophic lakes, in contrast, would have a very high volatile solids content since the bottom should be composed chiefly of dead algal cells. The data is plotted on the following graphs with water content and volatile solids (both as percentages) as a function of depth in the mud.

Lake Warner and Aldrich Pond are the two lakes where the inconsistency between the chemical analysis and the volatile solids content is present. Figure 28 illustrates the variation in water content and volatile solids content in the core obtained from Lake Warner. The average water content was 65% while the volatile solids content was 10%. This data must be disqualified since the core was taken near the outlet, only 7 feet from shore and only 10 feet from a bridge. The location of the sample was in an area where a lot of riverbank soil, sand, gravel, and wood had been deposited on the bottom. This, it is felt, is not a typical lake-derived sediment and has led to the erroneous results. Similar data derived from Aldrich

Figure 28

Lake Warner August, 1970 (1-9-71)

Water Content and Volatile Solids vs. Depth in core



Pond (Figure 29) yields a core water content of only 30% and volatile solids less than 10%. Aldrich Pond was formed around 1910 by a dam. The bottom sediment obtained from the core sample was only about 6 inches deep, being mixed with coarse sand, pine needles, and soil which composed the original bottom. This mixture was not considered to be a typical lake-derived sediment and could not be used to compare it to the other lakes.

The data from the other lakes does not yield strikingly different results, but some trends can be identified. As shown in Figure 30, the volatile solids content averaged about 50% for a Metacomet Lake core while the water content was about 93%.

Figures 31,32,33, and 34 illustrate the pattern of water and volatile solids content obtained in four different cores from Lake Wyola. These are all very similar. Water content was approximately 90% and volatile solids content averaged about 28%. All graphs show a maximum volatile solids content near the interface which decreases to a minimum near the 5 inch depth and then increases slightly at lower depths. That this variation is significant or merely reflects the method of extracting the mud from the core is hard to answer. It does seen however that higher amounts of volatile solids are found at the mud-water interface than at slightly deeper depths. This appears reasonable since new organic matter is always being deposited at the interface.

The average water content (90%) of Lake Mattawa, as shown in Figure 35, is about the same as that for Lake Wyola. Lake Mattawa had a

Figure 29

Aldrich Lake September, 1970 (4-12-71)

Water content and volatile solids vs. depth in core

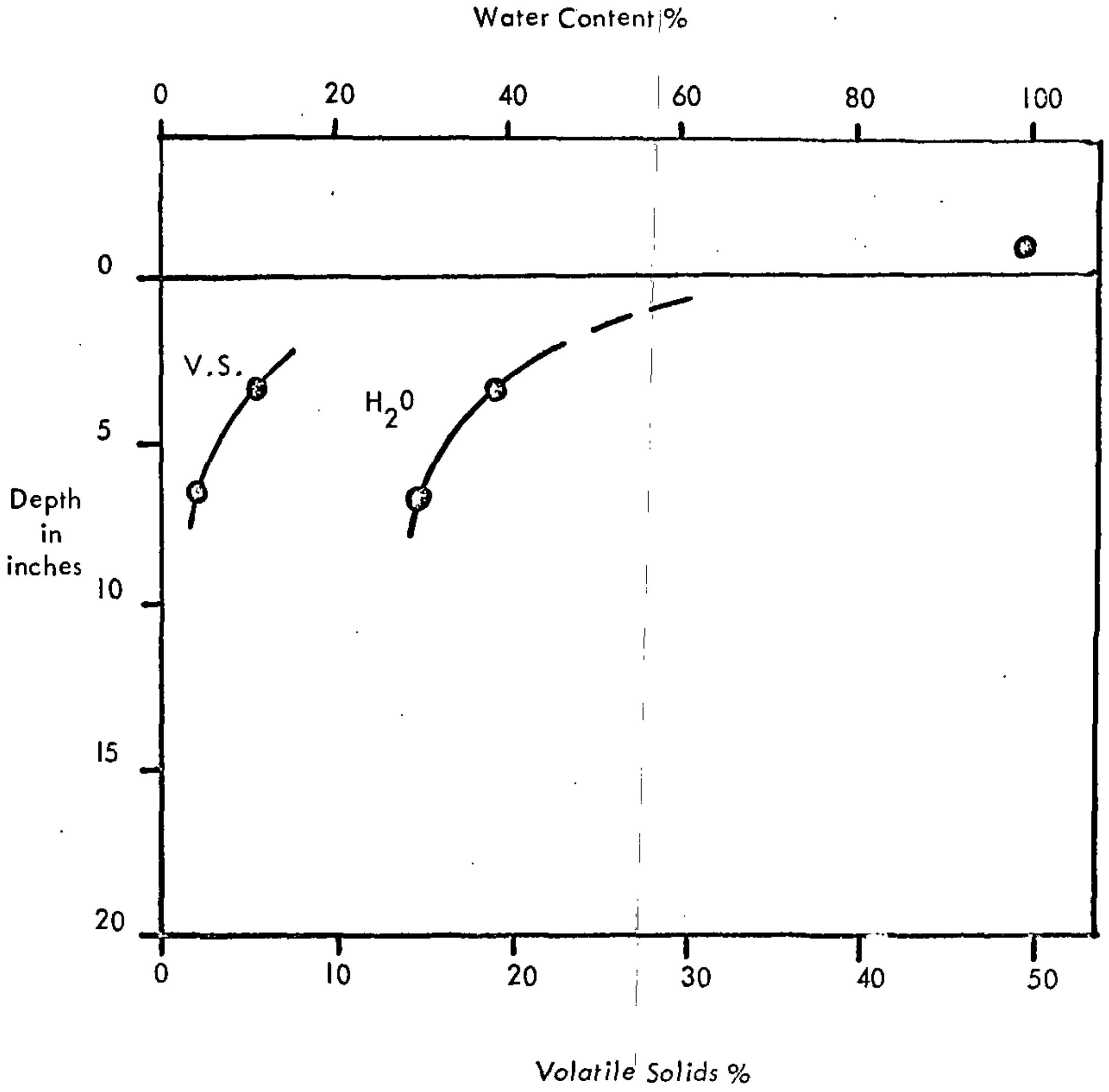


Figure 30
Lake Metacomet August,1970 (3-1-71)

Water Content and Volatile Soldis vs. Depth in Core

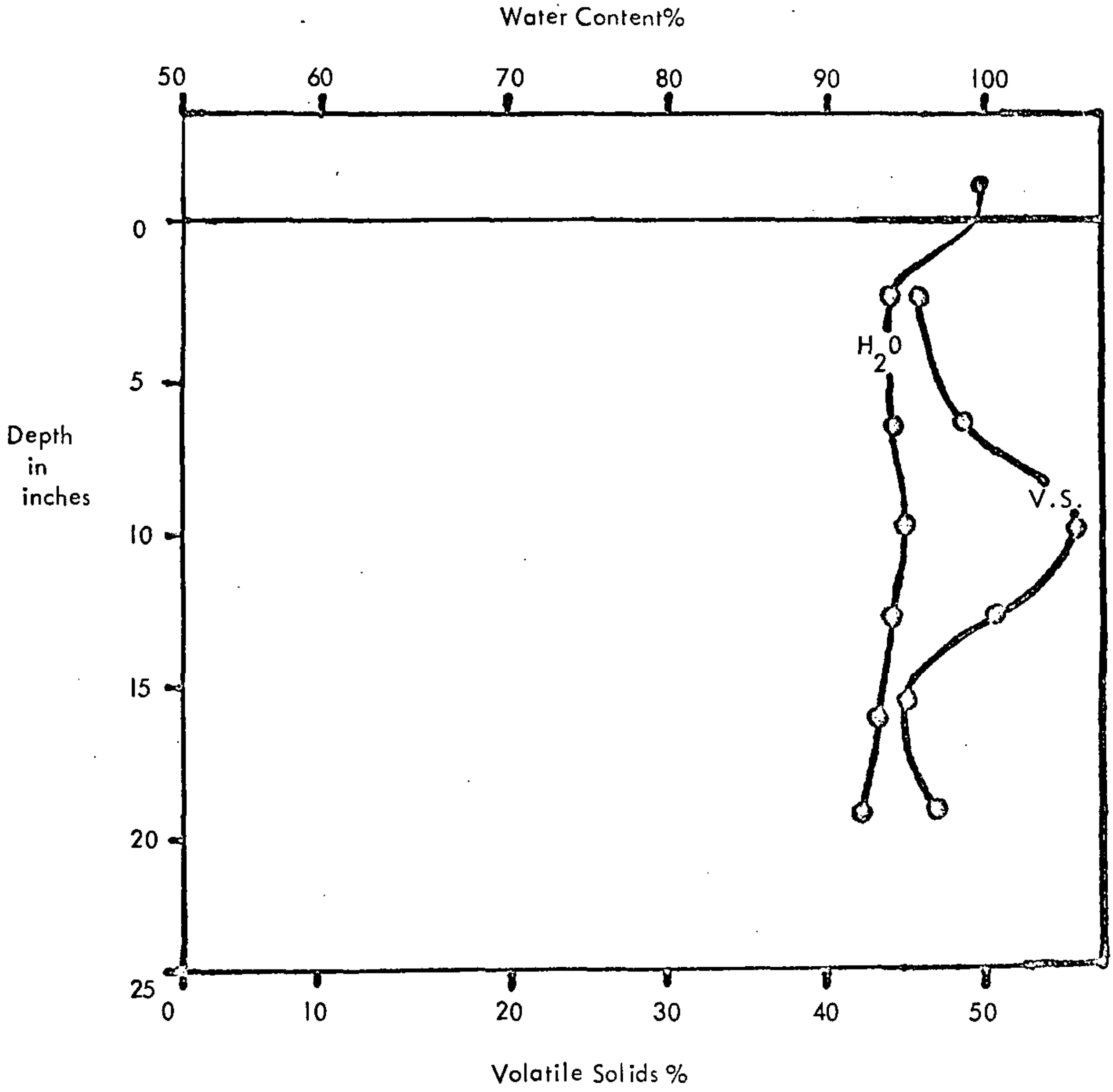


Figure 31

Lake Wyola 9-4-70 (3-10-71)

Water Content and Volatile Solids vs. Depth in Core

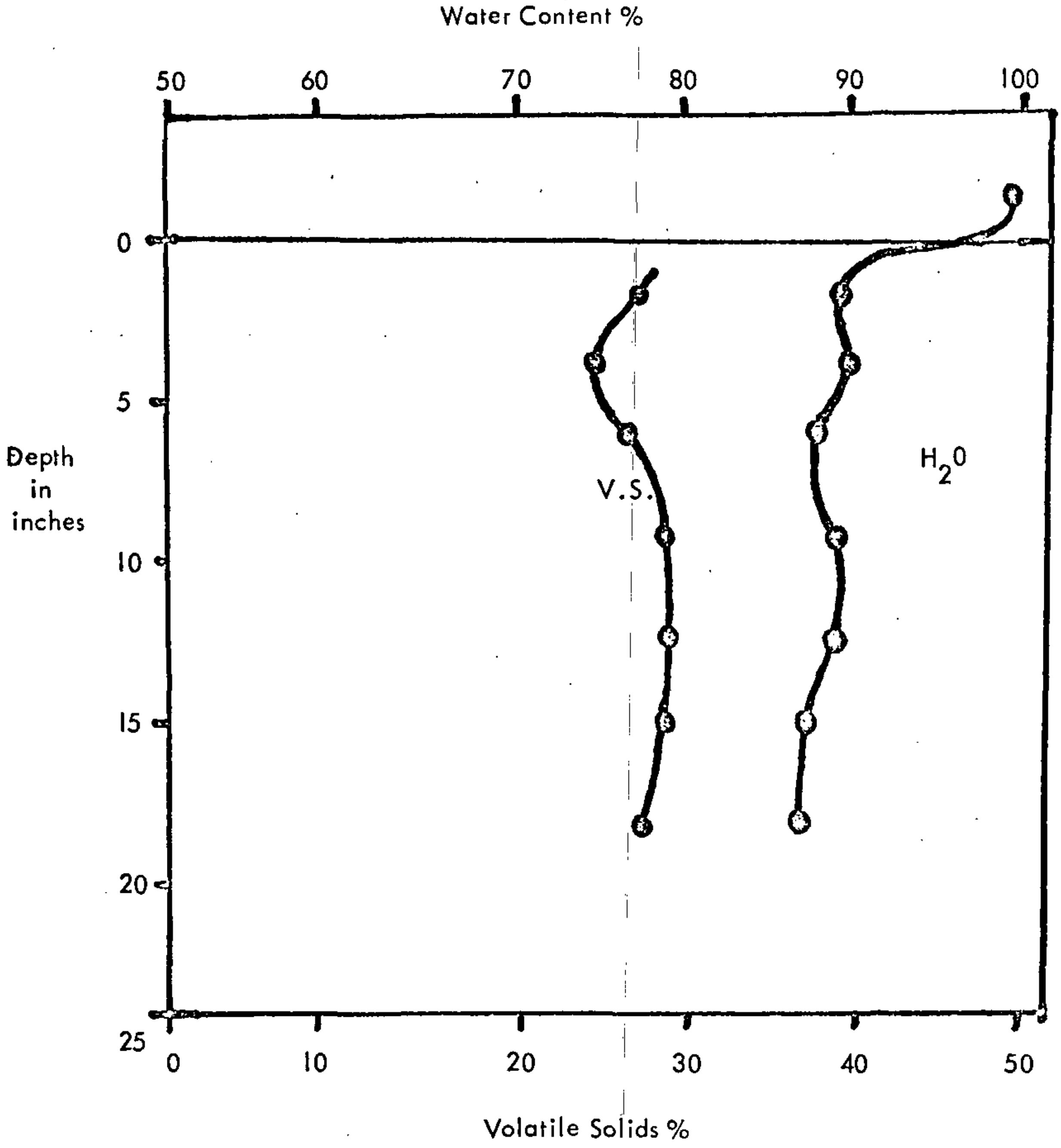


Figure 32

Lake Wyola 11-7-70 (1-25-71)

Water Content and Volatile Solids vs. Depth in Core

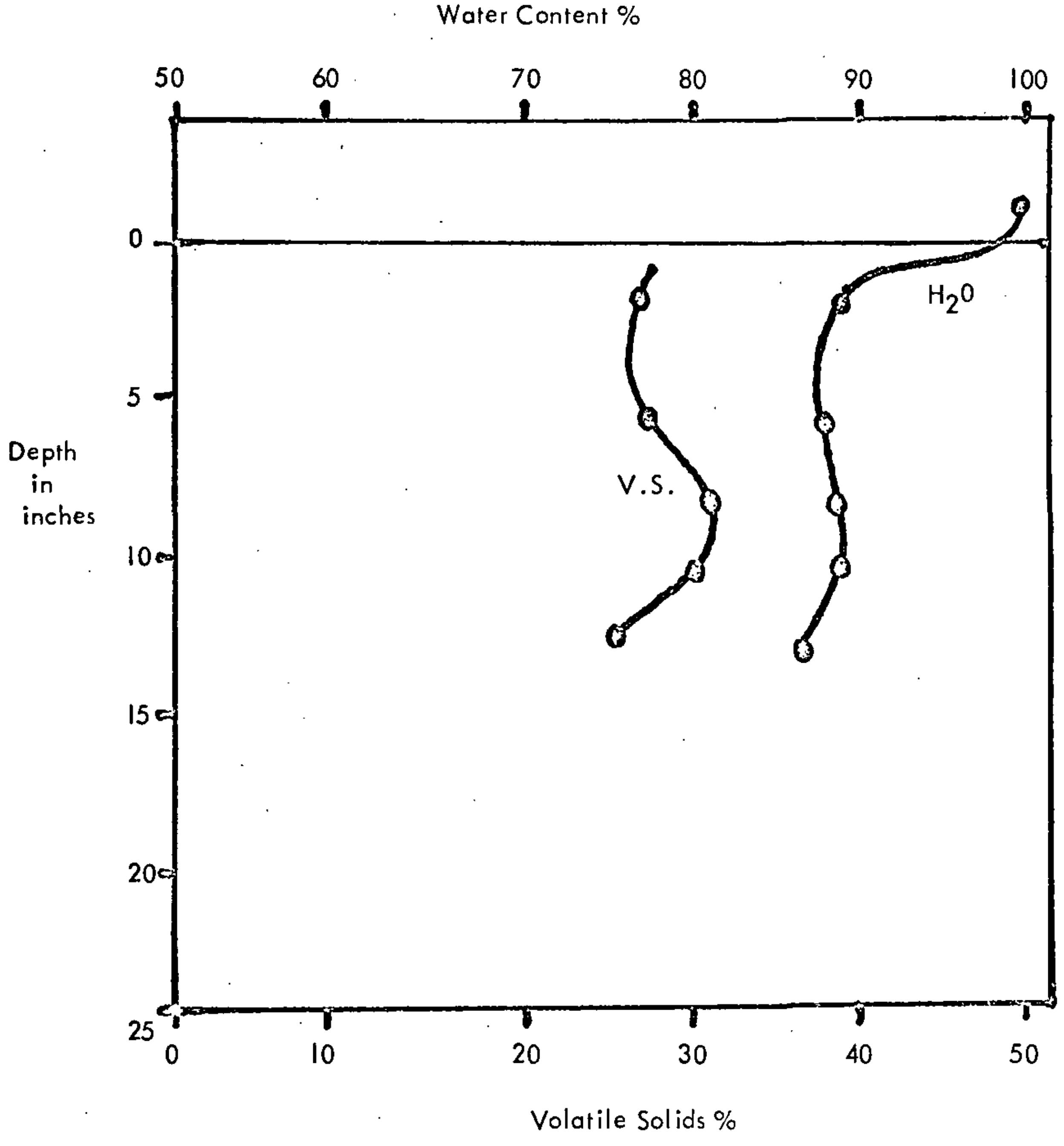


Figure 33

Lake Wyola 11-1-70 (2-22-71)

Water Content and Volatile Solids vs. Depth in Core

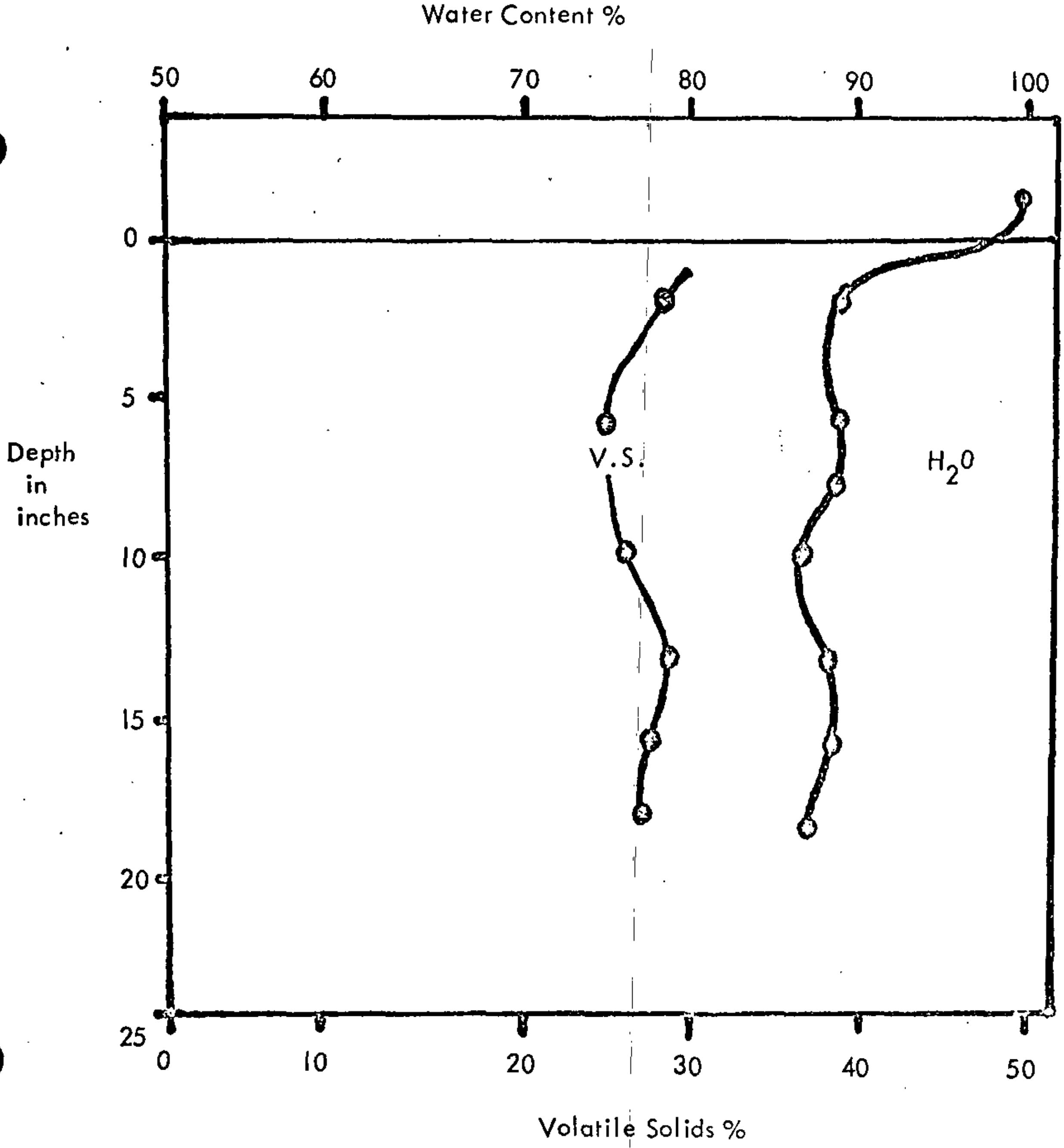


Figure 34

Lake Wyola 11-7-70 (11-21-70)

Water Content and Volatile Solids vs. Depth in Core

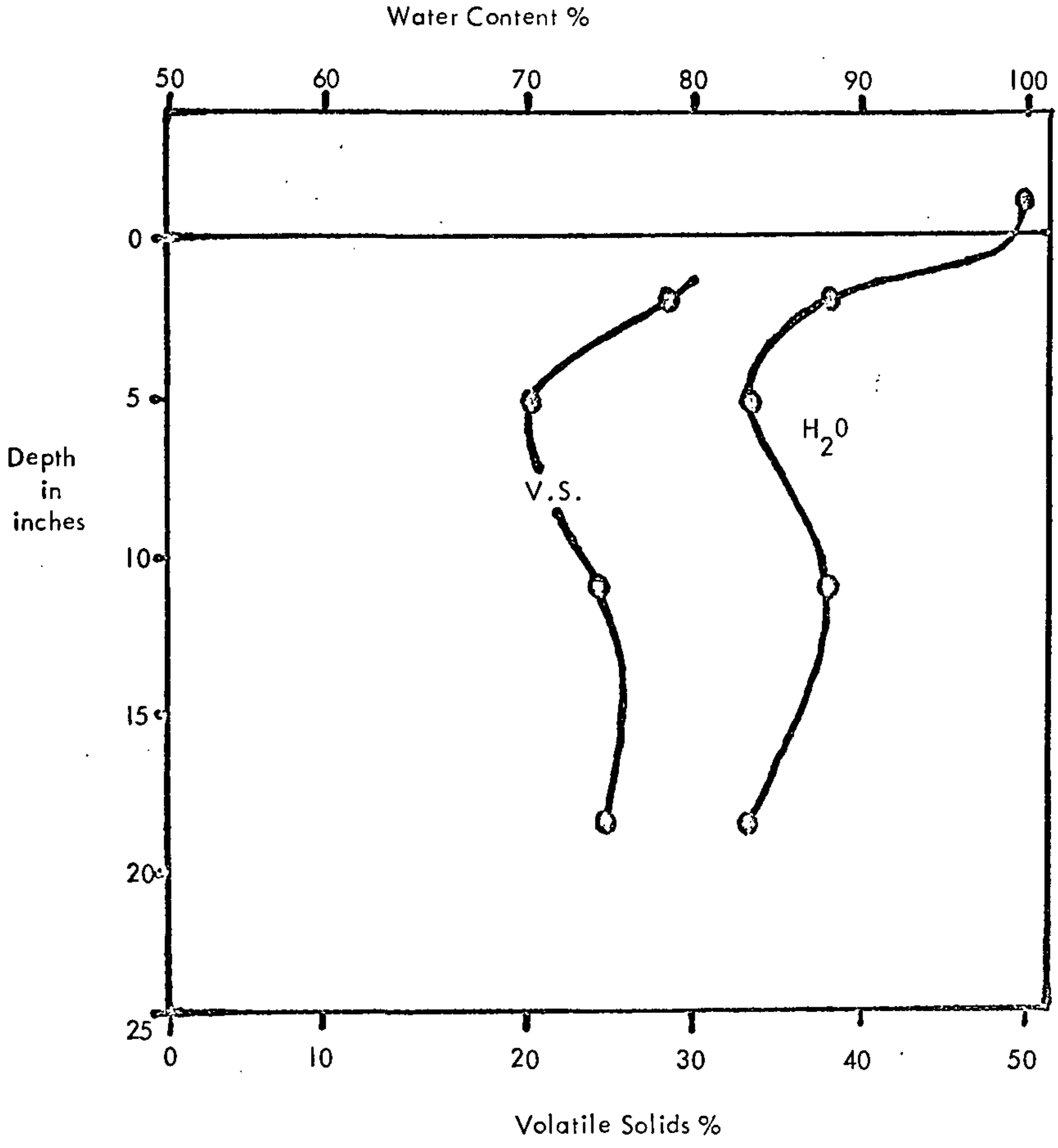
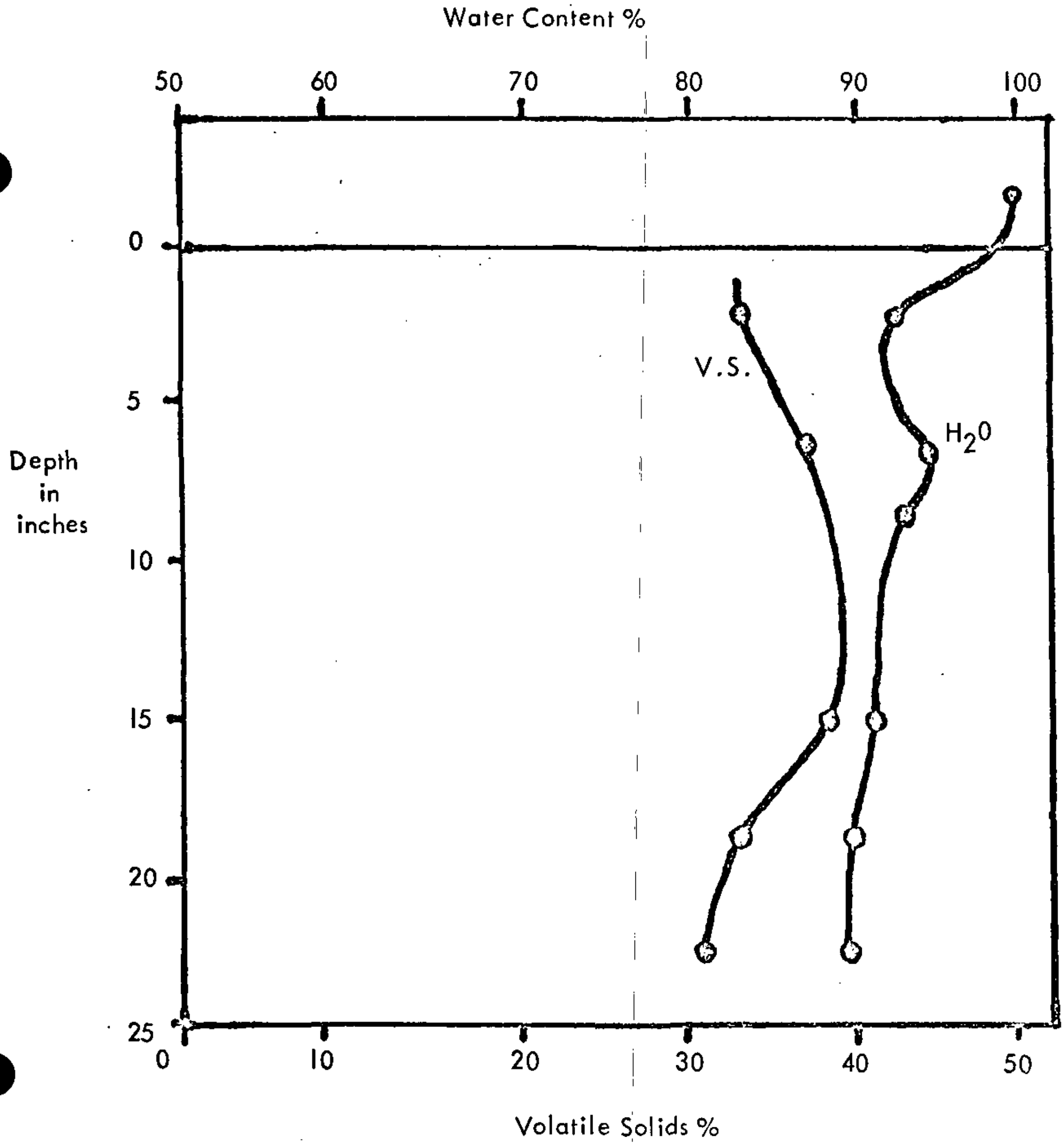


Figure 35

Lake Mattawa August, 1970 (1-20-71)

Water Content and Volatile Solids vs. Depth in Core



slightly higher volatile solids content. Since Lake Mattawa has previously been called oligotrophic and Lake Wyola has some indications of being mesotrophic, the volatile solids data appears to be inconsistent. The only justification for this difference may be in the original rationale for studying volatile solids. It is possible that the intuitive idea that a large volatile solids content correlates with large concentrations of orthophosphate is not strictly valid. Other mechanisms such as redox potential, intensity of bacterial action, or initial input of phosphate could be more of a control of the system than volatile solids. The supposition that a eutrophic lake would have more organic matter in the mud than in an oligotrophic lake is obvious, but the correlations from this study seem to indicate that a study of volatile solids alone is not a good criteria upon which to classify lakes.

VII. Relationship of Orthophosphate and Iron

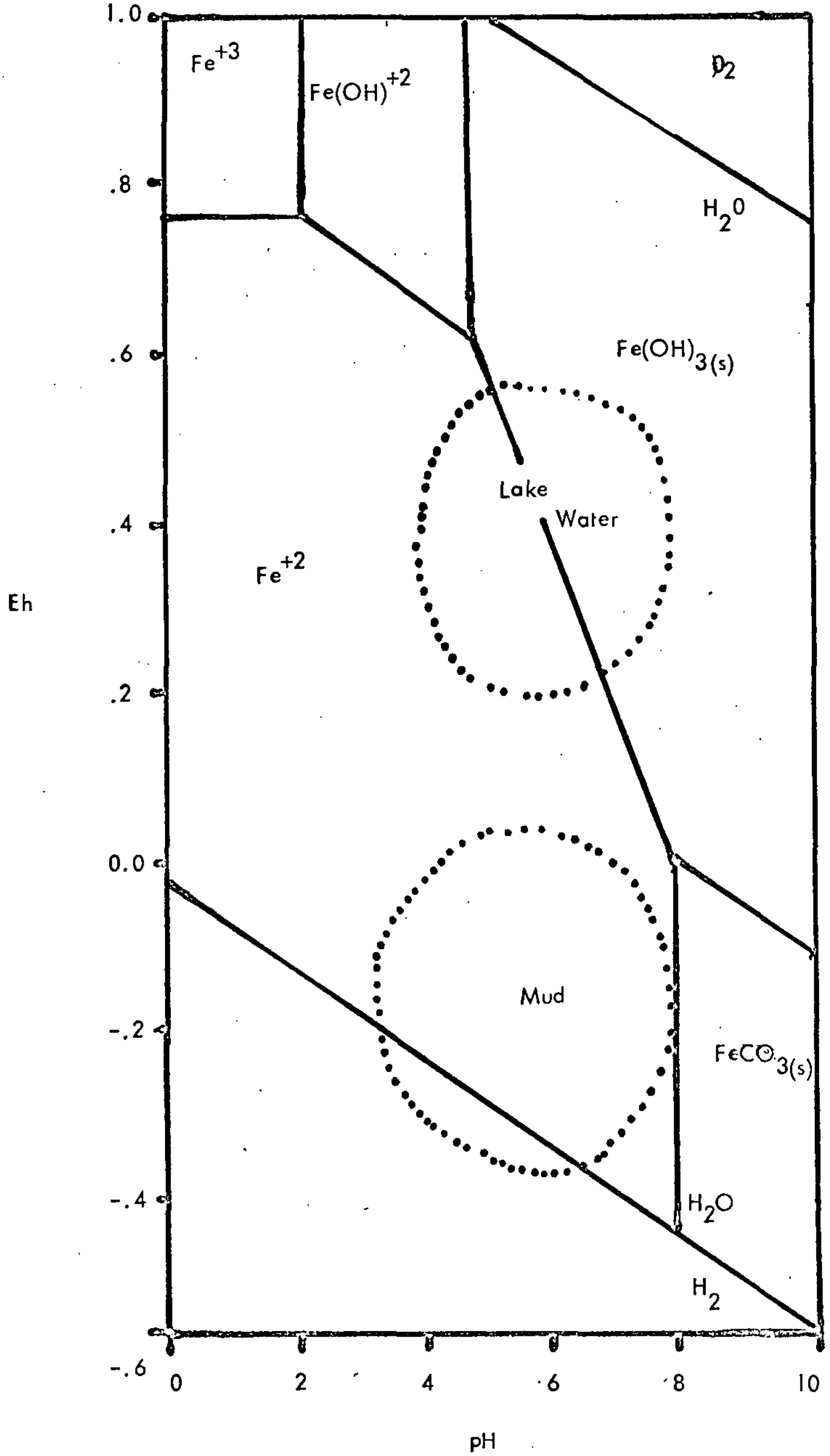
The role of iron in tying up orthophosphate in water as $FePO_4$ have been extensively reviewed and studied (Stumm and Morgan, 1964). Earlier works (Hutchinson, 1941) stress the formation of $FePO_4$ in lake water and its presence in mud as the main inorganic mineral controlling the concentration of orthophosphate. Figure 36, is a composite (Garrels and Christ, 1965, Stumm and Morgan, 1970) of the iron system relating species present to the Eh and pH of the system. Also shown are the regions of lake water environments and fresh water mud environments with respect to Eh and pH. Boundaries on the graph are at 10^{-6}M between ions and solid phases and boundaries between two ions separate fields dominated by the labeled ions. It is obvious from the graph that the concentration of free ferric ion is very small in lake water and almost nonexistent in the mud. Any ferric ion in water will occur as $Fe(OH)_3$ or possibly as a complex ion. Secondly, the equilibria of $FePO_4$ with ferric iron and orthophosphate would occur at concentrations much higher than those present in the lakes studied. A much more favorable mechanism is the sorption of PO_4 into the predominant ferric iron species, $Fe(OH)_3$ (see graph):

$Fe(OH)_3 + H_2PO_4^- = FePO_4 \cdot 2H_2O + OH^-$ (Stumm and Morgan, 1970).

This form, known as strengite, is a mineral present in oxidized sediments and the sorption of PO_4^{-3} increases with a decrease in pH. A similar sorption mechanism may also be occuring in the lakes studied. This would

Figure 36

pH versus Eh for Iron Species



be the formation of variscite:

$Al(OH)_3 + H_2PO_4^- = AlPO_4 \cdot 2H_2O + OH^-$ (Stumm and Morgan, 1970).

This form is probably a more reasonable phosphate mineral since its solubility is much lower than $FePO_4$:

Mineral	pH	Solubility
$FePO_4$	5	100 ppb as P
$FePO_4$	6	1000 ppb as P
$AlPO_4$	5	30 ppb as P
$AlPO_4$	6	10 ppb as P
$AlPO_4$	7	300 ppb as P

(Stumm and Morgan, 1970)

Since calcium ions and pH are both quite low in the lakes studied, minerals like hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, are not considered important (Snow, 1968). Therefore, it is reasonable in the lakes studied to presume that any mineral phase of phosphate is probably occuring as $AlPO_4$ or some solid solution phase such as aluminum hydroxide - phosphate, $Al(OH)_x(PO_4)_{1-x/3}$. The ferric phosphate mineral phase would appear to be completely soluble in the lakes studied and would not occur in the muds due to the low redox potential.

Adsorption and ionic substitution of orthophosphate is also possible with clay minerals in the mud. The phosphate can either be adsorbed on the clay mineral, actually bonded to positively charged edges of the clay, or substituted for aluminum or silicon in the clay structure (Stumm and Morgan, 1970). All mechanisms are much more favorable at a low pH. A typical kaolinite-phosphate, $Si_2O_5(OH)_4 \cdot (PO_4)$,

VIII Conclusions

The overall conclusion reached from analysis of all of the data indicates the following limnological classification of the various lakes studied: Aldrich Pond, Forge Pond, and Lake Warner - eutrophic; Metacomet Lake and Lake Wyola - mesotrophic; and Lake Mattawa, Norwich Pond, Asnacomet Pond, and Laurel Lake - oligotrophic. The pertinent parameters which can be used to separate lakes into different categories are temperature profile, pH, alkalinity, orthophosphate concentration and profile in both the overlying lake water and interstitial water of the deposit, dissolved oxygen profile and algal productivity in the summer months. The parameters that were not studied but which could be useful in future work are 1) conductivity, 2) Eh or redox potential, 3) concentrations of calcium, magnesium, silica and aluminum ions, 4) direct measurement of algal concentrations, and 5) measurement of carbon dioxide concentrations. The first three parameters would be useful in determining what ionic and mineral phases were present in the lake-mud system and what chemical - mineral equilibria system was predominating in the water. The last two parameters would be necessary to determine algal productivity and the availability of carbon in the system.

From the core studies, it may be concluded that large amounts of phosphate are stored in the bottom deposits of lakes exhibiting high concentrations of phosphate. Moreover, much of the phosphate in the deposit is located close to the overlying water interface. The low redox potential imposed on the cores during storage did release high concentrations of iron to the overlying water but the amount of orthophosphate released was very small in comparison. It is incorrect to suppose from this that orthophosphate is not readily released from mud under anaerobic conditions. Since the core barrels are plastic, they have a strong tendency to adsorb orthophosphate from solution and would therefore make the solution much lower in phosphate than could be expected. It may be postulated then that because large amounts of iron were released from the mud under conditions of low redox potential perhaps large amounts of phosphate were also liberated.

The ability to liberate large amounts of orthophosphate is also directly dependent on the amount of that nutrient in the mud. All of the eutrophic lakes showed very high phosphate concentrations near the mud-water interface. Transfer of some of the phosphate into the water, especially under low dissolved oxygen conditions, is very likely to occur. From the graphs, significant phosphate transfer would not appear to go deeper than 2 to 3 inches. Below a depth of 5 to 10 inches, the concentration of iron stabilized, thus indicating little chemical migration of that ion.

The postulation regarding ferric phosphate as the sole control of orthophosphate in the water-mud system is questionable for the lakes studied. A more likely solid phase would be either an aluminum hydroxide-phosphate or a clay-phosphate, since both of these could operate in the water as well as in the low redox environment of the mud.

Future work will involve studies on Lake Warner since its eutrophic condition should provide for active nutrient exchange between the deposit and the overlying water. This will then enable extension of laboratory quantitative analysis of nutrient transport rates. In addition, the limnological classification of other lakes will be attempted. This data will hopefully be useful in determining the treatment or management necessary in the future to maintain or improve the quality and usefulness of the lakes in Massachusetts.

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Appendix I

Phosphate (PO_4^{-3}-P) Method

PHOSPHATE METHOD

All glassware to be rinsed in 2N sulfuric acid, then stored under deionized water. The acid rinse need only be initial, with rerinsing every ten or twelve runs.

Mixed reagent: 50 ml 5N sulfuric acid

20 ml Ammonium Molybdate solution (15 gm. Ammonium Molybdate in 500 ml)

10 ml Potassium Antimony Tartrate solution (0.34 gm in 500 ml)

1.08 g Ascorbic Acid to 20 ml with deionized water

The above constituents are to be mixed in order prescribed.

This reagent is to be mixed fresh each time, discarding unused portions.

Control Stock Solution: dilute 5 ml Stock #8 to 100 ml with deionized. 5.3 ppb

Procedure:

1. Measure out 100 ml of the sample in a graduated cylinder and transfer to separatory funnel. Samples A and B are to be deionized water and control stock solution respectively.
2. To each separatory funnel add 10 ml mixed reagent with a 10 ml pipette. Shake the funnel vigorously immediately after adding the reagent. (1 minute)
3. To each separatory funnel add 20 ml isobutanol with a 20 ml pipette. Shake the funnel vigorously immediately after adding the alcohol. (1 minute)

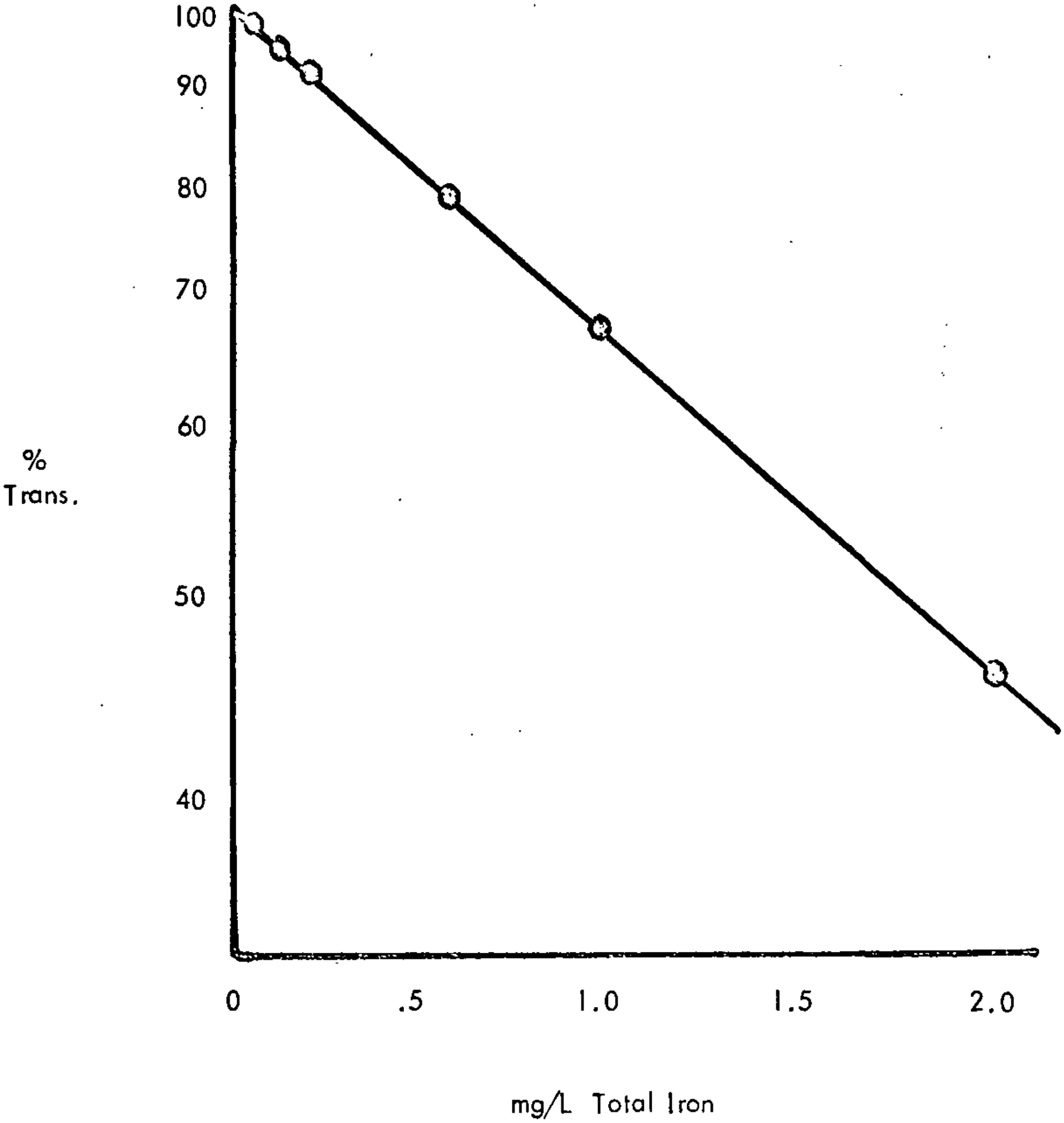
4. After all the isobutanol has been added to the funnels and shaking has been effected, shake each funnel once more in turn. (1 minute)
5. Separate the organic layer (top) from the water layer and discard the water layer. Transfer the organic layer directly to respective calorimeter tubes to which have been added each .8 ml 95% ethanol by auto-pipette.
6. Swirl tubes to insure mixing of the butanol and ethanol and measure transmittance against the deionized sample at 690 millimicrons. Remember to use the red tube and filter for this measurement. Estimate measurements to 1% transmittance.

Appendix II

Iron and Phosphate Calibration Curves

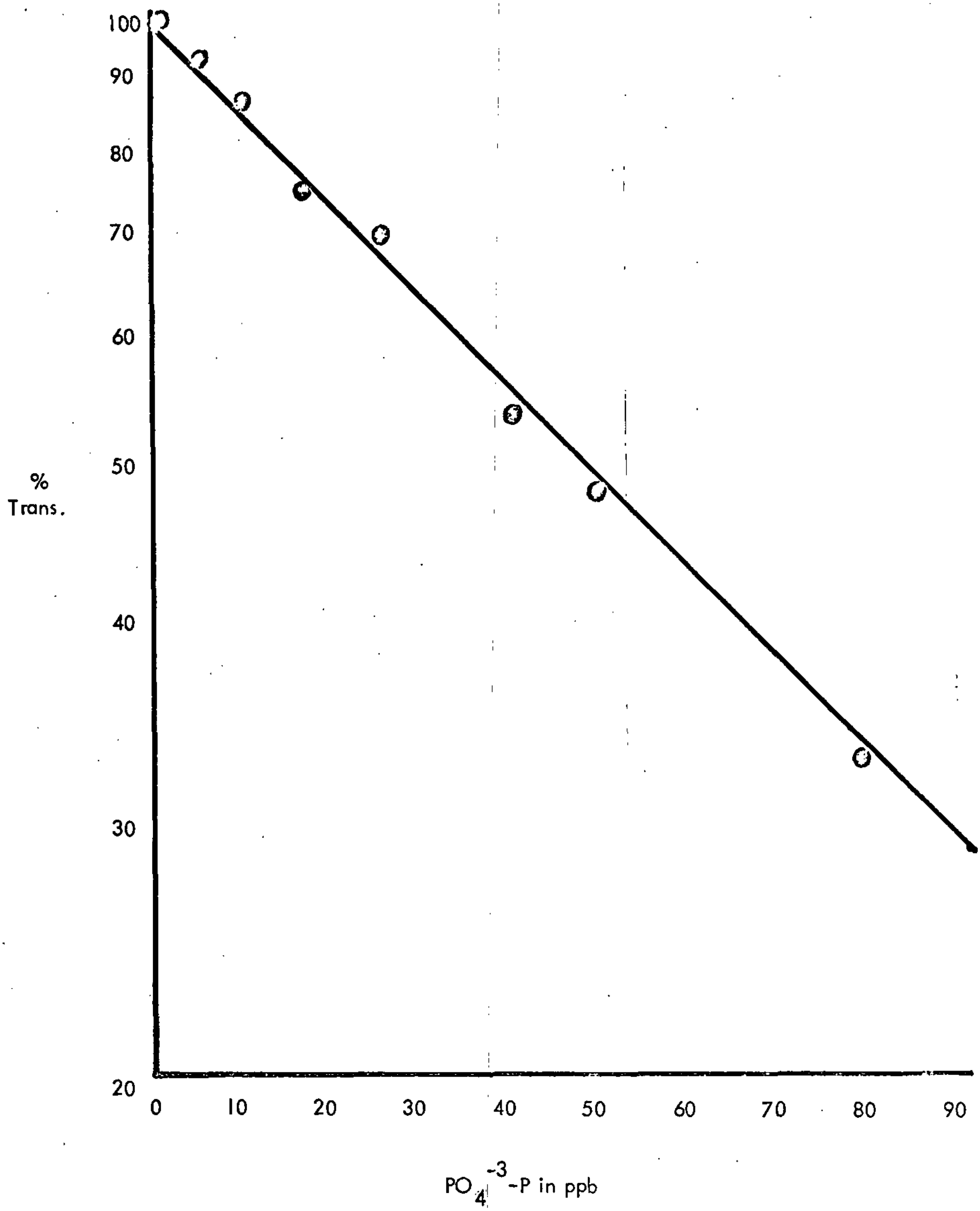
Iron Calibration Curve

% Transmittance versus mg/L Total Iron



Phosphate Calibration Curve

% Transmittance versus ppb PO_4^{-3}-P



Appendix III

Date on Lake Studies

Metacomet Lake 74 acres 8-27-70

#	Depth	Temp°C	pH	D.O. ppm	AlK ppm	Fe^{+2} mg/L	Fe Total mg/L
A-1	0'	25.5	6.15	7.3	8	.1	.53
A-2	2'	25					
A-3	5'	24.5		6.3			
A-4	10'	24.3		4.8			
A-5	13'	23.5	6.15	3.5			
A-6	14'	23.0	5.65	2.7	12	.47	1.5
A-7	15' (mud)	17.0	5.5	1.6			

Comments

a) Mud-brown color, slight smell of H_2S

b) Lake treated with 60,000 gal of sodium arsenite solution on 8-18-70

c) Attached weeds (water lilies) dying along with some shoreline plants

d) Fresh water clams dead (possibly from arsenite)

e) Transparency - 6'

f) PO_4 surface = 10,000 ppb (10 mg/L) and PO_4 bottom = 1,000 ppb PO_4 (1 mg/L) - both values inaccurate due to interference of arsenic.

Aldrich Pond 9-10-70

#	Depth	Temp°C	pH	D.O. ppm	AlK ppm	Fe^{+2} mg/L	Fe Total mg/L
A-1	0'	20	8.25	15.7	34	.02	.23
A-2	11'	19.5					
A-3	12'	18.5	6.7	3.5	36	.01	.5
A-4	Mud 13'	16.0					

Comments:

a) Thick pea soup algae bloom, some duckweed

b) Lake formed approximately 50 years ago (dam at one end) had only 6 inches of sediment above sand and pine needle bottom

c) PO_4 = 122 ppb at surface, 118 ppb at bottom

Forge Pond 9-10-70 and 8-18-70

#	Depth	Temp °C	pH	D.O. ppm	AlK ppm	Fe^{+2} mg/L	Fe Total mg/L
A-1	0'	26.5	8.05	16	34	.03	.62
A-2	1'	26.0		13.5			
A-3	6'	25.0		4.7			
A-4	mud 7'	25.0		.5			

Comments:

a) Lake very shallow, 6 feet.

b) Mud exposed on banks

c) Lake in algae bloom, lot of filamentous algae, duckweed and mucoid blue green algae

d) Transparency - 2' max

e) PO_4 = 250 ppb in lake water, 1 mg/L in interstitial water

Lake Warner 68 acres 8-25-70

#	Depth	Temp°C	pH	D.O. ppm	Alk ppm	Fe^{+2} mg/L	Fe total mg/L
A-1	0'	21	6.65	9.3	19.5	.08	.83
A-2	6'	20		6.1			
A-3	7'(bottom)	20					
B-1	0'	23	8.8	12.0	26	.05	.38
B-2	7'	21		7.8			
B-3	8' (bottom)	20		6.6			
B-4	in mud	20		2.8			

Comments:

a) Algae in abundant bloom, also a lot of duckweed and water lilies

b) Fish - bullhead, bluegills

c) Core taken near outlet, some sand and wood chips in mud

d) PO_4 = 25-50 ppb in water

Data: Laurel Lake - 51 Acres 7-30-70

#	Depth	Temp°C	pH	D.O. ppm	Alk ppm	Fe^{+2} mg/L	Fe Total mg/L
A-1	0'	28.5		10.2			
A-2	2'	28.0					
A-3	5'	N.R.					
A-4	10'	23.3					
A-5	15'	22.4		11.0			
A-6	16'	22.5		12.6			
A-7	bottom 16'	22.5					

#	Depth	Temp°C	pH	D.O. ppm	Alk ppm	Fe^{+2} mg/L	Fe Total mg/L
B-1	0'	28.5		10.1			
B-2	2'	28.0					
B-3	5'	N.R.					
B-4	10'	26.5					
B-5	15'	22.3		11.2			
B-6	20'	16.6					
B-7	25'	14.0		4.5			
B-8	27'	14.5		3.0			
B-9	32' bottom	12.0		1.5			
B-10	in mud	11.0	6.15	.5			

Laurel Lake

Comments:

a) Spring at beach, T= 19°C, D.O.= 12.5ppm.

b) at beach, T= 29°C, D.O. = 8.75 ppm.

c) at 16' depth, dense vine growth, good light penetration to this depth.

d) no visible amount of algae present, very clean.

e) mud is black-brown with visible black specks.

f) PO_4 in interstitial water = 40 ppb.

g) PO_4 in lake water = 4ppb.

Lake Wyola 129 acres 8-11-70

#	Depth	Temp°C	pH	D.O. ppm	AlK. ppm	Fe^{+2} mg/L	Fe Total mg/L
A-1	0'	25.0		9.0			
A-2	2'	25.0					
A-3	5'	25.0					
A-4	10'	25.0					
A-5	15'	19.0					
A-6	20'	11.0		7.3			
A-7	23'	10.5		6.5			
A-8	Mud 24'	9.0		1.5			

9-3-70

#	Depth	Temp°C	pH	D.O. ppm	AlK ppm	Fe^{+2} mg/L	Fe total mg/L
B-1	0'	20.5	6.6	12.6		.05	.28
B-2	27'	11.0	5.8	.5	14		
B-3	32' (mud)	9.0	6.05	0.0		1.16	2.2

Lake Wyola 11-7-70

#	Depth	Temp°C	pH	D.O. ppm	AlK ppm	Fe^{+2} mg/L	Fe Total mg/L
C-1	0'	9.5	6.9	12.7	4		
C-2	28'	9.0	6.92	10.3	5		
C-3	34 (mud)	10.0	N.R.	.2			

Comments:
a) little, if any algae

b) two samples (A and B) before thermal inversion, and (C) is after overturn.

c) PO_4 (summer) = 18 ppb

Lake Mattawa 112 acres 8-30-70

#	Depth	Temp °C #1	Temp °C #2	pH	D.O. ppm	AlK ppm	Fe^{+2} mg/L	Fe Total mg/L
A-1	0'	30.5	28.5	6.2	9.6			
A-2	2'	28.3	28.0					
A-3	5'	28.3	27.7					
A-4	10'	27.2	27.0		9.4			
A-5	15'	24.0	24.0		10.5			
A-6	20'	15.0	15.0					
A-7	25'	13.0	11.1		11.2			
A-8	30'	12.2	9.5					
A-9	31'	13.0	12.7		2.8			
A-10	31' bottom	13.0	12.7					

Comments:

a) Quite clean lake,

b) No bottom attached plants even at 3 foot depth

c) Slight brown color to water

d) PO_4 = 2-4 ppb in lake water

Norwich Pond 122 acres 8-20-70

#	Depth	Temp°C	pH	D.O. ppm	AlK ppm	Fe^{+2} mg/L	Fe Total mg/L
A-1	0'	25		9.6			
A-2	2'	25					
A-3	5'	24.5					
A-4	10'	24.5		8.9			
A-5	15'	24.5					
A-6	20'	17.7		8.6			
A-7	25'	12.2					
A-8	30'	10.2		4.5			
A-9	35'	9.5					
A-10	37'	9.0		5.0			
A-11	38' (mud)	9.5					

Comments:

a) Quite clean lake, no algae present 10' - 15' light penetration

b) PO_4 = 160 ppb in top of mud core, and 21" down it is 60 ppb

Asnacomet Pond 127 acres 8-4-70

#	Depth	Temp°C	pH	D.O. ppm	AlK ppm	Fe^{+2} mg/L	Fe Total mg/L
A-1	0'	26.6		8.9			
A-2	2'	26.6					
A-3	5'	26.0					
A-4	10'	26.0		8.3			
A-5	15'	25.8					
A-6	20'	20.0		12.0			
A-7	25'	14.4					
A-8	30'	11.0		14.5			
A-9	35'	8.9					
A-10	40'	8.3		10.5			
A-11	45'	7.7					
A-12	47'	7.7		3.0			
A-13	48' (mud)	8.0		1.1			

Comments:
a) Very clean lake, no algae present

Appendix IV

Data on Core Studies

Data Aldrich Lake (dam constructed 1910)

Core collected: September, 1970
Analysis: 4-12-71

Length 8", Eh = 180 mv, D.O. = 0.0 mg/L., pH in core water= 6.21

* sand and pine needles from excavated bottom

#	Depth in inches from bottom	pH of mud	Total Iron mg/L.	PO_4 in ppb
G-1	8-5"	N.R.	N.R.	176
G-2	5-2"	N.R.	2.4	131
G-3	2-0"	N.R.	6.0	414
G-4	core water	6.21	6.48	55 (118)

#	Depth in inches from bottom	% H_20 in mud	% dry mud solids	** % Volatile solids in mud	** % Ash in mud
G-1	8-5"	31.1	68.9	2.61	97.39
G-2	5-2"	39.9	60.1	5.8	94.2
G-3	2-0"	N.R.	N.R.	N.R.	N.R.

Data L. Warner

Core collected: August, 1970
Analysis: 1-9-71

Length 16", D.O. = 0.0 mg/L., pH = 6.13 in core water

#	Depth in inches	pH centrifuge H_2O	Total Fe mg/L	PO_4 ppb
1-B	16-13"	6.30	5.83	356
2-B	13-11"	6.42	6.8	172
3-B	11-9"	6.57	6.8	160
4-B	9-6"	6.52	9.5	189
5-B	6-3"	6.56	13.6	320
6-B	3-0"	6.56	11.0	464
8-B	core water	6.30	2.67	38

#	Depth in inches from bottom	% H_2O mud	% dry mud solids	% Volatile solids	% Ash
1-B	16-13"	59.5	40.5	10.55	89.45
2-B	13-11"	59.8	40.2	N.R.	N.R.
3-B	11-9"	42.5	47.5	6.0	94.0
4-B	9-6"	60.1	39.9	10.1	89.9
5-B	6-3"	66.2	33.8	11	89
6-B	3-0"	71.1	28.9	11	89

Data L. Metacomet

Core collected: August, 1970
Core Analysis: 3-1-71

Length 20", D.O. = 0.0 mg/L., pH = 5.78 in core water

#	Depth in inches	pH of mud	Total Fe mg/L.	PO_4 in ppb
1-E	20-17"	5.40	2.8	233
2-E	17-14"	5.48	1.6	156
3-E	14-11"	5.53	1.94	84
4-E	11-8"	5.50	2.2	76
5-E	8-5"	5.54	1.48	47
6-E	5-0"	5.58	1.96	44
7-E	5-0"	5.58	N.R.	N.R.
8-E	core water	5.78	4.2	71*

* Arsenic interference

#	Depth	% H_2O in mud	% dry mud solids	% Volatile solids in mud	% Ash in mud
1-E	20-17"	92.3	7.7	47	53
2-E	17-14"	93.55	6.45	45.5	54.5
3-E	14-11"	94.1	5.9	51.5	48.5
4-E	11-8"	95.15	4.85	56.2	43.8
5-E	8-5"	94.8	5.2	49	51
6-E	5-0"	94.63	5.37	46.5	53.5
7-E	5-0"	94.2	5.8	45.5	54.5

Data L. Wyola　　　Core collected 11-7-70
Analysis 11-21-70

Length 20", storage 14 days at 20°C, core water aerated for 15 minutes before analysis, pH initially - 5.3, after aeration pH = 6.3

#	Depth in inches	pH cent. H_20	Total Fe mg/L.	$P0_4$ ppb
4-3	20 - 15"	6.71	1.04	N.R.
E-1	14 - 7"	6.90	1.70	54
I -1	6-4"	6.81	2.5	100
E-3	4" - top	6.73	1.175	64
6-3	composite, mud and distilled	6.74	1.57	N.R.
4-2	composite, mud and distilled	6.73	1.95	N.R.
E-4	Lake water	N.R.	-	4
E-5	incore water	6.3	4.75	76

#	Depth in inches	% H20 in mud	% dry mud solids	% Volatile solids	% Ash
4-3	20-15"	83.75	16.25	25.1	74.9
E-1	14-7"	88.35	11.65	24.8	75.2
I-1	6-4"	83.5	16.5	20.4	79.6
E-3	4" - top	88.1	11.9	28.3	71.7
6-3	composite, mud and distilled	N.R.	N.R.	N.R.	N.R.
4-2	composite, mud and distilled	N.R.	N.R.	N.R.	N.R.
E-4	lake water	N.R.	N.R.	N.R.	N.R.
E-5	in core	N.R.	N.R.	N.R.	N.R.

Data L. Wyola

Core collected 11-7-70 Analysis 1-25-71

Length 14", D.O. = 0.0 mg/L., pH = 5.46 in core water

#	Depth from bottom in inches	pH centrifuged H_2O	Total Fe mg/L.	PO_4 ppb
A-1	14 - 11"	6.04	1.21	386
A-2	11 - 9"	6.01	1.25	142
A-3	9-7"	5.93	1.416	96
A-4	7-4"	5.88	3.50	123
A-5	4" - Top	5.87	3.63	179
A-6	surface water	6.17	1.58	16.7
A-7	surface water			
A-8	in-core water	5.71	6.0	6.68

#	Depth	% H_2O in mud	% dry mud solids	% Volatile solids	% Ash
A-1	14 - 11 "	87.4	12.6	25.8	74.2
A-2	11-9"	89.05	10.95	30.3	69.7
A-3	9-7"	88.8	11.2	31.5	68.5
A-4	7-4"	88.1	11.9	27.5	72.5
A-5	4" - top	89.3	10.7	27.2	72.8
* A-6	At cent. mud	64.8	35.2	27.5	72.5
* A-7	A-3 cent. mud	78.5	21.5	28.5	71.5
* A-8	A-5 cent. mud	74.0	26.0	27.0	73

* Analysis on mud after extracting centrifuge water

Data L. Wyola

Core collected: 9-4-70
Analysis: 3-10-71

Length 19", D.O. = 0.0 mg/L., pH = 5.52 in core water

#	Depth from bottom in inches	color of ash	pH of mud before centrifuge	Total Fe mg/L.	PO_4 in ppb
1-F	19-16"	white	5.49	1.6	496
2-F	16-13"	white	5.43	1.8	348
3-F	13-11"	reddish	5.43	2.8	224
4-F	11-9"	reddish	5.44	2.48	127.5
5-F	7-5"	red	5.54	3.44	96
6-F	3-0"	red	5.46	3.6	100
7-F	5-3"	red	N.R.	N.R.	N.R.
8-F	in core water		5.52	2.88	5

#	Depth from bottom in inches	% H_2O	% dry mud solids	% Volatile solids	% Ash
1-F	19-16"	86.7	13.3	27.8	72.2
2-F	16-13"	87.35	12.65	28.8	71.2
3-F	13-11"	89.0	11.0	28.7	71.3
4-F	11-7"	89.15	0.85	28.7	71.3
5-F	7-5"	88.0	12.0	27.0	73.0
6-F	3-0"	89.7	10.3	27.4	72.6
7-F	5-3"	90.2	9.8	24.4	75[illegible]
8-F	N.R.	N.R.	N.R.	N.R.	N.R.

Data L. Wyola

Core collected: 11-1-70
Analysis: 2-22-71

Length 19", D.O. = 0.0 mg/L., pH = 5.42 in core water

#	Depth from bottom in inches	Color of ash	pH mud before centrifuge	pH after centrifuge	Total Fe mg/L	Total $P0_4$ pp
1-D	19 - 16"	white	5.35	5.80	1.8	1600
2-D	16-14"	white	5.40	5.78	1.4	408
3-D	14-11"	white	5.44	5.76	1.72	160
4-D	11-8"	light red	5.41	5.72	2.5	129
5-D	7-4.5"	reddish	5.33	5.82	3.44	72
6-D	4-0"	red	5.38	5.82	2.70	92
7-D	8-7"	red	N.R.	N.R.	N.R.	N.R.
8-D	4-0"	N.R.	N.R.	N.R.	N.R.	N.R.
9-D	in core water		5.42	N.R.	4.0	5

#	Depth in inches	% H_20	% dry mud solids	% Volatile solids	% Ash
1-D	19-16"	87.0	13.0	27.2	72.8
2-D	16-14"	88.2	11.8	27.8	72.2
3-D	14-11"	88.05	11.95	28.7	71.3
4-D	11-8"	86.65	13.35	26.0	74.0
[illegible]-D	7-4.5"	88.9	11.1	25.2	74.8
6-D	4-0"	88.8	11.2	28.6	71.4
7-D	8-7"	88.73	11.27	28.7	71.3
8-D	4-0"	89.1	10.9	28.4	71.6

Data L. Mattawa

Core collected: August, 1970
Analysis: 1-20-71

Length 23", D.O. = 0.0 mg/L., pH = 5.64 in core water

#	Depth in inches from bottom	pH of cent. H_2O	pH of mud before cent.	Total Fe mg/L.	PO_4 in ppb
1-C	23-20"	5.58	5.36	5	156
2-C	20-16"	5.80	5.51	5	84
3-C	16-13"	5.85	5.64	5.5	67
4-C	12-9"	6.02	5.92	7.0	56
5-C	8-5"	6.08	6.00	8.0	53.2
6-C	5-0"	6.03	6.02	6.8	64
7-C	13-12"	N.R.	N.R.	N.R.	N.R.
8-C	9-8"	N.R.	N.R.	N.R.	N.R.
9-C	5-0"	N.R.	N.R.	N.R.	N.R.
10-C	water in core	5.66	5.62	2.0	6.6

#	Depth	% H_2O in mud	% dry mud solids	% Volatile solids	% ash
1-C	23-20"	89.55	10.45	31.	69.
2-C	20-16"	90.0	10.0	33.4	66.6
3-C	16-13"	91.8	8.2	38.6	61.4
4-C	12-9"	87.15	1.285*	N.R.*	incorrect
5-C	8-5"	95.2	4.8	37.5	62.5
6-C	5-0"	92.71	7.29	33.4	66.6
7-C	13-12"	87.2	12.8*	22.2*	incorrect
8-C	9-8"	92.7	7.3	35.3	64.7
9-C	5-0"	92.6	7.4	33.4	66.6