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# DISTRIBUTION OF TRACE ELEMENTS IN IMPOUNDMENTS

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# ABSTRACT

## DISTRIBUTION OF TRACE METALS IN IMPOUNDMENTS

An investigation of the trace element content of two impoundments on the Ouachita River, Arkansas, was conducted. Common water quality parameters were followed in the reservoirs in an effort to determine the factors which were influencing the trace element concentration. The following trace metals were determined in both the particulate phase (retained by a 0.45 micron filter) and the soluble phase (passed by a 0.45 micron filter): iron, manganese, copper, cobalt, nickel, lead, chromium, and zinc. These measurements were made periodically for one and a half years.

Results indicate that the chemical regime of the impoundments which were studied was greatly influenced by the cool water releases from an upstream impoundment. A cold density current throughout the entire main stem of the reservoir furnished dissolved oxygen to the lower portion of the impoundments and prevented the accumulation of large quantities of iron and manganese. More typical hypolimnic conditions were observed in the sidepockets of the reservoir.

Data suggest that outside of hypolimnic zones in the reservoir, soluble iron is present in very small quantities, usually less than 10 ppb.

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# ORGANIZATION OF REPORT

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## SECTION I - BACKGROUND INFORMATION

The Ouachita River and its tributaries comprise the major drainage system for south-central Arkansas. Three dams have been constructed on the main stem of the Ouachita River forming a chain of impoundments extending from Mt. Ida, Arkansas, to near Malvern, Arkansas. The upper impoundment is Lake Ouachita, constructed by the U. S. Corps of Engineers in 1952 (36,740 acres). Immediately below Lake Ouachita is Lake Hamilton, constructed by Arkansas Power and Light Company in 1931 (7,195 acres). Immediately downstream from Lake Hamilton is Lake Catherine, constructed by Arkansas Power and Light Company in 1925 (1,940 acres). The reservoirs of the upper Ouachita River basin are shown in Figure 1.

The Ouachita River basin above Lake Catherine drains an area of sandstone and shales. The area is essentially void of limestone formations. The drainage is generally forested with a hardwood-pine mixed cover. Agriculture in the area is limited to the bottom lands along streams and does not comprise a large percentage of the basin.

The river basin above the dam which forms Lake Ouachita is only sparsely inhabited. The shoreline of this reservoir has minimal developments, including several marinas, resort areas, and camping areas. Lake Ouachita receives the treated sewage effluent from the small town of Mt. Ida, Arkansas (population 564). Beginning at the upper end of Lake Hamilton, the shoreline is almost continually lined with private development, composed of private homes and cottages, extensive resort establishments, apartment complexes, marinas, and some industry. Due to the proximity of this reservoir to Hot Springs National Park, this reservoir is used extensively for recreation, including fishing, water skiing, and sight seeing. Lake Ouachita is also used for recreation, but due to the extensive private development, Lake Hamilton appears to support the larger numbers of persons per unit area of reservoir.

The shoreline of Lake Catherine supports considerable private development but not to the extent of Lake Hamilton. Some industry is also located along the northern shore of this reservoir. The Union Carbide Corporation was beginning an extensive vanadium mining and milling operation near the upper end of Lake Catherine at the time of this study. Arkansas Power and Light Company operates a steam generating facility on the shore of this reservoir in the vicinity of the dam.

The Ouachita River below Lake Catherine is used as a water supply for the municipalities of Malvern and Arkadelphia, Arkansas.

The characteristics of the three dams and reservoirs on the Ouachita River are given in Table 1. All three of the dams are used for hydroelectric power generation. The penstock elevations are at depths which cause water of considerable reduced temperature to be discharged during the summer period. In general, all three dams can be classified as cool water release structures.

## SECTION II - PROJECT DESCRIPTION

The increasing use of reservoirs for water supply and for stream flow augmentation has required some knowledge of the processes which take place in reservoirs and which cause alteration of the quality of the water stored. Knowledge of these processes is important from the standpoint of water quality as well as the productivity of the reservoir. Alteration of water released from storage reservoirs may have an effect on the downstream users of water as well as the productivity of the stream.

The chemical nature of reservoir water depends on many parameters. Processes related to thermal properties of reservoirs vary highly from region to region, depending on climate, as well as differences in original water type, storage ratio, morphology, etc. Many of these parameters and their relationship to reservoir productivity have been studied by Jenkins (17). Since the dissolution of heavy metals such as iron and manganese has been shown to be one of the principal types of water quality alterations taking place in storage reservoirs, some of the parameters related to the distribution of these and other trace metals have been investigated.

The two reservoirs chosen for this study were Lakes Hamilton and Catherine, the lower two reservoirs on the

Ouachita River. General water quality parameters were followed in these reservoirs in an attempt to relate the distribution of trace metals to various processes taking place within the reservoirs.

The state of occurrence of some of the trace metals (soluble, particulate) has been investigated, as has the concentrations of these metals being released from the lower of the two dams.

Analytical methods were developed for the determination of ppb levels of eight trace metals. Other water quality parameters were measured by standard procedures. Some of the procedures were modified to better suit the specific water type which was being studied.

Sampling stations were established on the reservoirs and the various water quality parameters, including trace metals were followed for a period of one and a half years. Sampling stations were selected to give a representative picture of the reservoirs. These stations were located over the old river channel and are shown in Figure 2. Stations were also established in representative sidepockets.

Other phases of the investigation include a study of the water quality and trace metals in the tailwaters of Lake Catherine, the analysis of bottom muds in Lake Hamilton, the simulation of reservoir conditions in the laboratory for the study of the migration of trace metals from bottom muds. A summary of water quality studies conducted at Greers Ferry National Fish Hatchery and Greers Ferry Reservoir on the Little Red River is included.

# SECTION III - METHODS

## A. Sampling and Station Location

Two-liter samples were taken from selected depths using a Van Dorn type water sampler. The sampler was constructed of plastic with rubber end closures. A minimum of metallic surface was exposed on the sampler.

The pH of the samples was taken within one minute after the sample was taken. Immediately after sampling, a 100 ml aliquot of the sample was filtered through a 0.45 micron Millipore filter (3.5 cm diameter). A gasoline powered vacuum pump was used to provide suction for the filtration. The filtrate from this step was acidified with eight drops of concentrated hydrochloric acid (stored in a 200 ml polyethylene bottle) and reserved for analysis of trace metals. Metals determined in this fraction are denoted with the subscript "f", indicating the filtered fraction ($Fe_f$, $Cu_f$, etc.). The millipore filter holding the particulate matter (retained by the 0.45 micron filter) from the same 100 ml aliquot was also reserved for trace metal analysis. Data reported for analysis of this fraction are denoted by the subscript "p", indicating the particulate fraction ($Fe_p$, $Cu_p$, etc.).

A one liter aliquot of the raw water sample was reserved for the analysis of Ca, Mg, Na, K, Cl, $NO_3$, $PO_4$, and COD. This sample was stored in a polyethylene bottle.

Sampling stations were located at representative points in the reservoir. Stations were located by traversing the reservoir between two marked points and locating the deepest points using a Simrad sounder. The location of these stations on both Lakes Hamilton and Catherine is shown in Figure 2. Stations 1 through 8 on Lake Hamilton represent the main stem of the reservoir and Station MC represents a typical sidepocket. On Lake Catherine, Stations 1 through 5 represent the main stem of the reservoir, while Station TC represents a typical sidepocket.

The location of five stations downstream from Lake Catherine are shown in Figure 1.

## B. Analytical Methods

### 1. Temperature and Dissolved Oxygen

Temperature and dissolved oxygen were measured insitu using a Precision Galvic Cell Oxygen Analyzer. The oxygen analyzer was equipped with a 30 meter temperature and oxygen probe. Calibration of the temperature scale was checked periodically against an accurate thermometer. The oxygen probe was calibrated by the Winkler Method prior to each field trip.

### 2. pH

The pH of each sample was measured immediately upon collection of the sample using a Taylor Color Comparator. The indicators which were used were bromothymol blue (pH 6.0-7.6), Chlorophenol red (pH 5.2-6.8), and cresol red (pH 7.6-8.8). The accuracy of these determinations was on the order of ± 0.1 pH units.

### 3. Chloride

Determination of chloride was carried out by the Mercuric Nitrate Method as described in Standard Methods (36). Since the chloride levels in the reservoirs which were studied were quite low, it was desirable to increase the precision of the method to allow determination in the range from 1.0 to 5.0 ppm. Dilution of the mercuric nitrate solution to

0.007 N instead of the recommended 0.014 N proved to add some precision. A 100 ml aliquot of a sample containing 2.5 ppm of $Cl^-$ requires 1.0 ml of the mercuric nitrate. A 10 ml burette was useful in this titration. Thus the chloride data are probably correct to within ± 0.5 ppm of chloride.

4. Fluoride

The fluoride concentration was measured using an Orion Fluoride Specific Electrode in conjunction with a Beckman Expanded Scale pH Meter. A calibration curve was prepared in the concentration range 0.00-1.00 ppm. Reproducibility checks indicate that the fluoride data are correct to within ± 0.03 ppm.

5. Nitrate

The nitrate ion concentration was measured by the method of Goldman and Jacobs (11). This method utilizes the absorption of the nitrate ion at 210 mμ. This method allows the determination of nitrate in the 0-10 ppm range with a precision of around 0.2 ppm.

6. Phosphate

Phosphate was determined by the indirect-ultraviolet spectrophotometric method (with some modifications). After treating the water sample with an acid-molybdate reagent, the molybdophosphoric acid was extracted with a 1:1 mixture of chloroform and n-butanol. The absorption of the extract was determined at 310 mμ. This method determines the orthophosphate with some contribution from phosphate groups that are easily hydrolized from organic substrates. The exact procedure used is given below. The method allows the determination of $PO_4$ to within ± 0.02 ppm.

Wadelin and Mellon (43) have reported the extraction of molybdophosphoric acid using a mixture of 1-butanol and chloroform. This procedure was modified and standardized for the range of phosphate up to 1.00 ppm. The procedure allowed the detection of 0.01 ppm of phosphate. This method is sensitive to the orthophosphates and probably the easily hydrolizable organic phosphate. No attempt was made to determine total phosphate.

Reagents:

Acid-Molybdate - dissolve 100 g of $Na_2MoO_4$ in 2000 ml of 1:1 HCl

Chloroform-Butanol - mix 1000 ml of chloroform with 1000 ml of n-butanol

Procedure:

Measure out 50 ml of sample into a 250 ml separatory funnel. Add 10 ml of acid-molybdate reagent and allow to stand 2 minutes after mixing. Add 10 ml of chloroform-butanol and extract (shake vigorously) for one minute.

Separate the chloroform-butanol mixture into a small test tube containing approximately one gram of anhydrous sodium sulfate. Allow the chloroform mixture to stand in contact with the sodium sulfate for around one-half hour. Measure the absorbance of the chloroform-butanol extract at 310 mμ in a quartz cell.

Blank:

Pure chloroform-butanol should be used as a blank.

Standardization:

Prepare a standard solution of $Na_3PO_4$ that contains 10 mg/l of $PO_4^{\equiv}$. Make the necessary dilutions (with distilled water) to make standards containing 0.10, 0.20, 0.40, 0.80, and 1.00 mg/l of $PO_4$. Treat 50 ml aliquots of each of these standards as described above. Measure the absorbance against the pure chloroform-butaonl reagent. The standard curve prepared from these data gives a straight line which can be used repeatedly as long as the proper type of blank is used.

### 7. Chemical Oxygen Demand

The dichromate oxidation method as described in Standard Methods (36) was used to determine chemical oxygen demand as an indicator of organic matter or other reducible matter. The method was modified to allow the determination of residual dichromate spectrophotometrically rather than by titration. The procedure is given below:

Reagents:

Stock Dichromate solution - 0.25 N sodium dichromate This solution is diluted to 0.025 N dichromate for use in the analysis

Sulfuric acid - dissolve 1.0 gram of silver sulfate in 75 ml of concentrated $H_2SO_4$.

Procedure:

Pipette 2.5 ml of raw water sample into a small beaker. Add 1.5 ml of 0.025 N dichromate and 3.8 ml of sulfuric acid reagent. Mix well and transfer to a small test tube. The test tubes are placed in a boiling water bath for two hours. After cooling the absorbance of each sample was determined at 350 mμ using a Beckman D.U. Spectrophotometer. A blank was prepared by substituting 2.5 ml of organic free water for the sample. All samples were run in duplicate.

A standard curve was prepared by adding different quantities of the 0.025 N dichromate, 3.8 ml of the sulfuric acid solution and enough organic free water to make the total volume 7.8 ml. Calculations of COD from the amount of dichromate consumed is given in Standard Methods (36).

### 8. Sodium, Potassium and Magnesium

The concentration of sodium, potassium and magnesium were determined using direct aspiration of raw water samples into the atomic absorption spectrometer. Instrument settings were those recommended by the instrument manufacturer (2). Absorption of the samples were compared to absorption obtained from standard solutions of the metals.

### 9. Calcium

Calcium was determined in the raw water samples using atomic absorption spectroscopy after pre-treatment of the sample to prevent interferences (2). A two ml aliquot of the sample was pipetted into a small beaker, then 0.2 ml of 10 percent solution of lanthanum nitrate was added. 0.1 ml of concentrated hydrochloric acid was then added and the resulting solution was aspirated into the atomic absorption spectrometer. Absorption of the samples were compared to standards which had been treated in an identical manner.

SECTION III C

# THE SIMULTANEOUS EXTRACTION OF IRON, MANGANESE, COPPER, COBALT, NICKEL, CHROMIUM, LEAD, AND ZINC FROM NATURAL WATER FOR DETERMINATION BY ATOMIC ABSORPTION SPECTROSCOPY+

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# Abstract

A method for the determination of eight heavy metals (iron, manganese, copper, cobalt, nickel, chromium, lead, and zinc) in natural water in the concentration range of a few ppb is presented. The method utilizes a diethyldithiocarbamic acid chelation followed by a methyl isobutyl ketone extraction to preconcentrate all eight of the metals in a single extract. This extract can be used for the determination of the metals by atomic absorption spectroscopy. Using proper field filtration, the method can be adapted for the determination of both the filtered and particulate fraction of these metals in natural waters.

## Introduction

The concentration of most heavy metals in unpolluted surface waters is generally below 0.1 ppm (12). Exceptions may occur where there is a sizable influx of heavily mineralized ground water or in streams receiving large silt burdens. Iron and manganese have been reported to exceed this level in organic rich waters (2). It is also well known that iron and manganese exceed this level in the deeper waters of many stratified reservoirs and lakes (3). As the dissolved oxygen level of the deeper water of these bodies of water decreases, the reduced state of both iron and manganese migrate throughout the low oxygen zone (14).

In order to study the distribution of heavy metals in a stratified impoundment in South-Central Arkansas, it was desirable to develop an atomic absorption procedure which could be used to determine a number of heavy metals in the ppb range when relatively large amounts of iron and manganese are often present.

The sensitivity required by the study demanded that some type of preconcentration step be used before determination by atomic absorption. Mulford (28) has described several solvent extraction systems useful in the concentration of metals for determination by atomic absorption. Joyner and Finley (19) have used diethyldithiocarbamate-methyl isobutyl ketone systems to concentrate iron and manganese in sea water. Platte and Marcy (32) have used a similar system for the extraction of lead, copper and iron from phosphate compounds. From data reported by these authors, it appeared that the chelation of metals with diethyldithiocarbamic acid followed by extraction with methyl isobutyl ketone would be adaptable to the determination of several heavy metals in water from the reservoirs to be studied.

A study was undertaken to determine if several heavy metals could be extracted in one step and the single extract used for the atomic absorption determination of these metals. The metals which were studied were iron, manganese, copper, cobalt, nickel, lead, zinc, and chromium. Since relatively large excesses of iron and manganese could be expected in samples taken from the deeper portion of the reservoir during the summer stratification period, possible interferences by high concentrations of these two metals were also studied.

The results of this study show that a one step extraction can be used to concentrate the eight trace metals and that these metals could be determined by atomic absorption in this single extract. The procedure was modified so that the concentration of these metals in both the soluble and particulate phases could be determined.

## Reagents and Instrumentation

The reagents used in this study were as follows: (1) Diethyldithiocarbamate (DDC) - 20 grams of Eastman Diethyldithiocarbamic Acid Sodium Salt were mixed with 380 ml of deionized water. The resulting solution was filtered through a 0.45 micron Millipore Filter. The filtrate was then extracted two times with 15 ml portions of methyl isobutyl ketone. (2) Methyl isobutyl ketone was Eastman 4-methyl-2-pentanone. (3) Phthalate Buffer - 102 grams of Baker Reagent Grade Potassium Biphthalate were dissolved in deionized water and diluted to 500 ml. 14 ml of 1 M HCl were added the the resulting solution diluted to 1.0 liter. (4) Sodium hydroxide and hydrochloric acid used to adjust pH were both reagent grade chemicals. (5) 1,000 ppm stock standards for each of the metals (there standards were acidified with HCl after preparation).

iron - Baker Reagent Grade powdered iron dissolved in hydrochloric acid

manganese - Baker Reagent Grade manganese sulfate

copper - Baker Reagent Grade copper metal dissolved in nitric acid

cobalt - Baker Reagent Grade cobalt carbonate dissolved in hydrochloric acid nickel - Baker Reagent Grade nickel carbonate dissolved in hydrochloric acid

lead - Baker Reagent Grade lead nitrate

zinc - Baker Reagent Grade zinc metal dissolved in hydrochloric acid

chromium - Baker Reagent Grade sodium chromate

A Perkin Elmer Model 303 Atomic Absorption Spectrometer was used. During the late stages of the investigation a recorder readout accessory in conjunction with a Sargent Recorder was used. A Beckman pH meter was used for all pH adjustments.

Note: Extreme caution must be taken to avoid contamination of glassware and reagents. Rinsing of all glassware with 1:1 nitric acid containing a small amount of hydrofluoric acid followed by rinsing with distilled water, acetone, then deionized water proved to be successful.

## The Effect of pH on Extraction of Heavy Metals

Lakanen (24) has discussed the effect of pH on the extraction of metals chelated with pyrrolidine dithiocarbamic acid. Chelation of several metals with this compound as well as with diethyldithiocarbamic acid is usually carried out in acidic solution. The manganese chelate formed by these reagents has been reported to have a low extraction efficiency in solutions with a pH lower than 3 (24).

A solution containing 0.50 ppm of each of the trace metals studied was prepared by diluting the stock standards. The pH of the resulting solution was 3.0. A 10.0 ml portion of the DDC solution was added to six 100 ml aliquots of the solution and allowed to stand for 10 minutes. Dilute sodium hydroxide and dilute hydrochloric acid were used to adjust the pH of these solutions in the range from pH 2 to pH 7. After pH adjustment, each solution was extracted with a 10.0 ml portion of MIBK. The organic extract was removed from the separatory funnel and was aspirated into the flame of the atomic absorption spectrometer. The absorbance was determined for each of the metals at the recommended settings for the instrument (2). The results of this determination are shown in Figure 3. It is clear that with the exception of manganese, all of the metals studied can be extracted with equal efficiency over the pH range from 2 to 7.

Further experiments indicated that, in addition to the pH of the media which is extracted, the pH at which the chelation takes place is also important. For example, if the pH of the initial solution was in excess of 4.0 (before addition of the DDC), the amount of iron which can be extracted is greatly reduced. Since the hydrolysis of the iron (III) ion can be expected as the pH is increased, it is highly likely that precipitation of iron prior to chelation may cause this decrease in extractibility. Since some of the samples were expected to contain relatively large amounts of iron, the possibility of coprecipitation of other ions with large amounts of hydrated iron (III) could serve as a potential source of error.

To eliminate this problem, samples, standards, and test solutions were maintained at pH 1-2 until the beginning of the procedure. The pH of the solution to be extracted was adjusted to 3.6 immediately prior to the addition of the DDC. A phthalate buffer was used to facilitate this pH adjustment. No loss of the extractibility of iron was found at this pH.

A 7.0 ml aliquot of the DDC solution was determined to provide an adequate excess of the chelating agent. The addition of the DDC solution to the sample at pH 3.6 resulted in a solution with a pH of 7.0. Extraction at pH 7.0 provided a reasonable recovery of the eight metals which were studied.

### Stability of Extract

Five 100 ml aliquots of a solution containing 0.50 ppm of the metals which were being studied were measured and the pH adjusted (after addition of 2.0 ml of phthalate buffer) to 3.6. After the addition of 7.0 ml of DDC, the solutions were extracted with 10.0 ml of MIBK. These solutions were aspirated into the flame of the atomic absorption spectrometer and the absorbance of each metal was determined at varying times after the extraction. The results of this study for copper, iron and manganese are shown in Figure 4. The results obtained for the other metals gave lines essentially parallel to those determined for copper and iron. It is clear that the atomic absorption determination of manganese must be carried out very soon after extraction. A delay of one hour can cause a 60 percent reduction in sensitivity for this metal. In all cases, care should be taken to insure that the time period between extraction and aspiration of standards and unknowns is the same.

## Standardization and Sensitivity

Solutions containing 10. 25, 50, 75, and 100 ppb of each of the eight metals were prepared by appropriate dilution of the stock standards. The pH of these solutions was adjusted to 3.6 after the addition of 2.0 ml of the phthalate buffer. 7.0 ml of the DDC solution were added and the solutions were extracted with 15.0 ml portions of MIBK. The resulting extract was aspirated into the flame of the atomic absorption spectrometer and the absorption determined for each metal. The instrument settings for each of the determinations are shown in Table 2. A set of typical standard curves for the eight metals studied is shown in Figure 5.

The approximate concentration of each of the metals which gives 1.0 percent absorption was as follows: Chromium - 1 ppb, iron - 1 ppb, copper - 2 ppb, zinc - 2 ppb, cobalt - 1.5 ppb, nickel - 5 ppb, lead - 4 ppb, and manganese - 1.5 ppb. Sensitivity was improved by determining the amount of absorption using a recorder readout accessory with scale expansion.

## Interferences

No spectral interferences are reported in the procedure manual for the spectrometer (9). Since relatively large excesses of iron and manganese could be expected in some of the samples, the contribution of large excesses of both of these metals was investigated. A standard curve was prepared for each of the metals as described above and the contribution (in ppb) from a solution containing 5.0 ppm of iron and another containing 5.0 ppm manganese was determined and which had been extracted by the same procedure. The contribution by 1.0 ppm iron and 1.0 ppm manganese was computed for each of the metals. These contributions in ppb are given in Table 3. Using the information given in this table, it was possible to correct for the contribution from large concentrations of iron and manganese. It is clear that for most of the metals, the concentration of iron and manganese would have to exceed 100 ppb before the correction would become significant. For other metals, clearly no correction is needed until iron or manganese exceeds 1.0 ppm.

## Sampling and Preservation of Samples

Water samples were taken from the reservoirs which were studied using a Van Dorn type sampler. Immediately upon collection of the sample, a 200 ml aliquot was filtered through a 0.45 micron Millipore Filter. The filter was washed with 100 ml of deionized water immediately prior to filtration. The filtrate was acidified with 16 drops of concentrated hydrochloric acid and transported to the laboratory for analysis. The filters were reserved for analysis of the particulate fraction.

## Summary of Procedure

A 100 ml aliquot of the acidified water sample was measured into 1 250 ml Erlenmeyer flask. 2.0 ml of the phthalate buffer were added and the pH adjusted to 3.6 ± 0.1. After adjustment of the pH, 7.0 ml of the DDC solution were added. The solution was transferred into a 500 ml separatory funnel (teflon stopcock) and a 15.0 ml portion of MIBK was pipetted directly into the funnel. The mixture was shaken vigorously for 30 seconds, then allowed to separate. The MIBK layer was drawn off into a glass stoppered test tube.

A set of standards (10, 25, 50, 75, and 100 ppb) and a blank (deionized water) was prepared for each set of determinations. Between 20 and 30 water samples can be handled by this procedure at one time. Manganese must be determined immediately upon completion of the set of extractions in order to prevent loss of sensitivity. The other metals are generally determined within the following two to three hours.

## Reproducibility

A set of ten test samples containing 50 ppb of each of the metals was subjected to the analysis procedure described above. The results of these analysis are shown in Table 4.

## Determination of Metals in Particulate Fraction

One half of the Millipore Filter which had been reserved from the initial field filtering was treated with 3 ml of 1:1 hydrochloric acid and warmed for approximately 30 minutes. The acid and washings were quantitatively transferred to a 100 ml volumetric flask and diluted to the mark with deionized water. The diluted samples were subjected to the same procedure described above.

## Conclusion

The determination of eight heavy metals--iron, manganese, copper, cobalt, nickel, chromium, lead, and zinc--in surface water can be determined at concentrations of a few ppb using a single step chelation-extraction system. It is possible to correct for the interferences from relatively large concentrations of iron and manganese. Using proper field sampling and filtration procedures, the concentration of the metals in the filtered and particulate fraction (greater than 0.45 microns) can be determined.

Preliminary results indicate that silver and cadmium may be included in this one step extraction procedure and measured with a relatively high degree of sensitivity.

## SECTION IV - RESULTS AND DISCUSSION

### A. Temperature and Oxygen Regime in Lakes Hamilton and Catherine

Figure 6 shows a typical temperature profile for the three reservoirs on the upper Ouachita River. It is apparent that the thermal properties of both of the lower reservoirs is greatly influenced by the release of cold water from Lake Ouachita during the summer period. In the upper end of Lake Hamilton, the cold water from Lake Ouachita can be detected on the surface but as the channel begins to widen, the cold water dives under the warmer layer. The same pattern is present in Lake Catherine but due to the fact that this reservoir is considerably smaller, the point at which the colder water submerges is farther downstream. The actual point of submergence of the cold water is dependent on the rate of release from the upper reservoir. During periods of extremely heavy release, the warm layer on the surface of Lake Catherine may be confined to the extreme lower end of the impoundment.

The five day averages of volumes of water released from Lake Ouachita during the period of the study are given in Figure 7 (42). The temperature and dissolved oxygen profiles obtained in the main channel of Lake Hamilton are shown in Figure 8 through 36. Figure 37 summarizes the temperature and dissolved oxygen profiles taken at Station MC (sidepocket) in Lake Hamilton. Figure 38 through 42 summarize temperature and dissolved oxygen profiles taken on Lake Catherine during the period of the study.

## Temperature

From the period November through March there is essentially no thermal stratification present in the reservoir. With the development of stratification, the underflow of water released from Lake Ouachita can be detected by the sharp temperature breaks in the upper end of the reservoir (see Figure 7). The underflow becomes less pronounced in the lower end of the impoundment. The existence of this cold density current was detected by Stevenson and Hulsey (37) in their evaluation of the reservoir as a possible trout fishery. Several of the temperature profiles clearly show two breaks. The lower of the breaks in the temperature curves probably reflects the upper extent of the cold density current from Lake Ouachita while the upper break represents the lower extent of mixing of the epilimnion or normal thermocline.

When water is being released from Lake Ouachita during the period of summer stratification, a temperature profile at Station 8, as shown in Figure 11, is typical. As soon as generation releases are stopped, the reservoir reacts to "level itself" by the warmer layer moving upstream and the colder layer moving downstream in the extreme upper end of the impoundment. During such periods temperature profiles at Station 8 similar to that shown in Figure 8 are typical. During extremely heavy release periods such as that experienced during the spring of 1968, the point of submergence may extend well downstream from Station 6, as is the case in Figure 22.

Temperature profiles observed in the sidepocket station on Lake Hamilton appear to show the same general pattern as the profiles taken in the main channel of the reservoir. As is shown in Figure 37, thermal stratification was maintained until around late October or early November.

It is obvious that the sizable releases of cold water from Lake Hamilton prevent the development of an extensive epilimnic layer in the main channel of Lake Catherine. The high degree of fluctuation of the releases from Lake Hamilton produce a very unstable thermal pattern in Lake Catherine. Thermal profiles in the sidepockets seem to be more stable.

## Dissolved Oxygen

The factors affecting the distribution of dissolved oxygen in natural lakes has been reviewed by Hutchinson (14). Churchill and others (8) have reported on the oxygen regime of several of the TVA reservoirs in Tennessee. The general field of the distribution of dissolved oxygen in different types of reservoirs has been reviewed by Kitrell. In a discussion of the waste assimilative capacity of impounded waters, Krenkel, et al, (23) have presented a rather comprehensive review of the factors which influence the dissolved oxygen regime of impounded waters.

Krenkel, et al, (23) have discussed various parameters which are known to affect the dissolved oxygen concentration of reservoirs, including such factors as atmospheric reaeration, photosynthesis, oxygen solubility, retention time and BOD removal, oxygen demand of bottom muds, and stratified flow. Kitrell (21) emphasizes the distinction between the dissolved oxygen regime of storage reservoirs and main stream reservoirs, the latter having significantly smaller retention times. Kitrell also demonstrates the difference between reservoirs which receive cool inflows as compared to those which receive inflows with a temperature near reservoir surface temperatures.

Both Lakes Hamilton and Catherine seem to fit the description of the situation where the colder inflowing water underflows the warmer epilimnic water, producing a wedge shaped thermocline zone. As mentioned above, several of the temperature profiles taken in Lake Hamilton indicate that the colder water being released from Lake Ouachita flows as a density current through the bottom of the reservoir during the period of stratification.

In the absence of density currents, the distribution of dissolved oxygen in a reservoir would be expected to show values of saturation or above in the epilimnic water and a decreased dissolved oxygen concentration in and below the thermocline region. It is generally thought that the decrease in dissolved oxygen concentrations below the thermocline is produced by an oxygen demand of organic matter in the water and by the oxygen demand of bottom muds. With essentially no transfer of dissolved oxygen across the thermocline region from the aerated surface waters, these combined oxygen demands tend to produce the typical clinograde oxygen distribution with oxygen concentration decreasing toward bottom.

The pattern of dissolved oxygen distribution observed in Lake Hamilton during the period of this study can be summarized as follows:

(1) D.O. concentrations near saturation are observed during periods when there is no thermal stratification. (See Figures 14, 15, 31, and 32).

(2) As thermal stratification begins, small changes in D.O. concentration are observed in the vicinity of the thermocline (See Figures 16 and 17).

(3) When heavy runoff occurs during the period of summer stratification, such as from spring and early summer rains, an increase in the D.O. concentration is observed in the vicinity of the thermocline, producing a somewhat positive heterograde oxygen distribution (See Station 1, Figure 18).

(4) After secession of heavy inflows, an oxygen depletion occurs at the same depth at which the D.O. maximum was observed earlier, thus producing a negative heterograde oxygen distribution (See Figure 20).

(5) The dissolved oxygen concentration of the water below the thermocline region was observed to decline throughout the summer but at a much slower rate than observed in the thermocline region (See Figures 21, 22, 23, 24, 25, 26, and 27).

(6) The dissolved oxygen concentration in this lower zone seems to be related to discharges from the upstream,

Lake Ouachita. This is particularly evident in the upper half of the impoundment.

(7) As shown in Figure 37 the D.O. distribution in the sidepocket station of Lake Hamilton clearly showed the development of the minimum in the vicinity of the thermocline, followed by rather rapid oxygen depletion in this same zone. Oxygen depletion below this zone occurred at a much faster rate than observed in the main stem of the reservoir. Water under the thermocline was observed to be essentially void of dissolved oxygen from August until overturn in late September.

The more rapid depletion of dissolved oxygen in the vicinity of the thermocline has been observed in several reservoirs in Arkansas. Mullan, Morais and Applegate (29) have demonstrated the existence of this low oxygen zone in Beaver and Bull Shoals Reservoirs on the White River in northern Arkansas. Greers Ferry Reservoir on the Little Red River develops a similar D.O. minimum (30), and unpublished data from the Arkansas Game and Fish Commission show a similar pattern for Lake Ouachita. Hutchinson (14) has discussed several possibilities for the existence of such a minimum in natural lakes. One hypothesis, originally proposed by Birge and Juday (7) suggests that seston falling from the more productive epilimnic water would be retarded upon entering the colder zone due to increased viscosity. Another hypothesis, introduced by Alsterberg (1) proposes a system of horizontal currents interacting with varying surface areas of bottom deposits as the cause for such minima.

Krenkle, _et al_, (23) have discussed the possibility of a shallow strata of cooler or silt laden runoff water being trapped in or below the thermocline. As will be discussed in Section IV E of this report, interflows of silt laden runoff water in Lake Hamilton have been detected and characterized during the spring and early summer period. Higher values of chemical oxygen demand have been established for these interflows and it is reasonable to assume that, since these waters contain a higher concentration of organic material and debris from surface runoff, they would also exert a considerably higher biological oxygen demand.

If the D.O. minimum in the thermocline region is produced by an oxygen demand exerted by an interflow of debris laden water, the exact level of the D.O. minimum would be expected to occur at a level corresponding to the temperature (acutally density) of the interflow. Runoff water, especially in the spring, is generally cooler than the surface water of the reservoir. Should some runoff originate from rains associated with the presence of a cold front, the temperature of the runoff water could be expected to be considerably cooler than reservoir surface waters. Some convective showers also produce very cool rainwater. Irregular D.O. distributions such as those noted at Station 3 on Lake Hamilton during the spring of 1969 (Figures 34 and 36) may be explained by multiple interflows originating from runoff of two distinctive temperatures (densities). An oxygen distribution showing two minima was also observed at the Mazarn Creek Station (MC) on 6/21/68.

The dissolved oxygen below the thermocline in Lake Hamilton was observed to be considerably higher in the upper end of the reservoir. This pattern would be expected since the cold density current from Lake Ouachita would be expected to be more pronounced in the upper reservoir. As the colder layer spreads out in the larger portion of the reservoir, the actual flow velocity from a cold density current of the reservoir would be expected to be less. Thus more time would be allowed for oxygen consumption in the lower region of the reservoir.

Dissolved oxygen levels were observed to drop to 1 to 2 ppm in the cold water region of Station 1 during the months of September. Upstream stations maintained considerably higher oxygen levels during this time.

From September 20, 1968, to September 28, 1968 (Figures 27 and 28) an increase in dissolved oxygen concentration was observed in the cold water region at Station 1. Since there was no appreciable change in the temperature profile during this time and since there was no disruption of the dissolved oxygen minimum at 10 meters, the increase in dissolved oxygen is attributed to an increased rate of flow of the cold density current from Lake Ouachita. Figure 7 shows that there was an increase in discharge from Lake Ouachita in mid September of 1968. Other fluctuations in the dissolved oxygen concentration in the lower depths of the main stream of the reservoir are probably related to the discharge rate from the upstream reservoir.

The more rapid and complete removal of dissolved oxygen under the thermocline at the sidepocket station on Lake Hamilton reflects the absence of dissolved oxygen contributions from cold density currents. Station 5 has approximately the same depth of the sidepocket station. The difference in the dissolved oxygen concentration in these two stations probably reflects the contribution from the cold density current in the main stem of the reservoir. The fact that the oxygen demand of the bottom muds in the sidepockets may be greater than the muds in the main stream of the reservoir may contribute to the more rapid removal of oxygen at the sidepocket station.

As can be seen in Figures 38 through 42, the effect of the cool inflowing water is considerably greater on Lake Catherine than on Lake Hamilton. Since Lake Catherine is much smaller, the flow velocity of the cooler water through this reservoir would be expected to be much larger. Although the water entering the upper end of Lake Catherine shows lower dissolved oxygen concentrations during the late summer period, essentially no decrease in the D.O. level is observed throughout the main stream of the reservoir. The warm oxygenated layer of water on this reservoir is extremely restricted and appears to be greatly influenced by the releases from the upstream reservoirs. During periods of high release of cool water from Lake Hamilton, the warm layer on Lake Catherine may only exist in the lower two miles of the reservoir.

The year of 1968 was not a very typical year since extremely large rains occurred during May and early June. The release of stored water from Lake Ouachita through Lake Hamilton and into the upper end of Lake Catherine through mid July of 1968 obviously prevented the development of an extensive epilimnion. During years when a lower flow is experienced, it is anticipated that the development of this warm layer will progress to several meters depth.

Figures 38 through 42 also show the dissolved oxygen profiles at the sidepocket station in Lake Catherine. Like the sidepocket station on Lake Hamilton, the absence of the cold current from the upstream reservoir, oxygen depletion occurs to a much greater extent than in the main stem of the reservoir.

The absence of the development of a dissolved oxygen minimum in the vicinity of the thermocline in Lake Catherine is probably due to the fact that the increased mixing caused from the large flows of cool water does not allow stabilized stratification, thus sweeping debris laden interflows away with the cool water. This minimum may be expected to develop during dry years when there is less cool water flowing through the reservoir.

## B. General Water Quality Parameters

The data for the various components which were measured in Lakes Hamilton and Catherine are presented in Tables 5 through 28. Tables 5 through 14 present the data for Stations 1, 3, and 5 on Lake Hamilton. The mean values of these data are summarized in Tables 15 and 16. Data taken for Station MC on Lake Hamilton is given in Table 17 through 22.

Similarly, data from Stations 1, 3, and 5 on Lake Catherine are presented in Tables 23 through 26 and the data from Station TC in Tables 27 and 28.

The mean value, range, frequency of detection, and number of determinations for the analysis of samples from Lakes Hamilton and Catherine are given in Tables 29 and 30 respectively.

The values determined for Na, K, Ca, Mg, Cl and $NO_3$ are in general agreement with the range of data reported for the Ouachita River. The average phosphate concentration is considerably higher than would be expected for a stream or reservoir which did not receive domestic runoff and effluents. Figure 43 shows a plot of the phosphate concentration in samples taken from Station 1 on Lake Hamilton. This plot shows that the higher values of phosphate were observed during the winter months. Since the analytical procedure which was used reflects essentially the soluble or ortho phosphate, this decrease from around 0.40 ppm in the winter months to around 0.10 ppm during the spring and summer probably reflects, to some degree, the utilization of phosphate by plankton organisms.

Several abnormally high values of phosphate were observed at Station 1 during the period of study. On 8/2/68 a value of 0.50 ppm was observed at a depth of 5 meters at Station 1. Since the city of Hot Springs empties limited treated sewage into the Hot Springs Creek sidepocket of Lake Hamilton, (see Station HSC in Figure 2) it is highly likely that the abnormal values of phosphate are related to stratified flow of this effluent.

A comparison of the average phosphate data for Lakes Hamilton and Catherine indicate very little differences. It should be noted that there is very little data for Lake Catherine during the winter months. It was qualitatively observed that transparencies in Lake Catherine were much less than transparencies in Lake Hamilton, indicating heavier plankton production in Lake Catherine. This higher production is probably related to the addition of nutrients from such sources as the Hot Springs sewage effluent and other domestic effluents in the lower end of Lake Hamilton.

It is also noted that the values for the chloride content of Lake Catherine were considerably higher than the mean value reported for Lake Hamilton. An inspection of the individual chloride data for Lake Catherine indicates that the higher chloride values were observed in the surface waters during the period of thermal stratification.

The Union Carbide Corporation operates a large vanadium milling operation on the northern bank of Lake Catherine and is known to introduce an effluent containing relatively large amounts of chloride into this reservoir near Station 4. An inspection of the individual chloride data for Lake Catherine shows that the elevated chloride values are not limited to points downstream from Station 4. Higher surface values of chloride were also observed at Station 5 and at Station TC during the summer of 1968. The introduction of the chloride effluent near Station 4 apparently was very intermittent during the study period, since attempts to find high values of chloride in the vicinity of Station 4 were not successful. The effluent is apparently introduced at or near bottom of the reservoir near Station 4. The temperature and oxygen profiles taken for Lake Catherine indicate that introduction of an effluent at or near the bottom at Station 4 would introduce the effluent into the cold zone of the reservoir. As indicated from the temperature profiles taken on Lake Catherine, this cold density current originating from the cool releases from Lake Hamilton, probably exists and dominates the flow through this reservoir during the stratified period. Assuming that there is good mixing of the high chloride effluent within this zone, the results of this operation should be reflected by higher chloride values in the cold waters. Since this was not observed, it is likely that the elevated chloride values originate from some other source than the high chloride effluent introduced near Station 4. It is possible that surface runoff from the vicinity of the vanadium milling operation may contribute to the chloride content of the warmer surface water.

The calcium content of Lake Catherine was consistently higher than that of Lake Hamilton. The higher calcium values seem to correlate fairly well with the higher chloride values on Lake Catherine, indicating that the source of chloride may be the same as the source of calcium. The Union Carbide effluent is also high in calcium. A study conducted by Southwest Research Institute for Union Carbide (13) reports a mean value for the calcium content and chloride content of their mill waste for the period 6/25/68 to 9/30/68 as 3,600 ppm and 13,000 ppm respectively. Thus it is likely that the slightly higher values of both calcium and chloride in Lake Catherine surface waters is in some way related to the mill wastewater from the Union Carbide operation.

## C. Heavy Metals

With the exception of iron and manganese, very few attempts to measure the distribution of trace metals in impounded waters have been reported. Hutchinson (14) has reviewed a large amount of information concerning the occurrence of iron and manganese in natural lakes. Hutchinson also reviews some information of the distribution of copper, cobalt and nickel in lakes. Other authors have presented information on the iron and manganese contents of various reservoirs and lakes (Ingols (16), Symons (39), Walesh (44), Delfino (9), and others). Poon (33) has recently presented the results of laboratory experiments which cast some light on the manganese cycle in impounded waters and Delfion and Lee (9) have demonstrated the distribution of manganese in Lake Mendota. Delfino, et al, (9) have also demonstrated the existence of particulate oxides of manganese in Lake Mendota. Tanaka (40) has shown that a layer of particulate manganese oxide and iron oxides are present in Lake Kizakikoxi in Japan during stratification.

It is generally understood that under stratified conditions, dissolved oxygen is depleted in the deeper waters of lakes and reservoirs. The depletion of oxygen is in part due to the presence of organic matter in the water column and an oxygen demand by bottom muds. The typical pattern of oxygen distribution under stratified conditions show a decreasing oxygen concentration toward bottom. Should the oxygen concentration become very low (less than 1.0 ppm) soluble species of iron and manganese usually begin to appear. Many authors have suggested that biological activity is responsible for the solution of these heavy metals in oxygen depleted zones. More recently Ingols and Enginun have shown that biological activity is only responsible in that it removes the dissolved oxygen, then the reduction of manganese from its insoluble state ($MnO_2$) to its soluble state ($Mn^{+2}$) is purely a chemical reduction.

The general pattern of soluble iron and manganese under reducing conditions would indicate that simple chemical reduction is responsible for the appearance of both of these metals in solution. Koyana (22), working with paddy soils has shown that as the redox potential falls, the soluble species of manganese appears first then iron later. The author has investigated several ponds and reservoirs under stratified conditions and in all cases manganese appears in solution well in advance of the soluble iron. From the redox potentials involved in the two reactions, i.e. the oxidation of iron and manganese, manganese would be reduced first then iron would not be reduced until the redox potential had dropped further. As the redox potential continues to drop, hydrogen sulfide would appear from the reduction of sulfur species. At this point in the drop of the redox potential, the distribution of heavy metals throughout the water column is probably affected by the solubility of their respective sulfides. Under certain conditions, carbonate or phosphate may also limit the buildup of such metals.

Benoit, in his discussion of the geochemistry of eutrophication, has pointed out several factors concerning the relationship of trace metals and the productivity of natural waters. As reported by Hutchinson (14), Rhode (34) has demonstrated that in water from Skarsjön containing 100 ppb of total iron, iron starved cells of Scenedesmus quadricauda grow at a rate equivalent to a comparative culture containing 8 ppb of iron. He also showed that 10 ppb of the iron was reactive toward orthophenanthreline (ferrous iron). He concluded that the reduced iron was all that was available to the organisms for growth. More recently McMahone (26) has demonstrated that ferrous iron varies from hour to hour and follows a diurnal pattern, reaching a peak during strong light intensity periods.

It is well known that several trace metals, especially iron, occur in apparent solution well in excess of the thermodynamic calculated values in equilibrium with their oxides. Many authors have postulated the stabilization of such metals by organic materials present in water. Shapiro (35) has cast considerable light on this phenomena by investigating the metal holding capacity of the yellow organic acids extracted from natural waters. The existence of soluble iron in oxygenated waters in excess of values predicted from the solubilities of its oxides can be easily explained by some type of chelation with natural occurring organic matter.

During the course of this investigation, the levels of eight trace metals have been established in different portions of Lakes Hamilton and Catherine. Values are reported for both the soluble fraction and the particulate fraction (retained by a 0.45 micron filter). The metals which were studied were iron, manganese, copper, nickel, cobalt, lead, zinc, and chromium. The results of these analysis are given in Tables 5 through 28, and are summarized in Tables 29 and 30.

It is possible to recognize clear patterns of distribution for some of the metals. By far, iron and manganese are the most dynamic of the metals studied. It is clear that in the absence of the cold density current and its supply of dissolved oxygen, the deeper water in the sidepocket station on both Lakes Hamilton and Catherine become depleted in oxygen by mid to late summer. In these zones, both iron and manganese are observed to become solubilized and remain in solution until overturn in October. The pattern of dissolved oxygen, iron, and manganese distribution in Station MC on Lake Hamilton is shown in Figures 44, 45, and 46. From this data, it would appear that the solubilization of manganese begins to occur as the dissolved oxygen concentration approaches 1 ppm and significant increases of iron do not appear until the dissolved oxygen concentration has dropped below 0.5 ppm.

It is also interesting to note that the maximum concentration of manganese was reacted in late July even though the oxygen depleted zone remained until mid September. The maximum values for the iron concentration coincided more with the maximum depletion of the oxygen. This would suggest that some factor was limiting the concentration of manganese at approximately 0.9 ppm. Possible limiting factors would be the formation of the insoluble sulfide, silicate, phosphate and carbonate (less likely due to low pH), or absorption onto the hydrous oxides of iron and/or manganese (19). The iron and manganese concentration dropped sharply as the mixing of oxygenated waters into the lower water occurred.

The pattern for particulate iron and manganese for the same station is less well defined. It is clear that, in conjunction with the buildup of soluble iron in the deeper water at Station MC, there is also an increase in particulate iron. In the oxygen deficient zone, the particulate fraction represented from 20 to 50 percent of the iron present in these samples. The similar situation is not true for manganese. As manganese increases in the soluble phase, very small quantities of particulate manganese were detected, particulate manganese usually amounting to less than 5 percent of the manganese present. The presence of the particulate iron in the hypolimnic zone of Station MC is persistent throughout the period of oxygen depletion.

In the main stream of Lake Hamilton, as reflected by the data for Stations 1, 3, and 5, there was very little buildup of soluble iron and manganese even during the later period of thermal stratification. Apparently the solution of these metals has been prevented by the presence of dissolved oxygen which has been supplied by cold density currents originating from the upstream impoundments. Some relatively small accumulations of soluble iron and manganese were observed at Station 1 during the late summer. Since the rate of flow of the density current in the lower end of the impoundment would be expected to be less due to the increase in volume and depth of the cold zone, the water would remain in contact with bottom muds for a longer period of time. This longer contact period would allow more oxygen depletion and, hence, some solution of iron and manganese from the bottom muds.

The persistence of particulate iron throughout the water column in Lake Hamilton is apparent during most of the period studied. As discussed in a later section, particulate iron is introduced into Lake Hamilton from the interflow of runoff water laden with silt. The observation of higher particulate iron in the regions of the thermocline was observed on numerous occasions. Slightly higher values of soluble iron were observed to coincide with the higher values of particulate iron in the thermocline region. The presence of additional organic matter from runoff debris could furnish additional complexing agents to render iron more soluble in this interflow zone.

It would appear that a considerable quantity of particulate iron is present even in the deeper waters of Lake Hamilton. Data from Station 5 on Lake Hamilton show that there is considerable particulate iron present in the cold water originating from the upstream impoundment. As this flow progresses through the lower regions of Lake Hamilton, the rate of flow should decrease due to the increased width of the basin. It is not understood why the particulate iron does not sediment in the lower portion of the impoundment. Possibly the cold density produces enough turbulent action to keep these particles suspended throughout the cold zone. Sedimentation of silt from the interflow zone may contribute to the occurrence of the particulate iron in these deeper waters. Since the rate of release of water from the upstream impoundment was above average during the period that the reservoir was studied, it is likely that the majority of the particulate matter originates from the bottom muds and kept suspended by turbulent action.

The ratio of particulate iron to particulate manganese in this zone of the reservoir is considerably larger than the ratio of iron to manganese in the bottom muds from Lake Hamilton. The enrichment of particulate manganese may be related to a difference in the size of the particulate iron and particulate manganese, smaller particles being more easily suspended.

Concentration levels for the eight heavy metals have been established for Lakes Hamilton and Catherine. Other than iron and manganese, distinct patterns of occurrence of these metals is not apparent. A statistical evaluation of the observed levels of the eight metals in Lake Hamilton is presented graphically in Figures 47 through 54. The solid line indicates the occurrence of the metal in the soluble fraction while the dotted line indicates its occurrence in the particulate fraction. The following conclusions can be drawn from these data:

1. The principal form of iron in Lake Hamilton is particulate. The concentrations of soluble iron are usually very low. The occurrence of higher values of soluble iron is definitely related to the buildup of this metal in the oxygen deficient zone at Station MC. The concentration of soluble iron in the main stem of the reservoir was usually under 20 ppb.

2. The levels of manganese in the particulate and soluble fraction are very comparable in samples taken from the main stem of the reservoir. Higher values of soluble manganese occur primarily at Station MC during the period of oxygen depletion in the deeper water. The concentration of soluble manganese in the main stem of the reservoir was usually under 30 ppb.

3. Copper appears to exist at comparable levels in both the soluble and particulate phases in Lake Hamilton. These data have established average copper concentration of 8 ppb in the particulate fraction and 8 ppb in the soluble fraction for Lake Hamilton. Average value of soluble copper in Lake Catherine is 11 ppb in the soluble fraction and 8 ppb in the particulate.

4. The distribution of nickel between the particulate and soluble fractions seems to be about equal with the exception of the high values of particulate nickel which were observed on August 2, 1968 (discussed later). This would indicate that at higher concentrations, nickel in the particulate fraction is favored. An average value of 3 ppb for the soluble fraction and 9 ppb for the particulate fraction is established for Lake Hamilton. In Lake Catherine the mean values are 3 and 2 ppb respectively.

5. When cobalt concentrations in excess of 4 ppb were observed in Lake Hamilton, it appears that the metal is present almost totally in the soluble fraction. At lower concentrations a considerably higher proportion of particulate cobalt was observed. Average values for Lake Hamilton are 3 and 2 ppb for the soluble and particulate fractions respectively and 2 ppb for both fractions in Lake Catherine.

6. Lead seems to be present in approximately equal quantities in the soluble and particulate fractions in both reservoirs. Mean values for the soluble and particulate fractions are 7 and 9 ppb for Lake Hamilton and 11 and 9 ppb for Lake Catherine.

7. Although fewer determinations of zinc were made, it appears that the quantities present in both fractions are comparable with the exception that at higher concentrations

of zinc, the soluble fraction is definitely favored. Average values of 23 and 6 ppb for the soluble and particulate fractions were established for Lake Hamilton and 6 and 10 ppb for Lake Catherine.

8. Chromium shows the smallest concentration and the smallest number of occurrences of metals which were studied. Since the chromium concentration was observed to increase at the same time that abnormally high nickel values were reported (August 2, 1968), it is likely that the origin of the two metals is the same. The average chromium concentration for Lake Hamilton was 1 and 2 ppb in the soluble and particulate fraction with a frequency of detection of 34 and 55 percent respectively. In Lake Catherine these averages were 0 and 1 ppb with a frequency of detection of 4 and 37 percent.

An inspection of the individual trace metal data (Tables 5 through 28) shows that abnormal values of these metals have occurred on several occasions. On August 2, 1968, very high values of particulate nickel were observed throughout Lake Hamilton. The highest concentrations were observed at Station 1 at depths of 0 and 10 meters, although very atypical values were recorded throughout the water column at all stations in the main stem of the reservoir. The level of particulate nickel at Station MC on this date was in line with earlier values. Slightly higher chromium values were also reported during this same period. The effluent from an electroplating operation located on the northern bank of Lake Hamilton near Station 4 may account for these abnormal values. Abnormal nickel values were also observed at Station 5, which is upstream from the point of the introduction of the effluent. It would be difficult to account for this surge of nickel in the reservoir from a source other than an industrial effluent. If the nickel does in fact originate from such an effluent, it is interesting to note the extent of the distribution. The data from Station 1 would indicate that the particulate nickel was principally present in the upper layers of the reservoir and has gradually sedimented throughout the water column. The presence of the higher nickel values at the upstream station would indicate some upstream currents in the reservoir. Such currents could easily be produced when the release of the cold waters from Lake Ouachita stopped and the warmer water moved upstream in an attempt to level the thermocline.

Seasonal variations of the trace metals in the main stem of the reservoirs studied could not be well established.

Among the trace metals known to be required for growth of some algae are Fe, Mn, Zn, Cu, and Co. Very little information is available on the concentrations of these metals needed for aquatic productivity or the levels which would limit productivity in natural waters. Zinc, for example, has been shown by Bachman (3) to be present up to 12 ppb in rainwater. More recently, Lazurs, et al, (25) have reported an average zinc concentration for rain samples taken throughout the United States to be on the order of 100 ppb. Hutchinson (14) summarizes work done on the zinc concentration of lakes and reports values as low as 1 to 5 ppb in some Japanese lakes.

Hutchinson (14) has reported values for ionic copper in the range of 4 to 35 ppb for lakes. Cobalt levels are also summarized with values ranging from 0 to 7 ppb. Benoit (6) reports cobalt concentrations almost two orders of magnitude lower for various Connecticut waters.

Aside from the buildup in oxygen deficient zones, the concentration of soluble iron appears to be on the order of 10 to 15 ppb in Lake Hamilton with frequent values under 5 ppb. Although iron is considerably more abundant in bottom muds than the other heavy metals, the concentrations of soluble iron in the oxygenated zone of the reservoirs which were studied appears to be very low. Although growth limiting levels of this element are not well established, values under 10 ppb are rarely reported for productive lakes. It is possible that the extremely low levels of iron observed in oxygenated waters may limit the productivity of some species.

The high degree of fluctuation of most of the trace metals studied indicate that both Lake Hamilton and Catherine are very dynamic. Data indicate that although a warm layer exists on the surface of Lake Hamilton during the summer period, the trace metal concentration is highly variable. These changes may be related to the influx of runoff water since it is expected that this water would be restricted to the upper thermocline or epilimnic region of the reservoir. Large quantities of particulate iron from silt laden runoff water may provide absorption surfaces for other metals. Organic material from runoff debris cannot be overlooked as a source of materials which will complex metals, making them more available for biological utilization.

Recently, Bender, et al, (4) have shown that organic matter extracted from sewage is capable of binding to copper. This organic matter was present in two distinctive molecular weight fractions. The lower molecular weight fraction, when combined with iron, stimulated algal growth.

The supply of organic materials which would render trace metals usuable for biological productivity may be an important factor in the overall productivity of reservoirs. Information presented in this report on the chemical characterization of interflows indicate that organic matter in these runoff waters is capable of keeping larger quantities of iron in solution. If reservoirs could be managed so that interflows of runoff water would interflow into the photic zone, added productivity might be realized.

## D. Ouachita River Below Lake Catherine

On September 5, 1968, samples were taken from the Ouachita River at six stations as shown in Figure 1. The results of the analysis of these samples is shown in Figure 62.

As shown in Figure 41, Lake Catherine showed considerable lower dissolved oxygen values in the deeper water at Station 1 but not total depletion. At the depth of the midpoint of the penstock, 9.5 meters, the dissolved oxygen concentration was 3 ppm on 9/14/68. This number is in good agreement with the values of dissolved oxygen measured immediately downstream from Lake Catherine on 9/5/68. As shown in Figure 62, the dissolved oxygen content of the Ouachita River did not recover to values typical of other streams in the area until a point near Station 5 was reached. Station 5 is approximately 27 river miles downstream from Lake Catherine. Since the maximum value of the dissolved oxygen concentration reached by the river was in excess of saturation values it is likely that reoxygenation is occurring from both turbulent mixing as well as phytoplankton production.

River gravel at Station 3 was observed to be coated with a very black manganese compound, probably an oxide.

This manganese deposit causes the entire river bed between Station 2 and 4 to appear very black. The results of the analysis of manganese released from Lake Catherine is very near the level reported for the 10 meter depth on 9/14/68. The abnormal value of 750 ppb $Mn_f$ observed at Station 4 on the Ouachita River cannot be explained. Other than this atypical value, the general trend of manganese is to decrease in the downstream direction.

The trend of increasing pH in a downstream direction is no doubt due to the loss of free carbon dioxide as the water becomes aerated.

There is also a slight trend of a decrease in particulate iron in a downstream direction. It is very liekly that particulate iron is simply sedimenting into deeper portions of the river, thus producing the observed decrease.

Ingols (15) has discussed the occurrence of manganese in streams below impoundments and has assessed the pollutional aspects of the release of oxygen deficient tailwaters. The municipality of Malvern, Arkansas, takes its water supply from the Ouachita River at Station 3. Many residents of this town complain about the staining of plumbing fixtures and abnormal taste in their water supply during the months of August, September, and October. Some installations using filters have observed filter clogging during these months.

The summer of 1968 was very atypical since large quantities of water were released from Lake Ouachita through both Lakes Hamilton and Catherine during the entire summer period.

It is likely that during years when rainfall is more typical and less water is released from the upstream impoundments, the extent of iron and manganese buildup in the lower regions of Lake Catherine will be larger. There is little doubt that if this occurs, higher concentrations of manganese will be released into the Ouachita River. Such conditions did not develop during the course of this investigation and thus could not be evaluated. It is interesting to note that several fish kills have been reported in the Ouachita River below Lake Catherine. It is possible that these kills were related to the release of low oxygen water, possibly laden with manganese.

As manganese is released into the river below an impoundment, the oxidation of manganese to the insoluble oxide is expected to occur. From the qualitative observation of manganese deposited on river gravel in the vicinity of Station 3, it would appear that such deposition may account for the principal decrease of this element in the river. Morgan (27) has shown that the oxidation of manganese to its insoluble oxide proceeds quite slowly at the pH range observed in the Ouachita River. The rate of oxidation, sedimentation and/or deposition is probably related to many factors, including such things as the rate of flow of the river, the dissolved oxygen content, the pre-existence of manganese oxides, and other water quality parameters.

Should oxygen depletion in the lower regions of Lake Catherine occur to such an extent to allow large accumulation of soluble manganese, iron, and even hydrogen sulfide, the utilization of the Ouachita River as a water supply for the city of Malvern and even Arkadelphia (approximately 35 river miles below Lake Catherine) may be affected. Such conditions would be expected to occur during the periods of low rainfall when there were minimal releases from upstream impoundments. Such conditions often develop in the months of August and September in Arkansas. The utilization of releases from upstream impoundments to minimize the mobilization of manganese and possibly iron should be considered during these periods of low flow.

## E. Investigation of Interflow in Lake Hamilton

The existence of a minimum in the dissolved oxygen profile in the vicinity of the thermocline is common for Arkansas reservoirs. The minimum usually begins to develop in the early summer and progresses until mixing of epilimnic water into the thermocline zone occurs in the fall. Mullen and Applegate have observed such a negative heterograde oxygen distribution in Beaver and Bull Shoals Reservoirs in northern Arkansas. Similar oxygen distributions have been reported for Greers Ferry Reservoir (30) and for Lake Ouachita (20).

Hutchinson (14) has discussed the occurrence of the negative heterograde oxygen distribution and points out the suggestion of Birge and Juday (7) that the dissolved oxygen minima is produced by plankton falling from the productive zone into the thermocline region where it slows down and exerts its oxygen demand. Hutchinson also points out that Alsterberg (1) proposed a system of horizontal currents interacting with varying areas of bottom muds as an explanation for the oxygen minima.

As can be seen in Figures 19 through 29, the dissolved oxygen minima begins to develop in May and lasts into October. The lowest oxygen values were observed in September when there is no dissolved oxygen from a depth of six to twelve meters at Station 1. The dissolved oxygen minima are most pronounced at the downstream locations.

During the course of this investigation, darker filters were often observed from samples taken from the thermocline region. The filters taken from distinctively epilimnic water usually showed a slightly green color. Filters taken from the deeper waters usually were light brown but filters taken from the thermocline region often showed a very dark red-brown color. The darker filters were particularly noted after rains.

A limited survey conducted during May of 1968 clearly showed that cooler-silt laden runoff water originating from the watershed directly draining into Lake Hamilton, was underflowing the surface strata. As would be expected, these underflows remained confined to the thermocline region. Visual detection of the silt laden filters was apparent throughout the Mazarn Creek area and at Stations 3, 2, and 1 (in decreasing order of intensity).

The analysis of the particulate fraction indicated considerably higher iron content in the darker filters. The occurrence of layers of particulate iron in the thermocline region were observed several times during this investigation.

The dissolved oxygen profiles taken on Lake Hamilton on April 28, 1968, show indications of the beginning of a dissolved oxygen minimum at a depth of 4 to 8 meters. Extremely heavy rains occurred in late May, 1968. The dissolved oxygen profile taken on May 23, 1968, shows an increased dissolved oxygen content in the region from 4 meters to 8 meters at Station 1. Darker filters were also observed in this region. The next profile taken at Station 1 (May 30, 1968) indicates that some oxygen consumption has occurred between 4 and 8 meters. By June 14, 1968, a distinctive D.O. minimum had developed ranging from 3 meters to 8 meters.

It is expected that the silt laden runoff water would exert a considerably higher oxygen demand and thus produce the minimum in the D.O. profile.

On June 4, 1969, a silt laden density current was detected in the Mazarn Creek sidepocket. Rains had occurred on June 1 and 2, 1969. Samples were taken from Station 3 (approximately 1/2 mile downstream from the confluence of the Mazarn Creek pocket and the main stem of the reservoir). Samples were taken at 2 meter intervals. Station 3 was again sampled on June 26, 1969. The results of the analysis of these samples are shown in Figures 55 and 56.

As shown in Figure 55, the interflow observed on June 4, 1969, shows a different chemical nature than both water above and below this strata. The interflow, apparently extending from a depth of 5 meters to 10 meters, is characterized by a lower pH, distinctively higher C.O.D., higher values of nitrate, chloride, iron (particulate and filtered), and slightly higher value of particulate manganese. Both calcium and magnesium show values considerably lower in the interflow as compared to water above and below.

The data taken at the same station on June 26 (Figure 56) shows that most of the distinctive chemical nature of the interflow had dissipated. Apparently, much of the particulate matter had settled and abnormal concentrations of other components had dissipated.

The pattern of density flows throughout reservoirs would depend on such factors as the temperature profile, the temperature of the runoff water, the magnitude of the runoff, and the nature of the drainage basin. Double oxygen minimums could easily be produced from the interflow of runoff having different temperatures. Irregular fluctuations in the dissolved oxygen profiles observed during this study may be the result of interflows of different temperature.

If extensive agriculture practices are underway in the drainage basin of a stratified reservoir, it is highly possible that interflows could initially contain high concentrations of nutrients, such as phosphates. Nutrient materials originating from runoff sources may be introduced and begin their cycle within the confined regions of an interflow. Should interflows be too deep to interact with the productive zone, the benefits or detrimental effects from such nutrients might be avoided.

In areas where nutrient rich sewage effluents are introduced into stratified impoundments, the temperature (actual density) of the effluent may determine whether the effluent will enter the productive zone of the reservoir.

## F. An Investigation of Bottom Muds From Lake Hamilton

On July 13, 1968, mud samples were taken from each of the eight stations on Lake Hamilton. In all cases, the samples were taken from the deepest part of the reservoir on a transect at each station. Samples were taken using a tubular dredge which was constructed of 50 cm length of a 7.0 cm diameter steel pipe. Samples were sealed in plastic bags immediately upon collection and transported to the laboratory for analysis.

A portion of each sample was dried at 100°C for five hours. After drying, a portion of the sample was ignited in a muffel furnace at 1500°C for two hours. The loss on ignition was determined and reported as organic matter. The same samples were digested in aqua regia for two hours then diluted to 100 ml with deionized water. An aliquot of this solution was subjected to phosphate analysis by the method described earlier in this report. After appropriate dilution, each of the following metals were determined by atomic absorption spectroscopy: Ca, Mg, Fe, Mn, Cu, Ni, Co, Pb, Zn, and Cr. All analysis were done in triplicate.

The results of these analysis are presented in Figure 57. The depth of water at each of the stations is given in Table 31.

Several of the components measured showed a distinctive decline from Station 1 to Station 8. Notable is the organic matter (loss on ignition) which decreases from 12 percent to around 1 percent. The phosphate content drops from a value of $9 \times 10^{-3}$ at Station 1 to less than $1 \times 10^{-3}$ percent at Station 8. A similar trend can be seen for Mg, Fe, Mn, Zn, and Pb. Although the correlation is considerably weaker, there are indications that Ca, Cu, Ni and possibly Co follow a similar trend. The results of the Cr analysis indicate the reverse trend, increasing toward the upstream stations.

Delfino, et al, (10) have determined several components in sediments from Lake Mendota. Strong positive correlations with depth were observed for Mn, Fe, and Pb, while negative correlations were reported for magnesium and potassium. A very slight positive and negative correlation was observed for Ca and Na respectively.

The extent of the downstream enrichment of the bottom muds in organic matter, phosphate and several heavy metals probably reflects the relatively old age of this reservoir. Although the process which causes this enrichment is not known, it seems reasonable to assume that the buildup of these components in the bottom muds is in some way related to: 1) the depth of the overlying water and 2) the downstream movement of water in the reservoir.

The fact that both iron and manganese are enriched in the muds from deeper downstream stations indicate that these metals have been moved from upstream locations into the deeper sections of the reservoir. Since iron and manganese are known to become mobile during periods of oxygen depletion, it is reasonable to assume that iron and manganese have been reduced and become mobilized in the upstream section of the reservoir are swept downstream by currents. It has been shown that during periods of relatively low flow through the reservoir (low release from Lake Ouachita) that oxygen deficient zones may develop near bottom in the main stream of the reservoir. Increases in iron and manganese have also been observed in these oxygen deficient zones. As flows through the reservoir increase, the mobilized iron and manganese would be swept downstream. When autumnal overturn occurs or when oxygen is introduced into the lower regions of the impoundment, these metals would precipitate and sediment causing a buildup in the lower extent of the reservoir.

The transfer of nutrient material, as well as heavy metals from shallow water to the deeper portions of reservoirs, may play an important part in the short term aging of an impoundment. This phenomena should be studied further to determine if such processes are of general occurrence.

The depletion of nutrients in the shallow water could be very important in the overall productivity of such bodies of water.

## G. Simulation of Stratified Reservoir Conditions

An experiment was conducted to determine if the reducing conditions present in the lower regions of a stratified impoundment could be simulated under laboratory conditions. Symons (39) has used a large tank to study some water quality parameters under stratified conditions.

Thermally stratified conditions were simulated by wrapping the lower 30 cm of a fifty gallon polyethylene tank with 1/4 inch copper tubing through which cold antifreeze was continuously pumped. The entire tank (total height 135 cm) was insulated with glass wool insulating material. When the tank was filled with water, thermal stratification developed within a matter of hours. The "thermocline" developed between a depth of 15 cm and 90 cm.

A 10 cm layer of mud which had been taken from Station 1 on Lake Hamilton was placed in the bottom of the tank and the remainder of the tank carefully filled with water. The water for this experiment was taken from the Ouachita River at Arkadelphia.

The dissolved oxygen content and iron and manganese concentrations at various depths in the tank were monitored for a period of thirty days. Samples were taken from the tank using a small glass tube and were analysed for iron and manganese by atomic absorption spectroscopy. The results of these analysis are shown in Figures 58, 59, and 60.

Dissolved oxygen depletion in the lower regions of the tank were observed within two days after the beginning of the experiment. Iron and manganese concentrations were observed to increase in the oxygen deficient zone after approximately one week. The pattern of oxygen depletion and increases of iron and manganese are very similar to the patterns observed at Station MC on Lake Hamilton during the summer of 1968 (See Figures 44, 45, and 46).

This technique may provide a method to evaluate reservoir water quality prior to construction of a reservoir. It may also be useful in providing "in lab" samples for the study of the rates of migration of heavy metals from bottom muds.

Since the concentration of many trace metals such as cobalt are extremely low in Lake Hamilton, it is difficult to determine the pattern of distribution of such metals. Benoit (5) has reviewed much of the work concerning cobalt in natural waters. He quotes a work Sugawara, et al, (38) which shows that the cobalt content of oxygenated surface waters is lower than the hypolimnic water from Lindsey Pond. Parker and Hasler (31) have investigated cobalt in lakes.

Since the natural background of cobalt was too low to determine a distribution pattern with any degree of accuracy, the polyethylene tank was charged with distilled water containing 0.50 ppm of cobalt. The bottom of the tank was covered with mud from Station 1 on Lake Hamilton. The temperature, dissolved oxygen, and cobalt concentrations were monitored for a period of 50 days. Cobalt was determined by direct atomic absorption spectroscopy. The results of this experiment are shown in Figure 61.

After one day, the distribution of cobalt in the tank showed essentially a straight line at 0.5 ppm. By 10 days the cobalt concentration had dropped to 0.3 ppm in the entire tank. After 40 days, surface cobalt had risen to around 0.4 ppm but the cobalt concentration in the lower, oxygen depleted zone decreased to around 0.1 ppm. The decrease in the cobalt concentration in the deeper waters coincided with the appearance of the odor of $H_2S$ in these samples. Suguwara, et al, (38) reported that cobalt was observed to decrease in the sulfide zone of Lindsey Pond. It is likely that the precipitation of cobalt sulfide and subsequent sedimentation caused the decrease in cobalt concentration in the deeper portion of the tank. However, absorption of cobalt onto particulate iron may also be an important factor.

This method may be useful in studying the distribution of trace metals under the reducing conditions produced in hypolimnic waters.

### H. Manganese in the Water Supply of Greers Ferry National Fish Hatchery, Arkansas +

Severe rainbow trout mortalities were observed during the late fall and early winter at the Greers Ferry National Hatchery since becoming operational in July of 1965. Heavy mortalities were reported during January, 1966; November, 1966; December, 1967; January, 1968; November and December, 1968; November and December, 1969; and January, 1970. The hatchery water supply is taken from the 331 feet elevation of Greers Ferry Reservoir (at normal pool elevation this is equivalent to a depth of 36 meters). Investigations by the U. S. Corps of Engineers (41) during the years 1966 and 1967 indicate that the heavy mortalities occurred during the latter period of stratification and ended rather abruptly with reservoir overturn.

Investigations were conducted during 1967 and early 1968 to determine which water quality parameters could be related to the trout mortalities. The report of this study,

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+A portion of this work was supported by the Bureau of Sport Fisheries and Wildlife and was coordinated by the South Central Reservoir Investigation, Bureau of Sport Fisheries and Wildlife, Fayetteville, Arkansas. Mr. Maurice Bryant and the personnel of the Greers Ferry Hatchery furnished samples for manganese analysis and were responsible for much of the temperature and dissolved oxygen data presented herein.

which was submitted earlier (30), indicated that the mortalities were related to increased levels of manganese in the hatchery water supply. Studies of Greers Ferry Reservoir showed that manganese was diffusing throughout the oxygen deficient zone which developed in the lower portion of the reservoir during the months of October, November, and December. The rate of mortality was observed to increase as the level of manganese laden water reached the hatchery intake level.

Additional studies were conducted during the fall and early winter of 1968 and 1969 to determine the extent of oxygen depletion and accumulation of manganese in Greers Ferry Reservoir. Temperature and dissolved oxygen profiles were taken at a station located immediately upstream from the dam at a point directly behind the hatchery intake. Samples were taken at various depths, acidified with hydrochloric acid and later analysed for manganese by direct atomic absorption spectroscopy. The results of these determinations are summarized in Figures 63 through 70.

Mortalities were observed to increase during the period from November 1, 1968, to November 15, 1968. Manganese in the hatchery water supply also increased during this same period. Figure 71 shows the relationship between mortality and manganese for this period. Although the manganese level remained high through December 20, the mortality rate decreased during the period December 1-20. It appears that after a period of exposure, some acclamation or resistance to the manganese developed.

Figures 63 and 64 show the temperature and dissolved oxygen profiles which were determined for the period August, 1967, through March, 1968. The development of the low oxygen zone begins to appear during September and persists until reservoir overturn in early January. Samples taken for manganese analysis for this period were not acidified so only a qualitative accumulation of manganese in the oxygen deficient zone was observed. Maximum manganese values observed in the hatchery during this period was 1.5 ppm.

Figures 65, 66, and 67 show the distribution of dissolved oxygen, manganese, and the temperature profiles observed during the period July 1968 through December 1968. The development of the manganese in the oxygen deficient zone is apparent from this data. Diffusion of manganese from the bottom muds begins as the dissolved oxygen level decreases to around 3 ppb but does not become significant until the oxygen level has decreased to less than 2 ppm. The manganese was observed to diffuse throughout the zone of the reservoir which showed a dissolved oxygen concentration of less than 1 ppm. Maximum values of manganese observed in the hatchery during this period were around 1.0 ppm.

Figures 68, 69, and 70 present the results of similar studies for the period October 1969 through January 1970. the dissolved oxygen profile indicates that oxygen depletion in the vicinity of the bottom mud occurred as early as mid October of 1969. This occurred slightly earlier than during the comparable period of 1968. Manganese reached maximum concentrations during the first half of November and was observed to decrease from 2.0 ppm to 1.0 ppm in the deeper water before overturn in early January. It is interesting to note that the depth of the 1.0 ppm manganese contour for 1969 was much deeper than that observed during 1968. The maximum manganese concentration observed in the hatchery during this period was 0.6 ppm.

The manganese data for the period October 1969 through January 1970 indicate that manganese was reduced and migrated from the bottom muds earlier than previous years, then reached some limiting value and decreased before overturn. It is very likely that the concentration of manganese was being limited by the solubility of its sulfide since sulfide would be expected to appear under prolonged oxygen depelted conditions.

There are indications that the maximum concentration of manganese observed in the hatchery waters is decreasing each year. Due to the complex nature of the processes which

## SECTION V - SUMMARY OF FINDINGS

1. The temperature and dissolved oxygen regime of both Lakes Hamilton and Catherine are greatly affected by the release of cold water from the upstream Lake Ouachita.
2. The cold density current present throughout the lower portion of these reservoirs during the stratified period prevents total oxygen depletion and thus prevents the accumulation of heavy metals.
3. The proper regulation of cold water from upstream impoundments could prevent troublesome downstream water quality problems.
4. In the absence of cold density currents, oxygen depletion does occur in the sidepockets of the reservoirs which were studied. Accumulations of soluble heavy metals were observed in these areas.
5. Runoff water entering the reservoir during the period of thermal stratification will interflow at the level which coincides with its own density. These density currents are a source of particulate iron and may contribute a large quantity of organic matter.

6. It is suggested that through temperature control of sewage effluents released into impoundments, the detrimental effects of added nutrients could be avoided by allowing the sewage strata to flow through the reservoir below the productive zone. In other cases where nutrients are needed, warming of the effluent could cause the material to be introduced directly into the productive zone.

+7. There is a very distinctive relationship between the composition of bottom muds and the depth of recovery of these bottom muds from Lake Hamilton. The samples from deeper stations are enriched in organic matter, phosphate, iron, manganese, copper, lead, magnesium. The depletion of such species from shallow sediments may play an important role in the short term aging of impoundments.

+8. The concentration of iron, manganese, copper, nickel, cobalt, lead, zinc and chromium have been established for Lakes Hamilton and Catherine and are summarized in Tables 29 and 30.

9. Relatively high levels of particulate iron remain distributed throughout the reservoirs throughout most of the year and is probably related to turbulent action in the deeper water and sedimentation from silt laden density currents.

10. Preliminary results indicate that it may be possible to place soil from a potential reservoir site into a tank, cover the soil with water, induce artificial thermal stratification, and observe the dissolved oxygen, iron and manganese concentrations as an indicator of potential reservoir water quality.

11. The increased use of reservoirs and their tail waters as water supplies for munincipalities and industries necessitates that a basic knowledge of the water quality changes taking place within the impoundment be known. This work has established the range for several common water quality parameters and eight trace metals in two reservoirs on the Ouachita River, Arkansas. Fluctuations of the trace metal concentrations indicate that the factors which govern their distribution are complex.

12. Very low concentrations for soluble iron were frequently observed in the oxygenated water of both reservoirs. The availability of soluble species of iron may, to some degree, limit productivityoof these waters.

13. From the work conducted at Greers Ferry National Fish Hatchery, there are strong indications that manganese brought into solution in the lower regions of Greers Ferry Reservoir during the late period of stratification may contribute to the mortality of rainbow trout. Additional work should be conducted to determine the toxic

effect of manganese on various species of fish. The existence of manganese in the water supply of trout hatcheries should be viewed as a possible cause for concern.

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TABLE 1

| | Catherine | Hamilton | Ouachita |
|---|---|---|---|
| Drainage area (sq. miles) | 1,516 | 1,441 | 1,105 |
| Age (as of 1969) | 44 yrs. | 38 yrs. | 17 yrs. |
| Surface Area (Acres) | 1,940 | 7,195 | 36,740 |
| Average Depth (M) | 5.9 | 8.5 | 16.7 |
| Volume (acre feet) | 35,250 | 190,120 | 2,151,000 |
| Reservoir Elevation (feet - msl) | 305 | 400 | 572 |
| Height of Dam (M) | 24.5 | 37.8 | 75.7 |
| Penstock Depth (M) | 9.5 | 26.5 | 26.2 |

Note: Elevations and depths are given for "normal pool" levels.

### Table 2
### Instrument Settings for Determination of Heavy Metals
### (Perkin Elmer Model 303)

| Element | Wavelength Setting (UV range) | Lamp Current (ma) | Slit | Meter Response | Scale | Aspiration Rate (ml per minute) | Fuel | Air |
|---|---|---|---|---|---|---|---|---|
| Fe | 248 | 30 | 3 | 3 | 5 | 5.4 | 5 | 9 |
| Mn | 279 | 20 | 4 | 2 | 2 | 5.4 | 5 | 9 |
| Cu | 325 | 40 | 4 | 2 | 2 | 5.4 | 5 | 9 |
| Co | 241 | 30 | 3 | 3 | 5 | 5.4 | 5 | 9 |
| Ni | 232 | 25 | 3 | 3 | 5 | 5.4 | 5 | 9 |
| Cr | 358 | 25 | 3 | 3 | 5 | 5.4 | 5 | 9 |
| Pb | 217 | 30 | 4 | 3 | 5 | 5.0 | 5 | 9 |
| Zn | 214 | 15 | 5 | 3 | 5 | 4.0 | 5 | 9 |

Table 3

Contribution (ppb) caused by 1.0 ppm of Fe and 1.0 ppm of Mn

| | Metal Being Determined | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Fe | Mn | Cu | Co | Ni | Pb | Cr | Zn |
| 1.0 ppm Fe | | 9.0 | 0.6 | 0.0 | 0.0 | 4.6 | 0.0 | 0.0 |
| 1.0 ppm Mn | 1.2 | | 0.8 | 0.4 | 0.6 | 0.0 | 0.0 | 9.2 |

Table 4
Concentration of Metal Found in a Solution
Containing 50 ppb of Each of the Metals

| Determination Number | Mn | Cu | Zn | Fe | Pb | Co | Ni | Cr |
|---|---|---|---|---|---|---|---|---|
| | Concentration Found (ppb) | | | | | | | |
| 1 | 52 | 46 | 48 | 48 | 44 | 46 | 51 | 47 |
| 2 | 52 | 48 | 44 | 47 | | 52 | 48 | 47 |
| 3 | 52 | 46 | 44 | 47 | | 53 | 53 | 50 |
| 4 | 49 | 48 | 44 | 46 | | 51 | 48 | 50 |
| 5 | 47 | 44 | 48 | 45 | 42 | 51 | 52 | 46 |
| 6 | 48 | 50 | 49 | 50 | 46 | 50 | 50 | 49 |
| 7 | 53 | 46 | 46 | 46 | 45 | 50 | 50 | 49 |
| 8 | 52 | 47 | 47 | 45 | 44 | 50 | 51 | 52 |
| 9 | 58 | 46 | 46 | 45 | 56 | 50 | 47 | 50 |
| 10 | 52 | 47 | 47 | 47 | 52 | 49 | 47 | 49 |
| Mean Value | 51 | 47 | 46 | 47 | 47 | 50 | 50 | 49 |

Hamilton
4/28/68

## Table 5

| Depth (M) | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 7.5 | 3.6 | 1.3 | 6.2 | 1.5 | - | 2.5 | 0.16 | 7.4 | 2.6 | 1.0 | 5.6 | 1.5 | - | 0.8 | - | 7.3 | 5.5 | 1.0 | 6.0 | 1.5 | - | 0.9 | 0.11 |
| 5 | 7.2 | 3.5 | 1.1 | 6.2 | 1.5 | - | 1.8 | 0.08 | 7.4 | 3.1 | 1.1 | 6.3 | 1.6 | - | 1.6 | 0.11 | 7.2 | 2.3 | 0.9 | 5.7 | 1.7 | - | 0.8 | 0.12 |
| 10 | 7.0 | 2.7 | 1.0 | 7.0 | 1.6 | - | 1.2 | 0.12 | 7.1 | 2.5 | 1.0 | 7.0 | 1.7 | - | 1.0 | 0.15 | 7.1 | 2.5 | 0.9 | 7.4 | 1.7 | - | 1.7 | 0.11 |
| 15 | 7.0 | 2.5 | 1.0 | 7.5 | 1.7 | - | 1.9 | 0.57 | 7.2 | 2.6 | 0.9 | 7.5 | 1.5 | - | 2.7 | 1.02 | | | | | | | | |
| 20 | 7.0 | 2.3 | 0.9 | 7.0 | 1.7 | - | 1.7 | 0.12 | 7.2 | 2.6 | 0.9 | 7.2 | 1.7 | - | 1.1 | 0.34 | | | | | | | | |
| 25 | 7.0 | 2.7 | 0.3 | 7.0 | 1.7 | - | 2.8 | 0.12 | | | | | | | | | | | | | | | | |
| 30 | 7.0 | 2.3 | 1.0 | 7.4 | 2.0 | - | 2.7 | 0.59 | | | | | | | | | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 6 | 1 | 6 | 22 | 0 | 0 | 0 | 0 | 5 | 1 | 10 | 17 | 0 | 0 | 3 | 1 | 5 | 0 | 6 | 12 | 0 |
| 5 | 0 | 4 | 0 | 6 | 2 | 18 | 16 | 0 | 1 | 4 | 3 | 5 | 1 | 10 | 10 | 0 | 0 | 4 | 2 | 6 | 1 | 11 | 28 | 0 |
| 10 | 0 | 6 | 0 | 5 | 2 | 0 | 14 | 0 | 1 | 7 | 2 | 8 | 1 | 18 | 17 | 0 | 0 | 2 | 2 | 5 | 1 | 10 | 62 | 0 |
| 15 | 2 | 8 | 0 | 6 | 1 | 2 | 23 | 0 | 0 | 8 | 0 | 6 | 1 | 0 | 27 | 0 | | | | | | | | |
| 20 | 1 | 12 | 0 | 4 | 1 | 13 | 16 | 0 | 1 | 6 | 1 | 5 | 0 | 12 | 20 | 0 | | | | | | | | |
| 25 | 2 | - | 0 | 5 | 0 | 2 | 14 | 0 | | | | | | | | | | | | | | | | |
| 30 | 1 | 7 | 0 | 7 | 0 | 1 | 19 | 0 | | | | | | | | | | | | | | | | |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 67 | 26 | 0 | 1 | 0 | 0 | 0 | 0 | 115 | 27 | 2 | 9 | 4 | 0 | 0 | 0 | 123 | 36 | 0 | 3 | 3 | 5 | 0 | 0 |
| 5 | 68 | 21 | 1 | 4 | 0 | 0 | 0 | 0 | 156 | 52 | 2 | 10 | 2 | 0 | 0 | 0 | 123 | 31 | 1 | 0 | 2 | 3 | 0 | 0 |
| 10 | 132 | 26 | 7 | 10 | 0 | 8 | 0 | 0 | 69 | 42 | 2 | 9 | 1 | 0 | 0 | 0 | 96 | 47 | 3 | 6 | 2 | 11 | 2 | 0 |
| 15 | 135 | 38 | 8 | 3 | 0 | 1 | 0 | 0 | 140 | 32 | 3 | 8 | 2 | 0 | 0 | 0 | | | | | | | | |
| 20 | 112 | 34 | 6 | 3 | 0 | 0 | 0 | 0 | 103 | 76 | 12 | 11 | 4 | 0 | 0 | 0 | | | | | | | | |
| 25 | 185 | 29 | 9 | 1 | 4 | 4 | 0 | 0 | | | | | | | | | | | | | | | | |
| 30 | 114 | 48 | 12 | 5 | 3 | 0 | 0 | 0 | | | | | | | | | | | | | | | | |

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## Table 6

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 7.1 | 2.6 | 1.4 | 5.3 | 1.6 | 3.5 | 0.5 | 0.15 | | | | | | | | | 7.1 | 2.0 | 1.1 | 5.2 | 1.5 | 2.0 | 0.2 | 0.17 |
| 5 | 7.0 | 2.6 | 1.5 | 5.2 | 1.7 | 3.5 | 0.5 | 0.15 | | | | | | | | | 6.9 | 1.8 | 1.0 | 5.7 | 1.0 | 1.5 | 1.0 | 0.16 |
| 10 | 6.7 | 1.7 | 1.0 | 6.4 | 1.9 | 1.5 | 0.9 | 0.15 | | | | | | | | | 6.9 | 1.6 | 0.9 | 6.2 | 2.1 | 1.5 | 0.7 | 0.15 |
| 15 | 6.8 | 1.7 | 0.9 | 6.9 | 2.1 | 1.5 | 0.9 | 0.15 | | | | | | | | | | | | | | | | |
| 20 | - | - | - | - | - | - | - | - | | | | | | | | | | | | | | | | |
| 25 | 6.8 | 1.7 | 0.9 | 6.4 | 2.1 | 2.0 | 1.3 | 0.15 | | | | | | | | | | | | | | | | |
| 30 | - | - | - | - | - | - | - | - | | | | | | | | | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 14 | 5 | 10 | 0 | 1 | 4 | - | 0 | | | | | | | | | 10 | 7 | 8 | 2 | 2 | 2 | - | 0 |
| 5 | 10 | 3 | 17 | 0 | 2 | 1 | - | 0 | | | | | | | | | 17 | 8 | 18 | 3 | 3 | 2 | - | 0 |
| 10 | 21 | 9 | 14 | 2 | 1 | 3 | - | 0 | | | | | | | | | 16 | 14 | 16 | 0 | 3 | 4 | - | 0 |
| 15 | 19 | 19 | 17 | 1 | 2 | 2 | - | 0 | | | | | | | | | | | | | | | | |
| 20 | - | - | - | - | - | - | - | - | | | | | | | | | | | | | | | | |
| 25 | 22 | 34 | 10 | 1 | 1 | 5 | - | 0 | | | | | | | | | | | | | | | | |
| 30 | - | - | - | - | - | - | - | - | | | | | | | | | | | | | | | | |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 82 | 9 | 32 | 3 | 2 | 32 | - | 0 | | | | | | | | | 89 | 20 | 12 | 0 | 2 | 13 | - | 0 |
| 5 | 70 | 17 | 13 | 0 | 2 | 14 | - | 0 | | | | | | | | | 104 | 24 | 10 | 0 | 2 | 14 | - | 0 |
| 10 | 67 | 19 | 12 | 0 | 2 | 12 | - | 0 | | | | | | | | | 124 | 13 | 12 | 0 | 1 | 15 | - | 0 |
| 15 | 267 | 20 | 17 | 0 | 2 | 15 | - | 0 | | | | | | | | | | | | | | | | |
| 20 | - | - | - | - | - | - | - | - | | | | | | | | | | | | | | | | |
| 25 | 123 | 22 | 15 | 0 | 1 | 15 | - | 0 | | | | | | | | | | | | | | | | |
| 30 | - | - | - | - | - | - | - | - | | | | | | | | | | | | | | | | |

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## Table 7

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 8.1 | 8.9 | 1.6 | 6.0 | 1.5 | 4.0 | 7.9 | 0.13 | 8.0 | 2.5 | 1.3 | 5.2 | 1.5 | 3.5 | 0.4 | 0.13 | 7.8 | 2.2 | 1.3 | 5.9 | 1.5 | 2.8 | 0.3 | 0.12 |
| 5 | - | - | - | - | - | - | - | - | 6.8 | 1.9 | 1.1 | 6.8 | 1.7 | 2.0 | 0.6 | 0.14 | 6.8 | 1.8 | 1.1 | 6.3 | 1.8 | 1.8 | 0.6 | 0.14 |
| 10 | 7.4 | 2.9 | 1.7 | 4.8 | 1.5 | 4.0 | 0.4 | 0.13 | 6.8 | 1.8 | 1.0 | 7.2 | 1.8 | 1.8 | 0.9 | 0.18 | 6.7 | 1.7 | 1.1 | 8.0 | 1.8 | 2.0 | 1.5 | 0.15 |
| 15 | 6.7 | 1.8 | 1.1 | 6.9 | 1.7 | 2.0 | 0.9 | 0.14 | | | | | | | | | | | | | | | | |
| 20 | 6.7 | 1.8 | 1.0 | 6.9 | 1.9 | 1.8 | 1.0 | 0.17 | | | | | | | | | | | | | | | | |
| 25 | 6.8 | 1.9 | 1.1 | 7.4 | 1.9 | 1.8 | 1.1 | 0.14 | | | | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | | | | | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 14 | 5 | 15 | 1 | 4 | 4 | - | 0 | 0 | 8 | 8 | 0 | 4 | 2 | - | 0 | 0 | 5 | 10 | 0 | 2 | 6 | - | 0 |
| 5 | - | - | - | - | - | - | - | - | 2 | 5 | 14 | 0 | 3 | 4 | - | 0 | 7 | 9 | 14 | 0 | 3 | 10 | - | 0 |
| 10 | 1 | 3 | 12 | 0 | 2 | 8 | - | 0 | 3 | 15 | 13 | 0 | 4 | 5 | - | 0 | 2 | 12 | 11 | 0 | 4 | 0 | - | 0 |
| 15 | 9 | 10 | 15 | 0 | 3 | 0 | - | 0 | 11 | 107 | 13 | 0 | 4 | 6 | - | 0 | | | | | | | | |
| 20 | 7 | 50 | 18 | 0 | 4 | 0 | - | 0 | | | | | | | | | | | | | | | | |
| 25 | 35 | 225 | 17 | 1 | 5 | 4 | - | 0 | | | | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | | | | | | | | | | | | |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 2 | 4 | 4 | 0 | 2 | 1 | - | 0 | 14 | 7 | 5 | 0 | 2 | 1 | - | 0 | 72 | 16 | 5 | 0 | 2 | 3 | - | 0 |
| 5 | - | - | - | - | - | - | - | - | 102 | 37 | 7 | 0 | 4 | 4 | - | 0 | 65 | 19 | 5 | 0 | 2 | 1 | - | 0 |
| 10 | 13 | 6 | 6 | 0 | 2 | 0 | - | 0 | 62 | 22 | 5 | 0 | 2 | 0 | - | 0 | 95 | 12 | 5 | 0 | 2 | 27 | - | 0 |
| 15 | 47 | 13 | 5 | 0 | 4 | 3 | - | 0 | 103 | 20 | 5 | 0 | 2 | 4 | - | 0 | | | | | | | | |
| 20 | 107 | 30 | 4 | 0 | 2 | 2 | - | 0 | | | | | | | | | | | | | | | | |
| 25 | 157 | 38 | 6 | 0 | 4 | 14 | - | 0 | | | | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | | | | | | | | | | | | |

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## Table 8

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 8.1 | 3.5 | 2.2 | 5.1 | 1.3 | 4.5 | 1.3 | 0.15 | 7.3 | 2.7 | 1.6 | 4.9 | 1.3 | 3.2 | 1.2 | 0.30 | 7.3 | 2.7 | 1.7 | 4.9 | 1.4 | 3.3 | 1.7 | 0.21 |
| 5 | 6.7 | 3.2 | 2.0 | 4.9 | 1.4 | 2.8 | 1.3 | 0.50 | 6.8 | 2.2 | 1.2 | 5.6 | 1.5 | 2.0 | 1.2 | 0.16 | 6.9 | 2.2 | 1.5 | 5.4 | 1.4 | 2.5 | 1.4 | 0.16 |
| 10 | 6.7 | 2.6 | 1.6 | 6.0 | 1.5 | 1.8 | 1.7 | 0.18 | 6.7 | 1.9 | 1.3 | 5.6 | 1.4 | 4.3 | 2.6 | 0.25 | 6.7 | 1.9 | 1.3 | 5.7 | 1.5 | 1.8 | 2.0 | 0.18 |
| 15 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 6.7 | 2.6 | 1.6 | 6.2 | 1.5 | 2.0 | 1.8 | 0.19 | 6.7 | 1.8 | 1.2 | 5.8 | 1.4 | 2.0 | 1.7 | 0.24 | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | 6.7 | 2.2 | 1.4 | 5.9 | 1.5 | 2.0 | 1.8 | 0.17 | | | | | | | | | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 5 | 2 | 8 | 7 | 2 | 5 | 0 | 2 | 12 | 10 | 13 | 6 | 8 | 21 | 1 | 2 | 6 | 4 | 9 | 3 | 5 | 8 | 0 | 0 |
| 5 | 24 | 6 | 13 | 0 | 3 | 15 | 10 | 1 | 11 | 12 | 10 | 3 | 4 | 8 | 1 | 2 | 26 | 13 | 20 | 9 | 4 | 12 | 1 | 1 |
| 10 | 18 | 13 | 12 | 3 | - | 10 | 4 | 1 | 16 | 32 | 12 | 4 | 4 | 5 | 1 | 3 | 16 | 30 | 11 | 1 | 1 | 0 | 1 | 1 |
| 15 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 30 | 53 | 12 | 6 | 5 | 8 | 3 | 2 | 26 | 87 | 12 | 4 | 8 | 12 | 0 | 2 | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | 52 | 166 | 8 | 2 | 5 | 7 | 13 | 3 | | | | | | | | | | | | | | | | |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 25 | 12 | 4 | 114 | 0 | 13 | 3 | 1 | 34 | 25 | 6 | 25 | 0 | 25 | 7 | 6 | - | - | - | - | - | - | - | - |
| 5 | 34 | 18 | 5 | 51 | 0 | 5 | 14 | 4 | 45 | 29 | 10 | 36 | 0 | 17 | 15 | 4 | 103 | 36 | 4 | 20 | 0 | 17 | 2 | 6 |
| 10 | 97 | 31 | 4 | 104 | 0 | 8 | 1 | 5 | 90 | 35 | 7 | 56 | 0 | 14 | 7 | 5 | 106 | 16 | 10 | 13 | 0 | 14 | 3 | 6 |
| 15 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 132 | 45 | 6 | 56 | 0 | 7 | 2 | 5 | 230 | 82 | 10 | 21 | 0 | 16 | 29 | 6 | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | 192 | 34 | 6 | 86 | 1 | 10 | 5 | 4 | | | | | | | | | | | | | | | | |

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## Table 9

| Depth (M) | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 8.3 | 3.5 | 2.1 | 4.9 | 1.7 | 4.8 | 0.6 | 0.09 | 7.3 | 2.4 | 1.4 | 4.4 | 1.6 | 2.8 | 0.6 | 0.16 | | | | | | | | |
| 5 | 6.5 | 1.7 | 1.3 | 5.7 | 1.7 | 3.0 | 0.5 | 0.08 | 7.1 | 2.3 | 1.3 | 6.1 | 1.7 | 2.8 | 1.4 | 0.06 | | | | | | | | |
| 10 | 6.5 | 1.9 | 2.0 | 4.9 | 1.8 | 1.8 | 1.3 | 0.12 | 6.7 | 1.8 | 1.0 | 6.0 | 1.8 | 2.2 | 1.1 | 0.06 | | | | | | | | |
| 15 | 6.6 | 1.8 | 1.0 | 6.1 | 1.9 | 2.0 | 1.0 | 0.04 | 6.5 | 1.8 | 0.9 | 7.1 | 1.8 | 2.2 | 1.3 | 0.08 | | | | | | | | |
| 20 | 6.5 | 1.7 | 1.0 | 5.0 | 1.8 | 1.6 | 1.2 | 0.08 | 6.7 | 1.7 | 1.0 | 4.9 | 1.8 | 1.6 | 1.1 | 0.06 | | | | | | | | |
| 25 | 6.6 | 1.7 | 0.9 | 5.0 | 1.8 | 1.8 | 1.2 | 0.08 | | | | | | | | | | | | | | | | |
| 30 | 6.5 | 1.8 | 0.8 | 4.9 | 1.9 | 1.6 | 1.1 | 0.13 | | | | | | | | | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 9 | 6 | 1 | 0 | 2 | 2 | 5 | 0 | 0 | 4 | 0 | 1 | 0 | 13 | 6 | 0 | | | | | | | | |
| 5 | 0 | 5 | 0 | 0 | 0 | 0 | 4 | 0 | 3 | 9 | 2 | 0 | 2 | 16 | 2 | 1 | | | | | | | | |
| 10 | 5 | 8 | 1 | 0 | 4 | 10 | 2 | 0 | 9 | 25 | 0 | 0 | 2 | 3 | 3 | 1 | | | | | | | | |
| 15 | 13 | 15 | 3 | 2 | 1 | 4 | 3 | 0 | 7 | 109 | 2 | 0 | 1 | 3 | 0 | 1 | | | | | | | | |
| 20 | 17 | 62 | 2 | 0 | 0 | 1 | 3 | 0 | 21 | 214 | 1 | 0 | 2 | 0 | 3 | 0 | | | | | | | | |
| 25 | 19 | 82 | 1 | 0 | 0 | 4 | 5 | 0 | 118 | 479 | 2 | 0 | 2 | 2 | 7 | 0 | | | | | | | | |
| 30 | 95 | 34 | 4 | 0 | 0 | 16 | 4 | 0 | | | | | | | | | | | | | | | | |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16 | 8 | 12 | 5 | 0 | 7 | - | 4 | 9 | 10 | 9 | 6 | 0 | 0 | - | 3 | | | | | | | | |
| 5 | 40 | 20 | 7 | 5 | 0 | 0 | - | 5 | 61 | 38 | 12 | 2 | 0 | 0 | - | 3 | | | | | | | | |
| 10 | 49 | 6 | 6 | 3 | 0 | 1 | - | 4 | 72 | 62 | 8 | 1 | 0 | 5 | - | 2 | | | | | | | | |
| 15 | 73 | 50 | 3 | 3 | 0 | 0 | - | 4 | 129 | 58 | 4 | 5 | 0 | 2 | - | 1 | | | | | | | | |
| 20 | 162 | 60 | 26 | 7 | 0 | 1 | - | 5 | 182 | 57 | 6 | 2 | 0 | 0 | - | 3 | | | | | | | | |
| 25 | 116 | 60 | 10 | 6 | 0 | 10 | - | 5 | 118 | - | - | - | - | - | - | - | | | | | | | | |
| 30 | 230 | 42 | 16 | 5 | 0 | 7 | - | 6 | | | | | | | | | | | | | | | | |

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## Table 10

### Station No. 1

| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|
| 0 | - | 2.6 | 1.9 | 7.0 | 1.4 | - | 1.1 | 0.19 |
| 5 | - | 2.0 | 1.4 | 6.9 | 1.3 | - | 0.4 | 0.15 |
| 10 | - | 1.4 | 1.0 | 7.2 | 1.4 | - | 1.1 | 0.18 |
| 15 | - | - | - | - | - | - | - | 0.19 |
| 20 | - | 1.5 | 1.1 | 7.0 | 1.4 | - | 1.5 | 0.24 |
| 25 | - | 1.4 | 0.9 | 6.8 | 1.4 | - | 1.4 | 0.16 |
| 30 | | | | | | | | |

### Station No. 3

| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|
| 0 | - | 2.6 | 1.4 | 6.9 | 1.5 | - | 0.5 | 0.09 |
| 5 | - | 1.8 | 1.3 | 6.4 | 1.4 | - | 1.3 | 0.07 |
| 10 | - | 1.5 | 0.9 | 6.8 | 1.3 | - | 1.5 | 0.11 |
| 15 | - | 2.2 | 1.2 | 6.7 | 1.5 | - | 3.4 | 0.21 |
| 20 | - | 1.3 | 1.0 | 6.8 | 1.4 | - | 1.7 | - |

### Station No. 5

| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|
| 0 | - | 2.0 | 1.4 | 6.5 | 1.3 | - | 0.6 | 0.12 |
| 5 | - | 1.7 | 1.1 | 6.8 | 1.4 | - | 1.9 | 0.18 |
| 10 | - | 1.4 | 0.8 | 7.1 | 1.3 | - | 1.8 | 0.16 |
| 15 | - | | | | | | | |

### Filtered

Station No. 1

| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 15 | 2 | 6 | 0 | 2 | 10 | 134 | - |
| 5 | 9 | 9 | 14 | 0 | 1 | 18 | 173 | - |
| 10 | 66 | 74 | 11 | 0 | 3 | 17 | 143 | - |
| 15 | | | | | | | | |
| 20 | 14 | 46 | 8 | 0 | 1 | 11 | 102 | - |
| 25 | 49 | 123 | 9 | 0 | 3 | 23 | - | - |
| 30 | | | | | | | | |

Station No. 3

| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 15 | 6 | 3 | 0 | 2 | 5 | 29 | - |
| 5 | 4 | 6 | 8 | 0 | 2 | 8 | 45 | - |
| 10 | 28 | 16 | 12 | 0 | 2 | 6 | 79 | - |
| 15 | 29 | 34 | 18 | 0 | 3 | 5 | - | - |
| 20 | 21 | 28 | 10 | 0 | 2 | 9 | 100 | - |

Station No. 5

| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 4 | 5 | 0 | 0 | 4 | 173 | - |
| 5 | 8 | 10 | 14 | 0 | 1 | 9 | 19 | - |
| 10 | 32 | 38 | 17 | 0 | 3 | 11 | 14 | - |

### Particulate

Station No. 1

| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 31 | 8 | 7 | 0 | 2 | 23 | 4 | - |
| 5 | 95 | 5 | 49 | 0 | 1 | 14 | 21 | - |
| 10 | 46 | 33 | 82 | 0 | 2 | 23 | 34 | - |
| 15 | | | | | | | | |
| 20 | 107 | 45 | 24 | 0 | 3 | 6 | 7 | - |
| 25 | 116 | 33 | 15 | 0 | 3 | 10 | 8 | - |
| 30 | | | | | | | | |

Station No. 3

| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 31 | 8 | 7 | 1 | 4 | 7 | 13 | - |
| 5 | 44 | 16 | 16 | 0 | 3 | 6 | 14 | - |
| 10 | 57 | 36 | 17 | 0 | 4 | 9 | 11 | - |
| 15 | 94 | 34 | 33 | 0 | 3 | 5 | 13 | - |
| 20 | 107 | 27 | 13 | 0 | 3 | 8 | 9 | - |

Station No. 5

| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 36 | 12 | 10 | 0 | 2 | 7 | 9 | - |
| 5 | 74 | 23 | 25 | 5 | 1 | 6 | 14 | - |
| 10 | 53 | 28 | 14 | 0 | 4 | 9 | 14 | - |

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## Table 11

| Depth (M) | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | - | 2.9 | 1.5 | - | 1.6 | 4 | 0.2 | 0.38 | - | 2.4 | 1.3 | - | 1.6 | 3 | 0.4 | 0.46 | - | 2.3 | 1.2 | - | 1.6 | 2 | 0.4 | 0.29 |
| 5 | - | 2.4 | 1.3 | - | 1.6 | 3 | 0.0 | 0.28 | - | 2.4 | 1.2 | - | 1.5 | 2 | 0.0 | 0.28 | - | 1.7 | 1.0 | - | 1.6 | 2 | 0.2 | 0.22 |
| 10 | - | 2.0 | 1.2 | - | 1.3 | 2 | 0.0 | 0.22 | - | 2.3 | 1.2 | - | 1.6 | 3 | 0.4 | 0.19 | - | 1.6 | 0.8 | - | 1.6 | 2 | 0.2 | 0.24 |
| 15 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | - | 2.3 | 1.0 | - | 1.6 | 2 | 0.5 | 0.28 | - | 1.6 | 1.0 | - | 1.6 | 2 | 0.7 | 0.35 | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | - | 1.9 | 1.1 | - | 1.6 | 3 | 0.6 | 0.26 | | | | | | | | | | | | | | | | |

### Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 9 | 2 | 2 | 0 | 3 | 1 | - | 3 | 5 | 1 | 10 | 1 | 5 | 4 | - | 4 | 41 | 11 | 5 | 1 | 4 | 11 | - | 2 |
| 5 | 22 | 3 | 7 | 1 | 5 | 8 | - | - | 3 | 1 | 3 | 0 | 4 | 0 | - | 2 | 24 | 1 | 7 | 0 | 4 | 0 | - | 4 |
| 10 | 15 | 10 | 5 | 0 | 5 | 0 | - | 1 | 17 | 2 | 8 | 0 | 4 | 3 | - | 0 | | | | | | | | |
| 15 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 29 | 27 | 6 | 0 | 2 | 2 | - | 2 | | | | | | | | | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | 22 | 36 | 9 | 0 | 4 | 0 | - | 0 | | | | | | | | | | | | | | | | |

### Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 23 | 10 | 4 | 2 | 1 | 21 | - | 3 | 21 | 11 | 6 | 2 | 3 | 22 | - | 4 | 27 | 15 | 5 | 2 | 0 | 0 | - | 3 |
| 5 | 43 | 25 | 8 | 3 | 1 | 11 | - | - | 31 | 13 | 7 | 4 | 0 | 12 | - | 4 | 44 | 39 | 8 | 0 | 2 | 10 | - | 2 |
| 10 | 65 | 40 | 4 | 2 | 1 | 16 | - | 2 | 68 | 50 | 7 | 2 | 2 | 15 | - | 3 | 85 | 28 | 4 | 2 | 1 | 9 | - | 0 |
| 15 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 59 | 39 | 5 | 0 | 1 | 9 | - | 4 | 84 | 36 | 9 | 5 | 1 | 17 | - | 3 | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | 126 | 42 | 4 | 2 | 1 | 10 | - | 3 | | | | | | | | | | | | | | | | |

Hamilton
11/23/68

## Table 12

|  | Station No. 1 |  |  |  |  |  |  |  | Station No. 3 |  |  |  |  |  |  |  | Station No. 5 |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 6.8 | 2.4 | 1.3 | 6.5 | 1.6 | 4 | 0.5 | - | 6.8 | 2.2 | 1.2 | 6.2 | 1.7 | 2 | 0.9 | - | 6.8 | 1.6 | 0.9 | 6.7 | 1.7 | 2 | 0.0 | - |
| 5 | 6.7 | 2.6 | 1.6 | 6.0 | 1.6 | 2 | 0.5 | - | 6.8 | 2.2 | 1.2 | 6,0 | 1.6 | 2 | 0.1 | - | 6.7 | 1.7 | 0.9 | 7.1 | 1.6 | 2 | 0.4 | - |
| 10 | 6.6 | 2.7 | 1.5 | 6.6 | 1.6 | 4 | 0.2 | - | 6.7 | 2.2 | 1.2 | 6.0 | 1.7 | 3 | 0.1 | - | 6.6 | 1.9 | 1.1 | 7.2 | 1.8 | 3 | 1.4 | - |
| 15 | 6.6 | 3.0 | 1.5 | 6.2 | 1.6 | 4 | 0.7 | - | 6.7 | 1.9 | 1.0 | 6.5 | 1.6 | 3 | 0.1 | - |  |  |  |  |  |  |  |  |
| 20 | 6.7 | 3.8 | 1.5 | 6.2 | 1.6 | - | 0.2 | - | 6.6 | 1.9 | 1.0 | 6.2 | 1.6 | 3 | 0.6 | - |  |  |  |  |  |  |  |  |
| 25 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 30 | 6.6 | 2.7 | 1.5 | 7.4 | 1.6 | 4 | 0.8 | - |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Filtered

|  | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 10 | 7 | 11 | 7 | 4 | - | - | 0 | 11 | 5 | 13 | 6 | 5 | - | - | 0 | - | 6 | 11 | 5 | 0 | - | - | 0 |
| 5 | 8 | 5 | 12 | 2 | 6 | - | - | 0 | 8 | 4 | 7 | 0 | 5 | - | - | 1 | - | 9 | 9 | 3 | 7 | - | - | 4 |
| 10 | 16 | 6 | 10 | 3 | 6 | - | - | 2 | 10 | 3 | 6 | 3 | 6 | - | - | 3 | - | 57 | 14 | 1 | 7 | - | - | 2 |
| 15 | 10 | 4 | 12 | 5 | 5 | - | - | 1 | 15 | 4 | 12 | 10 | 2 | - | - | 4 | - |  |  |  |  |  |  |  |
| 20 | 13 | 5 | 12 | 2 | 6 | - | - | 4 | 15 | 14 | 9 | 5 | 5 | - | - | 9 |  |  |  |  |  |  |  |  |
| 25 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 30 | 10 | 12 | 11 | 9 | 5 | - | - | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Particulate

|  | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 19 | 9 | 5 | 0 | 1 | - | - | 2 | 17 | 9 | 3 | 0 | 1 | - | - | 1 | - | 12 | 3 | 1 | 1 | - | - | 2 |
| 5 | 16 | 8 | 5 | 1 | 0 | - | - | 2 | 19 | 10 | 3 | 1 | 1 | - | - | 1 | - | 14 | 4 | 1 | 1 | - | - | 4 |
| 10 | 23 | 10 | 4 | 0 | 0 | - | - | 1 | 28 | 11 | 2 | 0 | 0 | - | - | 0 | - | 50 | 3 | 1 | 1 | - | - | 0 |
| 15 | 30 | 11 | 3 | 1 | 2 | - | - | 1 | 40 | 15 | 1 | 0 | 1 | - | - | 0 | - |  |  |  |  |  |  |  |
| 20 | 31 | 13 | 4 | 1 | 1 | - | - | 1 | 77 | 21 | 2 | 1 | 0 | - | - | 2 |  |  |  |  |  |  |  |  |
| 25 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 30 | 75 | 19 | 4 | 0 | 1 | - | - | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Hamilton
1/11/69

## Table 13

| Depth (M) | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 7.0 | 1.8 | 1.1 | 6.6 | 1.7 | 2 | 0.9 | 0.06 | 6.9 | 1.6 | 0.9 | 6.5 | 1.8 | 1 | 0.7 | 0.05 | 6.9 | 1.6 | 0.9 | 6.5 | 1.8 | 1 | 1.9 | 0.07 |
| 5 | 6.9 | 1.8 | 1.0 | 6.0 | 1.7 | 3 | 0.9 | 0.07 | 6.9 | 1.6 | 0.9 | 6.4 | 1.7 | 3 | 0.8 | 0.07 | 6.9 | 1.7 | 0.9 | 6.7 | 1.8 | 2 | 1.1 | 0.09 |
| 10 | 6.9 | 1.7 | 0.9 | 5.7 | 1.7 | 2 | 0.8 | 0.08 | 6.9 | 1.6 | 0.9 | 6.4 | 1.8 | 1 | 0.7 | 0.07 | 6.9 | 1.6 | 0.8 | 6.7 | 1.8 | 1 | 0.9 | 0.08 |
| 15 | 6.9 | 1.8 | 0.9 | 5.9 | 1.7 | 1 | 0.8 | 0.06 | 6.9 | 1.7 | 0.9 | 6.6 | 1.8 | 2 | 0.8 | 0.07 | | | | | | | | |
| 20 | 6.9 | 1.8 | 1.0 | 6.1 | 1.7 | 3 | 0.8 | 0.06 | | | | | | | | | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | | | | | | | | | | | | |

Filtered

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
| 0 | 10 | 1 | 3 | 5 | 4 | 10 | - | - | 15 | 4 | 6 | 5 | 3 | 4 | - | - | 0 | 3 | 3 | 7 | 3 | 26 | - | - |
| 5 | 10 | 3 | 3 | 6 | 1 | 21 | - | - | 5 | 1 | 2 | 7 | 4 | 2 | - | - | 21 | 7 | 21 | 5 | 4 | 20 | - | - |
| 10 | 7 | 2 | 2 | 6 | 4 | 2 | - | - | 5 | 6 | 2 | 5 | 2 | 4 | - | - | 3 | 4 | 0 | 5 | 3 | 7 | - | - |
| 15 | 7 | 2 | 2 | 6 | 3 | 0 | - | - | 18 | 2 | 1 | 4 | 2 | 0 | - | - | | | | | | | | |
| 20 | 14 | 1 | 0 | 6 | 4 | 23 | - | - | 7 | 3 | 0 | 4 | 4 | 0 | - | - | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | | | | | | | | | | | | |

Particulate

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
| 0 | 70 | 36 | 5 | - | 0 | 0 | 2 | 3 | 86 | 18 | 4 | - | 0 | 0 | 5 | 0 | 75 | 54 | 6 | - | 0 | 0 | 5 | 0 |
| 5 | 280 | 22 | 6 | - | 0 | 0 | 9 | 0 | 116 | 25 | 5 | - | 0 | 0 | 27 | 2 | 246 | 22 | 3 | - | 0 | 0 | 5 | 2 |
| 10 | 47 | 28 | 3 | - | 0 | 0 | 9 | 0 | 78 | 40 | 5 | - | 0 | 0 | 9 | 2 | 120 | 26 | 5 | - | 0 | 0 | 9 | 2 |
| 15 | 74 | 58 | 11 | - | 0 | 0 | 3 | 1 | 293 | 24 | 6 | - | 0 | 0 | 3 | 0 | | | | | | | | |
| 20 | 141 | 26 | 6 | - | 0 | 0 | 17 | 1 | 137 | 38 | 8 | - | 0 | 0 | 13 | 0 | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | | | | | | | | | | | | |

Hamilton
3/15/69

## Table 14

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 6.7 | 1.8 | 1.0 | | 1.8 | | | | 6.9 | 1.7 | 0.7 | | 1.8 | | | | | | | | | | | |
| 5 | 6.7 | 1.9 | 0.9 | | 1.8 | | | | 6.8 | 1.6 | 1.0 | | 1.8 | | | | | | | | | | | |
| 10 | 6.7 | 1.9 | - | | 1.7 | | | | 6.8 | 1.7 | 0.8 | | 1.7 | | | | | | | | | | | |
| 15 | 6.7 | 2.0 | - | | | | | | | | | | | | | | | | | | | | | |
| 20 | 6.7 | 1.9 | 0.6 | | 1.7 | | | | 6.8 | 1.7 | 0.5 | | 1.8 | | | | | | | | | | | |
| 25 | 6.6 | 1.8 | 1.0 | | 1.6 | | | | | | | | | | | | | | | | | | | |
| 30 | 6.6 | 1.9 | 1.0 | | 1.6 | | | | | | | | | | | | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 12 | 3 | 3 | 6 | 6 | - | 1 | 0 | 12 | 6 | 6 | 5 | 8 | - | 28 | 0 | | | | | | | | |
| 5 | 11 | 2 | 5 | 7 | 9 | - | 9 | 0 | 9 | 4 | 4 | 6 | 6 | - | 20 | 0 | | | | | | | | |
| 10 | 9 | 2 | 3 | 5 | 7 | - | 1 | 0 | 9 | 2 | 6 | 5 | 7 | - | 5 | 0 | | | | | | | | |
| 15 | 7 | 3 | 5 | 7 | 9 | - | 5 | 0 | | | | | | | | | | | | | | | | |
| 20 | 11 | 4 | 5 | 5 | 7 | - | 10 | 0 | 8 | 2 | 6 | 0 | 3 | - | 13 | 0 | | | | | | | | |
| 25 | 6 | 3 | 5 | 6 | 7 | - | 13 | 0 | | | | | | | | | | | | | | | | |
| 30 | 9 | 8 | 4 | 4 | 5 | - | 21 | 0 | | | | | | | | | | | | | | | | |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 30 | 0 | 6 | 27 | 10 | 22 | 0 | 0 | 26 | 0 | 8 | 26 | 11 | 24 | 0 | 0 | | | | | | | | |
| 5 | 19 | 0 | 7 | 25 | 10 | 26 | 0 | 0 | 0 | 0 | 4 | 26 | 11 | 22 | 0 | 0 | | | | | | | | |
| 10 | 38 | 0 | 5 | 24 | 3 | 30 | 0 | 0 | 12 | 0 | 2 | 33 | 13 | 25 | 0 | 0 | | | | | | | | |
| 15 | 35 | 0 | 8 | 25 | 10 | 30 | 0 | 0 | | | | | | | | | | | | | | | | |
| 20 | 26 | 0 | 6 | 26 | 11 | 25 | 0 | 5 | 14 | 0 | 6 | 25 | 12 | 25 | 0 | 0 | | | | | | | | |
| 25 | 15 | 0 | 4 | 22 | 9 | 22 | 0 | 0 | | | | | | | | | | | | | | | | |
| 30 | 0 | 1 | 9 | 30 | 12 | 25 | 0 | 0 | | | | | | | | | | | | | | | | |

## Table 15

## MEAN VALUES FOR Na, K, Ca, Mg, Cl, $NO_3$ and $PO_4$

## FOR STATIONS 1, 3, and 5 - LAKE HAMILTON

| Date | Station Number | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|
| 4/28/68 | 1 | 2.8 | 1.0 | 7.3 | 1.7 | - | 2.1 | 0.25 |
| | 3 | 2.7 | 1.0 | 6.7 | 1.6 | - | 1.4 | 0.40 |
| | 5 | 3.4 | 0.9 | 6.4 | 1.6 | - | 1.1 | 0.25 |
| 6/27/68 | 1 | 2.1 | 1.1 | 6.0 | 1.9 | 2.4 | 0.8 | 0.15 |
| | 3 | - | - | - | - | - | - | - |
| | 5 | 1.8 | 1.0 | 5.7 | 1.5 | 1.6 | 0.6 | 0.16 |
| 7/16/68 | 1 | 3.5 | 1.3 | 6.4 | 1.7 | 2.7 | 2.3 | 0.14 |
| | 3 | 2.0 | 1.1 | 6.6 | 1.7 | 2.3 | 0.7 | 0.15 |
| | 5 | 1.9 | 1.2 | 6.7 | 1.7 | 2.2 | 0.8 | 0.14 |
| 8/2/68 | 1 | 2.8 | 1.8 | 5.6 | 1.5 | 2.6 | 1.6 | 0.24 |
| | 3 | 2.2 | 1.3 | 5.5 | 1.4 | 2.9 | 1.7 | 0.24 |
| | 5 | 2.3 | 1.5 | 5.3 | 1.4 | 2.5 | 1.7 | 0.18 |
| 8/21/68 | 1 | 2.0 | 1.3 | 5.2 | 1.8 | 2.3 | 1.0 | 0.09 |
| | 3 | 2.0 | 1.1 | 5.7 | 1.7 | 2.3 | 1.1 | 0.08 |
| | 5 | - | - | - | - | - | - | - |
| 9/28/68 | 1 | 2.1 | 1.3 | 7.0 | 1.4 | - | 1.1 | 0.18 |
| | 3 | 1.9 | 1.2 | 6.7 | 1.4 | - | 1.8 | 0.12 |
| | 5 | 1.7 | 1.1 | 6.8 | 1.3 | - | 1.4 | 0.15 |
| 11/2/68 | 1 | 2.3 | 1.2 | - | 1.6 | 3 | 0.3 | 0.28 |
| | 3 | 2.2 | 1.2 | - | 1.6 | 3 | 0.4 | 0.32 |
| | 5 | 1.9 | 1.0 | - | 1.6 | 2 | 0.2 | 0.25 |

Table 15 (con't)

| Date | Station Number | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|
| 11/23/68 | 1 | 2.9 | 1.5 | 6.5 | 1.6 | 4 | 0.5 | - |
| | 3 | 2.1 | 1.1 | 6.1 | 1.6 | 3 | 0.4 | - |
| | 5 | 1.7 | 1.0 | 7.0 | 1.7 | 2 | 0.6 | - |
| 1/11/69 | 1 | 1.8 | 1.0 | 6.11 | 1.7 | 2 | 0.8 | 0.07 |
| | 3 | 1.6 | 0.9 | 6.4 | 1.8 | 2 | 0.7 | 0.07 |
| | 5 | 1.6 | 0.9 | 6.6 | 1.8 | 1 | 1.3 | 0.08 |
| 3/15/69 | 1 | 1.9 | 0.9 | - | 1.7 | - | - | - |
| | 3 | 1.7 | 0.8 | - | 1.8 | - | - | - |
| | 5 | - | - | - | - | - | - | - |

Table 16

## MEAN VALUE OF TRACE METAL CONCENTRATION

## FOR STATIONS 1, 3, and 5 - LAKE HAMILTON

| Date | Station Number | Fe | | Mn | | Cu | | Ni | | Co | | Pb | | Zn | | Cr | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | f | p | f | p | f | p | f | p | f | p | f | p | f | p | f | p |
| 4/28/68 | 1 | 1 | 116 | 6 | 32 | 0 | 6 | 6 | 4 | 1 | 1 | 6 | 2 | 18 | 0 | 0 | 0 |
| | 3 | 1 | 117 | 5 | 46 | 1 | 6 | 6 | 9 | 1 | 3 | 10 | 0 | 18 | 0 | 0 | 0 |
| | 5 | 0 | 114 | 3 | 38 | 2 | 1 | 5 | 3 | 1 | 2 | 9 | 7 | 34 | 1 | 0 | 0 |
| 6/27/68 | 1 | 17 | 122 | 14 | 17 | 14 | 18 | 1 | 1 | 1 | 2 | 3 | 18 | | | 0 | 0 |
| | 3 | | | | | | | | | | | | | | | | |
| | 5 | 14 | 106 | 10 | 16 | 14 | 11 | 2 | 0 | 2 | 2 | 2 | 14 | | | 0 | 0 |
| 7/16/68 | 1 | 13 | 65 | 59 | 18 | 15 | 5 | 0 | 0 | 4 | 3 | 3 | 4 | | | 0 | 0 |
| | 3 | 4 | 70 | 34 | 22 | 12 | 5 | 0 | 0 | 4 | 2 | 4 | 2 | | | 0 | 0 |
| | 5 | 3 | 77 | 9 | 16 | 12 | 5 | 0 | 0 | 3 | 2 | 5 | 10 | | | 0 | 0 |
| 8/2/68 | 1 | 26 | 96 | 48 | 28 | 11 | 5 | 4 | 82 | 3 | 0 | 9 | 9 | 8 | 5 | 2 | 4 |
| | 3 | 16 | 100 | 35 | 43 | 12 | 8 | 4 | 35 | 6 | 0 | 12 | 18 | 1 | 15 | 2 | 5 |
| | 5 | 16 | 105 | 16 | 26 | 13 | 7 | 4 | 16 | 3 | 0 | 7 | 15 | 1 | 3 | 1 | 6 |
| 8/21/68 | 1 | 22 | 98 | 30 | 140 | 2 | 11 | 0 | 5 | 1 | 2 | 5 | 4 | 4 | - | 0 | 5 |
| | 3 | 26 | 95 | 35 | 45 | 1 | 8 | 0 | 5 | 0 | 0 | 6 | 1 | 4 | - | 1 | 2 |
| | 5 | | | | | | | | | | | | | | | | |
| 9/28/68 | 1 | 31 | 79 | 51 | 25 | 10 | 35 | 0 | 0 | 2 | 2 | 16 | 15 | 138 | 15 | - | - |
| | 3 | 19 | 67 | 18 | 24 | 10 | 17 | 0 | 0 | 2 | 3 | 7 | 7 | 63 | 12 | - | - |
| | 5 | 13 | 54 | 17 | 21 | 12 | 18 | 0 | 2 | 1 | 2 | 8 | 7 | 69 | 12 | - | - |
| 11/2/68 | 1 | 19 | 63 | 16 | 30 | 6 | 5 | 0 | 2 | 4 | 1 | 2 | 13 | - | - | 2 | 2 |
| | 3 | 11 | 51 | 4 | 36 | 7 | 7 | 0 | 3 | 4 | 2 | 3 | 16 | - | - | 2 | 4 |
| | 5 | 31 | 52 | 11 | 27 | 6 | 6 | 0 | 1 | 3 | 1 | 4 | 6 | - | - | 2 | 2 |

## Table 16 (con't)

| Date | Station Number | Fe f | Fe p | Mn f | Mn p | Cu f | Cu p | Ni f | Ni p | Co f | Co p | Pb f | Pb p | Zn f | Zn p | Cr f | Cr p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/23/68 | 1 | 11 | 27 | 7 | 12 | 11 | 4 | 5 | 1 | 5 | 1 | - | - | - | - | 2 | 1 |
|  | 3 | 12 | 52 | 9 | 17 | 9 | 2 | 5 | 0 | 5 | 1 | - | - | - | - | 3 | 1 |
|  | 5 | - | - | 24 | 25 | 7 | 3 | 3 | 1 | 5 | 1 | - | - | - | - | 2 | 2 |
| 1/11/69 | 1 | 17 | 122 | 2 | 34 | 2 | 6 | 6 | - | 3 | 0 | 11 | 0 | - | 8 | - | 1 |
|  | 3 | 10 | 142 | 3 | 29 | 2 | 6 | 5 | - | 3 | 0 | 2 | 0 | - | 11 | - | 1 |
|  | 5 | 8 | 147 | 5 | 34 | 8 | 4 | 6 | - | 3 | 0 | 18 | 0 | - | 6 | - | 1 |
| 3/15/69 | 1 | 9 | 23 | 4 | 0 | 4 | 7 | 6 | 26 | 7 | 9 | - | 26 | 9 | 0 | 0 | 1 |
|  | 3 | 10 | 13 | 3 | 0 | 5 | 5 | 4 | 27 | 8 | 12 | - | 23 | 17 | 0 | 0 | 0 |
|  | 5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Hamilton
Station M.C.

Table 17

| Depth (M) | 5/30/68 |  |  |  |  |  |  |  | 6/14/68 |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 7.2 | 1.7 | 0.7 | 3.9 | 0.8 | - | 2.4 | 0.71 | 7.3 | 1.9 | 1.1 | 4.0 | 1.3 | 1.5 | - | 0.18 |
| 5 | 6.8 | 2.0 | 0.9 | 2.9 | 0.8 | - | 2.9 | 0.56 | 6.7 | 1.7 | 1.0 | 5.0 | 1.5 | 1.3 | - | 0.18 |
| 10 | 6.9 | 1.7 | 0.9 | 7.3 | 1.3 | - | 2.1 | 0.69 | 6.9 | 1.6 | 1.0 | 7.2 | 2.0 | 1.3 | - | 0.19 |
| 15 | 6.8 | 2.0 | 0.9 | 5.6 | 1.4 | - | 4.8 | 0.18 | 6.7 | 1.8 | 1.0 | 7.2 | 2.1 | 1.3 | - | 0.26 |
| 17 |  |  |  |  |  |  |  |  | 6.7 | 1.6 | 1.0 | 7.4 | 2.1 | 1.3 | - | 0.20 |

Filtered

|  | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21 | 5 |  |  | 2 | 3 |  | 5 | 15 | 2 | 11 |  | 4 |  |  |  |
| 5 | 62 | 21 |  |  | 2 | 3 |  | 0 | 23 | 7 | 11 |  | 6 |  |  |  |
| 10 | 19 | 33 |  |  | 2 | 3 |  | 0 | 13 | 9 | 9 |  | 6 |  |  |  |
| 15 | 30 | 220 |  |  | 4 | 3 |  | 0 | 30 | 85 | 30 |  | 4 |  |  |  |
| 17 |  |  |  |  |  |  |  |  | 51 | 138 | 30 |  | 8 |  |  |  |

Particulate

|  | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 |  |  |  |  |  |  |  |  | 24 | 15 | 4 |  | 2 |  |  |  |
| 5 |  |  |  |  |  |  |  |  | 31 | 16 | 5 |  | 1 |  |  |  |
| 10 |  |  |  |  |  |  |  |  | 36 | 14 | 6 |  | 3 |  |  |  |
| 15 |  |  |  |  |  |  |  |  | 72 | 21 | 3 |  | 2 |  |  |  |
| 17 |  |  |  |  |  |  |  |  | 140 | 25 | 7 |  | 3 |  |  |  |

Hamilton
Station M.C.

## Table 18

| Depth (M) | 6/27/68 pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | 7/16/68 pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 7.1 | 2.1 | 1.1 | 4.2 | 1.4 | 1.7 | 0.2 | 0.19 | 7.8 | 2.2 | 1.2 | 4.5 | 1.5 | 2.0 | 0.4 | 0.11 |
| 5 | 6.8 | 1.9 | 1.0 | 5.4 | 1.8 | 1.7 | 0.5 | 0.15 | 6.7 | 1.9 | 1.2 | 6.0 | 1.6 | 1.8 | 0.5 | 0.14 |
| 10 | 6.7 | 1.7 | 0.9 | 7.3 | 2.0 | 1.5 | 1.0 | 0.17 | 6.7 | 1.8 | 1.0 | 5.9 | 1.8 | 1.5 | 0.7 | 0.15 |
| 15 | 6.7 | 1.8 | 1.0 | 6.6 | 1.9 | 2.0 | 1.0 | 0.17 | 6.5 | 1.8 | 1.0 | 6.8 | 1.9 | 2.0 | 1.1 | 0.15 |
| 17 | | | | | | | | | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 17 | 5 | 16 | 3 | 2 | 3 | | 0 | 2 | 4 | 9 | 0 | 2 | 7 | | 0 |
| 5 | 15 | 8 | 16 | 1 | 1 | 3 | | 0 | 1 | 6 | 9 | 0 | 2 | 6 | | 0 |
| 10 | 34 | 46 | 14 | 1 | 3 | 4 | | 0 | 9 | 34 | 12 | 0 | 3 | 9 | | 0 |
| 15 | 78 | 210 | 16 | 0 | 1 | 4 | | 0 | 332 | 960 | 18 | 0 | 4 | 10 | | 0 |
| 17 | | | | | | | | | | | | | | | | |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 97 | 26 | 13 | 6 | 1 | 14 | | 0 | 62 | 16 | 8 | 1 | 2 | 2 | | 0 |
| 5 | 125 | 89 | 15 | 11 | 3 | 15 | | 0 | 103 | 27 | 8 | 0 | 2 | 2 | | 0 |
| 10 | 185 | 26 | 20 | 0 | 1 | 10 | | 0 | 74 | 19 | 4 | 0 | 2 | 0 | | 0 |
| 15 | 300 | 59 | 12 | 0 | 1 | 14 | | 0 | 594 | 7 | 4 | 0 | 2 | 1 | | 0 |
| 17 | | | | | | | | | | | | | | | | |

Hamilton
Station M.C.

## Table 19

| Depth (M) | 8/2/68 |  |  |  |  |  |  |  | 8/13/68 |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 7.4 | 2.6 | 1.4 | 4.5 | 1.3 | 2.5 | 1.6 | 0.15 | 7.4 | 2.6 | 1.5 | 5.0 | 1.7 | 2.8 | 1.3 | 0.09 |
| 5 | 6.5 | 2.4 | 1.6 | 5.4 | 1.5 | 2.0 | 1.5 | 0.15 | 6.7 | 2.3 | 1.4 | 5.1 | 1.5 | 2.5 | 1.0 | 0.08 |
| 10 | 6.7 | 3.1 | 1.9 | 5.8 | 1.6 | 2.3 | 1.7 | 0.21 | 6.7 | 1.9 | 1.1 | 6.4 | 1.5 | 2.2 | 1.4 | 0.08 |
| 15 | 6.7 | 2.2 | 1.7 | 6.0 | 1.6 | 2.3 | 2.0 | 0.17 | 6.7 | 1.8 | 1.1 | 6.5 | 1.7 | 1.7 | 1.5 | 0.08 |
| 17 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Filtered

|  | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21 | 11 | 9 | 2 | 5 | 10 | 0 | 3 | 2 | 9 | 4 | 0 | 1 | 10 | 3 | 0 |
| 5 | 50 | 115 | 13 | 00 | 4 | 18 | 0 | 1 | 10 | 260 | 10 | 0 | 1 | 25 | 10 | 0 |
| 10 | 516 | 208 | 11 | 5 | 4 | 15 | 12 | 2 | 735 | 380 | 30 | 4 | 1 | 15 | 12 | 2 |
| 15 | 1170 | 400 | 10 | 1 | 2 | 8 | 0 | 2 | 1600 | 495 | 27 | 3 | 2 | 15 | 12 | 0 |
| 17 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Particulate

|  | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 40 | 23 | 3 | 0 | 0 | 17 | 2 | 1 | 46 | 11 | 9 | 6 | 0 | 25 | - | - |
| 5 | 220 | 25 | 5 | 3 | 0 | 12 | 3 | 2 | 120 | 5 | 6 | 14 | 0 | 47 | - | - |
| 10 | 420 | 14 | 8 | 3 | 0 | 52 | 12 | 3 | 174 | 4 | 8 | 8 | 0 | 4 | - | - |
| 15 | 300 | 6 | 5 | 7 | 0 | 11 | 6 | 3 | 160 | 4 | 6 | 32 | 0 | 8 | - | - |
| 17 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Hamilton
Station M.C.

## Table 20

8/21/68

| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|
| 0 | 7.4 | 1.9 | 1.3 | 4.2 | 1.7 | 2.7 | 0.4 | 0.08 |
| 5 | 6.5 | 1.9 | 1.2 | 4.2 | 1.7 | 2.0 | 1.3 | 0.05 |
| 10 | 6.7 | 1.6 | 0.9 | 5.0 | 1.9 | 1.6 | 2.3 | 0.08 |
| 13 | 6.7 | 1.9 | 2.1 | 5.0 | 2.0 | 1.7 | 1.0 | 0.10 |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 30 | 0 | 0 | 1 | 3 | 1 | 0 |
| 5 | 134 | 207 | 0 | 0 | 2 | 0 | 1 | 0 |
| 10 | 780 | 212 | 0 | 0 | 0 | 8 | 3 | 0 |
| 13 | 1410 | 402 | 1 | 2 | 3 | 5 | 2 | 0 |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 21 | 10 | 7 | 5 | 0 | 0 | - | 3 |
| 5 | 198 | 5 | 10 | 2 | 0 | 1 | - | 2 |
| 10 | 72 | 2 | 14 | 7 | 0 | 0 | - | 4 |
| 13 | 237 | 9 | 9 | 6 | 0 | 5 | - | 2 |

9/28/68

| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|
| 0 | - | 2.8 | 1.9 | 6.2 | 1.4 | - | 0.5 | 0.20 |
| 5 | - | 1.9 | 1.3 | 6.0 | 1.3 | - | 1.6 | 0.20 |
| 10 | - | 1.5 | 0.9 | 7.2 | 1.4 | - | 1.5 | 0.20 |
| 15 | - | 1.6 | 1.1 | 7.5 | 1.5 | - | 2.6 | 0.43 |

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 8 | 2 | 7 | 0 | 0 | 0 | 35 | |
| 5 | 15 | 40 | 21 | 0 | 2 | 9 | 91 | |
| 10 | 50 | 157 | 14 | 0 | 2 | 10 | 42 | |
| 15 | 116 | 402 | 15 | 0 | 1 | 13 | 36 | |

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|
| 0 | 14 | 7 | 7 | 0 | 4 | 11 | 4 | |
| 5 | 76 | 74 | 5 | 5 | 3 | 8 | 16 | |
| 10 | 149 | 45 | 26 | 1 | 2 | 14 | 8 | |
| 15 | 61 | 2 | 13 | 8 | 3 | 3 | 8 | |

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Table 21

| Depth (M) | 11/2/68 |  |  |  |  |  |  |  | 11/23/68 |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | - | 2.3 | 1.2 | - | 1.6 | 3.0 | 0.1 | 0.22 | 6.8 | 2.2 | 1.2 | 5.7 | 1.6 | 2.8 | 0.0 | - |
| 5 | - | 2.4 | 1.2 | - | 1.6 | 3.0 | 0.0 | 0.19 | 6.7 | 2.5 | 1.4 | 6.6 | 1.6 | 2.0 | 0.6 | - |
| 10 | - | 2.2 | 1.2 | - | 1.6 | 3.0 | 0.2 | 0.10 | 6.6 | 2.2 | 1.2 | 6.3 | 1.6 | 2.8 | 0.2 | - |
| 15 | - | 2.3 | 1.3 | - | 1.6 | 3.2 | 0.1 | 0.24 |  |  |  |  |  |  |  |  |

Filtered

|  | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 15 | 2 | 7 | 1 | 7 | 1 | - | 0 | 12 | 3 | 8 | 3 | 7 | - | - | 3 |
| 5 | 12 | 1 | 8 | 0 | 5 | 4 | - | 1 | 12 | 5 | 9 | 10 | 5 | - | - | 5 |
| 10 | 9 | 2 | 13 | 0 | 5 | 3 | - | 0 | 32 | 4 | 11 | 3 | 7 | - | - | 3 |
| 15 | 15 | 57 | 12 | 0 | 5 | 1 | - | 4 |  |  |  |  |  |  |  |  |

Particulate

|  | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 36 | 23 | 5 | 2 | 2 | 13 | 3 | 4 | 22 | 10 | 2 | 0 | 1 | - | - | 1 |
| 5 | 38 | 27 | 6 | 9 | 1 | 7 | 5 | 3 | 22 | 12 | 2 | 0 | 0 | - | - | 1 |
| 10 | 42 | 16 | 7 | 2 | 1 | 10 | 7 | 1 | 54 | 19 | 1 | 0 | 1 | - | - | 1 |
| 15 | 140 | 65 | 5 | 2 | 1 | 2 | 6 | 3 |  |  |  |  |  |  |  |  |

Hamilton
Station M.C.

## Table 22

| | 1/11/69 | | | | | | | | 3/15/69 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 7.0 | 2.0 | 1.0 | 4.5 | 1.5 | 1.8 | 1.9 | 0.07 | 6.9 | 2.0 | 0.8 | | 1.4 | | | |
| 5 | 7.0 | 1.0 | 0.9 | 4.8 | 1.6 | 2.0 | 1.4 | 0.06 | 6.8 | 1.9 | 0.8 | | 1.4 | | | |
| 10 | 7.0 | 1.9 | 0.9 | 4.5 | 1.5 | 2.0 | 1.3 | 0.08 | 6.8 | 2.0 | 0.8 | | 1.3 | | | |
| 15 | | | | | | | | | 6.6 | 2.1 | 0.8 | | 1.3 | | | |

Filtered

| | 1/11/69 | | | | | | | | 3/15/69 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
| 0 | 12 | 1 | 2 | 5 | 3 | 0 | - | - | 11 | 4 | 4 | 5 | 4 | - | 4 | 0 |
| 5 | 14 | 3 | 3 | 12 | 9 | 27 | - | - | 12 | 3 | 5 | 5 | 5 | - | 16 | 0 |
| 10 | 15 | 18 | 2 | 6 | 3 | 2 | - | - | 20 | 10 | 6 | 6 | 4 | - | 17 | 0 |
| 15 | | | | | | | | | 20 | 10 | 5 | 5 | 6 | - | 17 | 0 |

Particulate

| | 1/11/69 | | | | | | | | 3/15/69 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
| 0 | 118 | 25 | 7 | - | 0 | 0 | - | 1 | 71 | 7 | 11 | 20 | 5 | 2 | 11 | 0 |
| 5 | 58 | 58 | 5 | - | 0 | 0 | - | 1 | 146 | 17 | 3 | 20 | 3 | 9 | 9 | 0 |
| 10 | 92 | 40 | 12 | - | 0 | 0 | - | 2 | 27 | 0 | 9 | 29 | 11 | 26 | 0 | 3 |
| 15 | | | | | | | | | 55 | 0 | 9 | 26 | 12 | 25 | 0 | 0 |

Catherine
6/7/68

Table 23

| Depth (M) | Station No. 1 |  |  |  |  |  |  |  | Station No. 3 |  |  |  |  |  |  |  | Station No. 5 |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 |  |  |  |  |  | 2.6 |  | 0.23 |  |  |  |  |  | 2.0 |  | 0.18 |  |  |  |  |  | 1.8 |  | 0.19 |
| 5 |  |  |  |  |  | 4.3 |  | 0.18 |  |  |  |  |  | 5.0 |  | 0.28 |  |  |  |  |  | 1.8 |  | 0.06 |
| 10 |  |  |  |  |  | 2.0 |  | 0.22 |  |  |  |  |  | 2.0 |  | 0.24 |  |  |  |  |  | 1.8 |  | 0.23 |
| 15 |  |  |  |  |  | 3.0 |  | 0.20 |  |  |  |  |  | 1.8 |  | 0.20 |  |  |  |  |  |  |  |  |

Filtered

| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 10 | 8 | 0 | 0 | 6 | 15 | 0 | 0 | 23 | 16 | 7 | 0 | 3 | 12 | 20 | 0 | 16 | 10 | 12 | 0 | 2 | 11 | 8 | 0 |
| 5 | 24 | 12 | 8 | 0 | 0 | 5 | 22 | 0 | 16 | 88 | 5 | 0 | 5 | 26 | 10 | 0 | 8 | 7 | 0 | 0 | 2 | 5 | 0 | 0 |
| 10 | 31 | 17 | 8 | 0 | 0 | 16 | 17 | 0 | 30 | 17 | 14 | 0 | 5 | 14 | 12 | 0 | 19 | 10 | 13 | 0 | 2 | 22 | 15 | 0 |
| 15 | 16 | 12 | 0 | 0 | 3 | 11 | 4 | 0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Particulate

| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 |  |  | 7 |  | 10 |  |  | 0 |  |  | 9 |  | 7 |  |  | 0 |  |  | 12 |  | 5 |  |  | 0 |
| 5 |  |  | 9 |  | 4 |  |  | 0 |  |  | 12 |  | 9 |  |  | 0 |  |  | 14 |  | 6 |  |  | 0 |
| 10 |  |  | 15 |  | 7 |  |  | 0 |  |  | - |  | - |  |  | 0 |  |  | 11 |  | 9 |  |  | 24 |
| 15 |  |  | 29 |  | 7 |  |  | 0 |  |  | 14 |  | 12 |  |  | 0 |  |  |  |  |  |  |  |  |

Catherine
7/26/68

Table 24

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 7.8 | 3.7 | 1.3 | 11.0 | 1.6 | 10.7 | 1.3 | 0.14 | 7.7 | 5.3 | 1.7 | 12.8 | 1.7 | 12.3 | 1.3 | 0.14 | 7.1 | 2.7 | 1.1 | 9.5 | 1.7 | 4.2 | 1.6 | 0.13 |
| 5 | 6.7 | 3.0 | 1.3 | 8.0 | 1.6 | 6.2 | 2.2 | 0.15 | 6.7 | 2.8 | 1.3 | 8.3 | 1.6 | 5.0 | 1.7 | 0.14 | 6.7 | 1.8 | 1.0 | 8.1 | 1.6 | 2.0 | 1.9 | 0.16 |
| 10 | 6.7 | 3.5 | 1.4 | 7.5 | 1.6 | 7.2 | 1.8 | 0.17 | 6.7 | 3.7 | 1.4 | 8.8 | 1.6 | 7.2 | 1.8 | 0.12 | | | | | | | | |
| 15 | 6.7 | 3.6 | 1.4 | 9.4 | 1.6 | 6.7 | 1.8 | 0.17 | | | | | | | | | | | | | | | | |

Filtered

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
| 0 | 4 | 6 | 13 | 20 | 0 | 20 | 0 | 0 | 3 | 4 | 12 | 6 | 0 | 10 | 0 | 0 | 10 | 36 | 12 | 6 | 0 | 8 | 0 | 0 |
| 5 | 21 | 79 | 16 | 7 | 2 | 9 | 0 | 0 | 8 | 67 | 15 | 6 | 2 | 5 | 0 | 0 | 17 | 81 | 13 | 6 | 0 | 0 | 0 | 0 |
| 10 | 27 | 112 | 18 | 8 | 2 | 8 | 0 | 1 | 18 | 97 | 16 | 10 | 0 | 12 | 0 | 0 | 15 | 95 | 12 | 9 | 0 | 4 | 0 | 0 |
| 15 | 31 | 142 | 18 | - | 2 | - | 23 | 0 | | | | | | | | | | | | | | | | |

Particulate

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
| 0 | 41 | 25 | 5 | 4 | 0 | 8 | 9 | 2 | 49 | 30 | 8 | 4 | 0 | 10 | 17 | 0 | 68 | 48 | 6 | 4 | 1 | 15 | 17 | 0 |
| 5 | 83 | 43 | 6 | 1 | 0 | 10 | 4 | 0 | 81 | 52 | 5 | 1 | 0 | 10 | 11 | 1 | 89 | 38 | 6 | 1 | 0 | 8 | 10 | 2 |
| 10 | 91 | 41 | 5 | 1 | 0 | 11 | 9 | 0 | 81 | 37 | 4 | 2 | 0 | 7 | 10 | 2 | | | | | | | | |
| 15 | 103 | 49 | 6 | 2 | 0 | 10 | 14 | 0 | | | | | | | | | | | | | | | | |

Catherine
9/14/68

## Table 25

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| epth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | | 2.4 | | 6.7 | 1.7 | 5.2 | 1.9 | 0.05 | | 3.1 | | 8.6 | 1.6 | 9.0 | 1.6 | 0.04 | | 2.9 | | 8.5 | 1.5 | 5.7 | 2.1 | 0.43 |
| 5 | | 2.3 | | 6.7 | 1.7 | 3.2 | 0.3 | 0.01 | | 2.5 | | 6.3 | 1.7 | - | 2.1 | - | | 2.0 | | 6.9 | 1.5 | 2.0 | 2.0 | 0.03 |
| 10 | | 2.0 | | 6.1 | 1.5 | 2.7 | 2.1 | 0.32 | | 2.1 | | 6.7 | 1.6 | 5.0 | 2.1 | 0.03 | | | | | | | | |
| 15 | | 1.9 | | 6.2 | 1.6 | 2.7 | 3.7 | 0.08 | | | | | | | | | | | | | | | | |

**Filtered**

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 6 | 10 | 14 | 0 | 0 | - | | 0 | 8 | 4 | 12 | 4 | 0 | - | - | 0 | 8 | 8 | 16 | 0 | 0 | - | - | 0 |
| 5 | 30 | 15 | 14 | 0 | 0 | - | | 0 | 18 | 47 | 10 | 0 | 0 | - | - | 0 | 22 | 104 | 16 | 3 | 0 | - | - | 0 |
| 10 | 24 | 134 | 21 | 5 | 0 | - | | 0 | 30 | 104 | 16 | 0 | 0 | - | - | 0 | | | | | | | | |
| 15 | 10 | 75 | 10 | 0 | 0 | - | | 0 | | | | | | | | | | | | | | | | |

**Particulate**

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 179 | 117 | 8 | 2 | 0 | 2 | - | 0 | 124 | 38 | 7 | 0 | 0 | 3 | - | 0 | 153 | 53 | 5 | 0 | 0 | 5 | - | 0 |
| 5 | 187 | 186 | 11 | 6 | 0 | 4 | - | 0 | 214 | 149 | 7 | 2 | 0 | 3 | - | 0 | 116 | 43 | 4 | 0 | 0 | 3 | - | 0 |
| 10 | 248 | 145 | 9 | 3 | 0 | 3 | - | 1 | 220 | 106 | 6 | 1 | 0 | 3 | - | 0 | | | | | | | | |
| 15 | 324 | 112 | 11 | 1 | 0 | 3 | - | 0 | | | | | | | | | | | | | | | | |

Catherine
10/30/68

## Table 26

| | Station No. 1 | | | | | | | | Station No. 3 | | | | | | | | Station No. 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | 6.8 | 3.6 | 1.2 | 9.8 | 1.7 | 8.2 | 0.1 | 0.19 | 6.7 | 3.1 | 1.3 | - | 1.7 | 12.5 | 0.1 | 0.31 | | | | | | | | |
| 5 | 6.7 | 3.8 | 1.2 | 9.8 | 1.6 | 11.7 | 0.0 | 0.27 | 6.9 | 3.8 | 1.2 | 9.9 | 1.7 | 11.3 | 0.0 | 0.31 | | | | | | | | |
| 10 | 6.9 | 2.6 | 1.1 | 7.9 | 1.7 | 6.2 | 0.1 | 0.27 | 6.7 | 2.2 | 1.0 | 6.9 | 1.7 | 7.2 | 0.0 | 0.26 | | | | | | | | |
| 15 | 6.7 | 2.6 | 1.0 | 7.9 | 1.7 | 6.3 | 0.0 | 0.21 | 6.7 | 2.5 | 1.0 | 7.4 | 1.7 | 5.3 | 0.0 | 0.30 | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16 | 14 | 8 | 1 | 2 | 10 | - | 0 | 16 | 14 | 17 | 4 | 6 | 9 | - | 0 | | | | | | | | |
| 5 | 20 | 12 | 1 | 2 | 0 | 8 | - | 0 | 19 | 5 | 10 | 1 | 3 | 9 | - | 0 | | | | | | | | |
| 10 | 10 | 23 | 4 | 0 | 2 | 10 | - | 0 | 28 | 45 | 10 | 0 | 2 | 6 | - | 0 | | | | | | | | |
| 15 | 22 | 67 | 7 | 6 | 1 | 0 | - | 0 | 24 | 55 | 9 | 0 | 4 | 7 | - | 0 | | | | | | | | |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 51 | 61 | 5 | 2 | 1 | 0 | 4 | 3 | 38 | 50 | 7 | 2 | 2 | 10 | 6 | 4 | | | | | | | | |
| 5 | 54 | 71 | 5 | 2 | 1 | 4 | 3 | 3 | 62 | 68 | 8 | 0 | 1 | 10 | 18 | 3 | | | | | | | | |
| 10 | 66 | 60 | 4 | 4 | 3 | 20 | 9 | 2 | 63 | 49 | 7 | 5 | 3 | 11 | 10 | 3 | | | | | | | | |
| 15 | 134 | 53 | 7 | 5 | 2 | 17 | 10 | 2 | 93 | 50 | 6 | 3 | 1 | 17 | 13 | 3 | | | | | | | | |

Catherine
Station T.C.

## Table 27

| Depth (M) | 6/7/68 | | | | | | | | 7/26/68 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | | | | | | 2.5 | | 0.26 | 7.7 | 3.4 | 1.3 | 10.0 | 1.6 | 9.2 | 0.2 | 0.14 |
| 5 | | | | | | 3.6 | | 0.20 | 6.7 | 3.3 | 1.3 | 9.1 | 1.6 | 9.2 | 1.8 | 0.15 |
| 10 | | | | | | 3.5 | | 0.01 | 6.7 | 3.1 | 1.3 | 10.0 | 1.6 | 7.0 | 2.1 | 0.14 |
| | Filtered | | | | | | | | | | | | | | | |
| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
| 0 | 15 | 8 | 0 | 0 | 4 | 16 | 0 | 0 | 0 | 7 | 10 | 7 | 3 | 14 | 0 | 0 |
| 5 | 30 | 13 | 11 | 0 | 5 | 13 | 17 | 0 | 27 | 90 | 15 | 9 | 1 | 9 | 0 | 0 |
| 10 | 75 | 65 | 22 | 3 | - | 47 | 17 | 12 | 135 | 220 | 16 | - | 1 | - | 0 | 0 |
| | Particulate | | | | | | | | | | | | | | | |
| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
| 0 | - | - | 14 | - | 5 | - | - | 0 | 47 | 34 | 4 | 2 | 0 | 7 | 7 | 0 |
| 5 | - | - | 12 | - | 9 | - | - | 0 | 129 | 53 | 5 | 2 | 0 | 10 | 14 | 0 |
| 10 | - | - | 16 | - | 10 | - | - | 0 | 300 | 41 | 5 | 3 | 0 | 21 | 14 | 0 |

Catherine
Station T.C.

Table 28

| | 9/14/68 | | | | | | | | 10/30/68 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (M) | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ | pH | Na | K | Ca | Mg | Cl | $NO_3$ | $PO_4$ |
| 0 | | 3.4 | | 8.0 | 1.7 | 11.2 | 1.6 | 0.03 | 6.9 | 3.8 | 1.3 | - | 1.8 | 8.3 | 0.0 | 0.33 |
| 5 | | 2.4 | | 8.6 | 1.6 | 4.8 | 3.4 | 0.05 | 6.9 | 3.5 | 1.2 | 9.8 | 1.7 | 9.2 | 0.0 | 0.25 |
| 10 | | 2.2 | | 6.3 | 1.5 | 4.2 | 2.8 | 0.05 | | | | | | | | |

Filtered

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 28 | 14 | 10 | 4 | 0 | - | - | 0 | 10 | 7 | 10 | 0 | 5 | 8 | - | 0 |
| 5 | 146 | 396 | 17 | 0 | 0 | - | - | 0 | 14 | 3 | 7 | 0 | 3 | 7 | - | 0 |
| 10 | 50 | 186 | 14 | 0 | 0 | - | - | 0 | 9 | 13 | 6 | 1 | 2 | 8 | - | 0 |

Particulate

| | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr | Fe | Mn | Cu | Ni | Co | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 115 | 46 | 5 | 0 | 0 | 5 | - | 0 | 45 | 60 | 6 | 0 | 2 | 14 | 3 | 4 |
| 5 | 402 | 15 | 9 | 3 | 0 | 6 | - | 0 | 92 | 79 | 7 | 0 | 2 | 17 | 10 | 3 |
| 10 | 460 | 181 | 6 | 0 | 0 | 5 | - | 0 | 114 | 93 | 4 | 0 | 2 | 19 | 8 | 1 |

Table·29

## SUMMARY OF DATA FROM LAKE HAMILTON
(Stations 1, 3, 5 and M.C.)

| | Mean Value (ppm) | Range (ppm) | Frequency of Detection (%) | Number of Determinations |
|---|---|---|---|---|
| Na | 2.1 | 1.0-8.9 | 100 | 169 |
| K | 1.2 | 0.5-2.2 | 100 | 167 |
| Ca | 5.9 | 2.9-7.5 | 100 | 138 |
| Mg | 1.6 | 0.8-2.1 | 100 | 168 |
| Cl | 2.3 | 1.0-4.8 | 100 | 117 |
| $NO_3$ | 1.1 | 0.0-7.9 | 96 | 149 |
| $PO_4$ | 0.18 | 0.04-1.02 | 100 | 136 |
| Filtered | (ppb) | (ppb | | |
| Fe | 55 | 0-1600 | 91 | 167 |
| Mn | 48 | 0-960 | 99 | 169 |
| Cu | 8 | 0-30 | 89 | 166 |
| Ni | 3 | 0-12 | 59 | 161 |
| Co | 3 | 0-9 | 92 | 169 |
| Pb | 7 | 0-27 | 86 | 133 |
| Zn | 23 | 0-173 | 91 | 82 |
| Cr | 1 | 0-9 | 34 | 131 |
| Particulate | | | | |
| Fe | 92 | 0-594 | 99 | 162 |
| Mn | 24 | 0-82 | 93 | 164 |
| Cu | 8 | 0-82 | 99 | 164 |
| Ni | 9 | 0-114 | 64 | 143 |
| Co | 2 | 0-12 | 62 | 164 |
| Pb | 9 | 0-52 | 75 | 141 |
| Zn | 6 | 0-34 | 66 | 79 |
| Cr | 2 | 0-6 | 55 | 130 |

## Table 30

## SUMMARY OF DATA FROM LAKE CATHERINE
(Stations 1, 3, 5 and T.C.)

| | Mean Value (ppm) | Range (ppm) | Frequency of Detection (%) | Number of Determinations |
|---|---|---|---|---|
| Na | 3.0 | 1.8-5.3 | 100 | 32 |
| K | 1.2 | 1.0-1.7 | 100 | 24 |
| Ca | 8.4 | 6.1-12.8 | 100 | 34 |
| Mg | 1.6 | 1.5-1.8 | 100 | 36 |
| Cl | 5.7 | 1.8-12.5 | 100 | 49 |
| $NO_3$ | 1.3 | 0.0-3.7 | 88 | 36 |
| $PO_4$ | 0.18 | 0.01-0.43 | 100 | 49 |
| Filtered | (ppb) | (ppb) | | |
| Fe | 24 | 0-146 | 98 | 50 |
| Mn | 52 | 4-396 | 100 | 50 |
| Cu | 11 | 0-22 | 94 | 50 |
| Ni | 3 | 0-20 | 48 | 42 |
| Co | 2 | 0-6 | 58 | 48 |
| Pb | 11 | 0-47 | 95 | 36 |
| Zn | 6 | 0-23 | 33 | 27 |
| Cr | 0 | 0-12 | 4 | 50 |
| Particulate | | | | |
| Fe | 134 | 38-460 | 100 | 36 |
| Mn | 65 | 15-186 | 100 | 37 |
| Cu | 8 | 4-29 | 100 | 49 |
| Ni | 2 | 0-6 | 75 | 36 |
| Co | 2 | 0-12 | 51 | 49 |
| Pb | 9 | 0-21 | 97 | 36 |
| Zn | 10 | 3-18 | 100 | 24 |
| Cr | 1 | 0-24 | 37 | 49 |

### Table 31

### Depth of Water at Stations on Lake Hamilton

| Station No. | Water Depth (M) |
|---|---|
| 1 | 34 |
| 2 | 28 |
| 3 | 22 |
| 4 | 15 |
| 5 | 11 |
| 6 | 9 |
| 7 | 7 |
| 8 | 5 |

Figure 1

Reservoirs of the Upper Ouachita River Basin, Arkansas

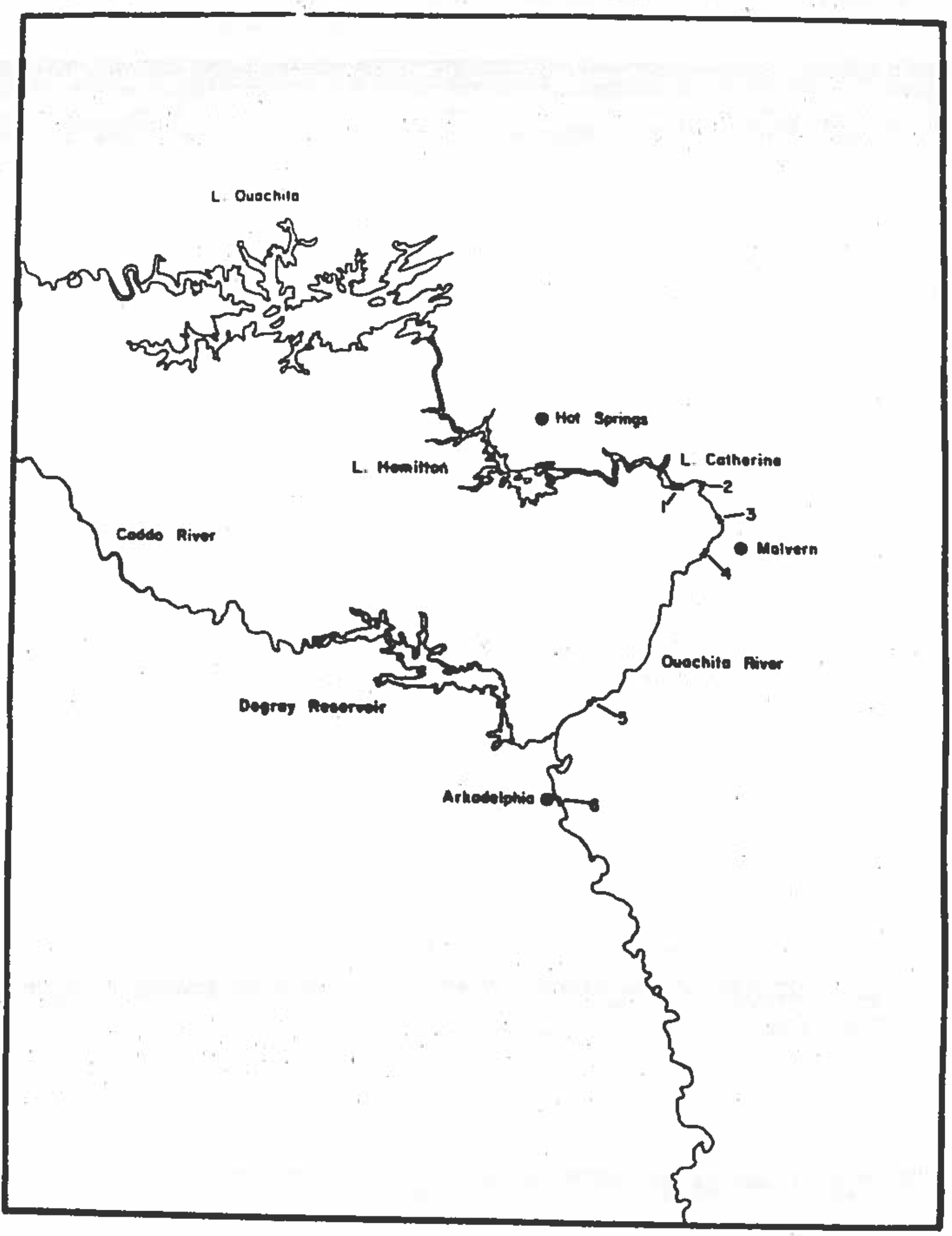

L. Ouachita
Hot Springs
L. Hamilton
L. Catherine
1
2
3
Malvern
4
Caddo River
Ouachita River
Degray Reservoir
5
Arkadelphia
6

Figure 2

Location of Sampling Stations on Lakes Hamilton and Catherine

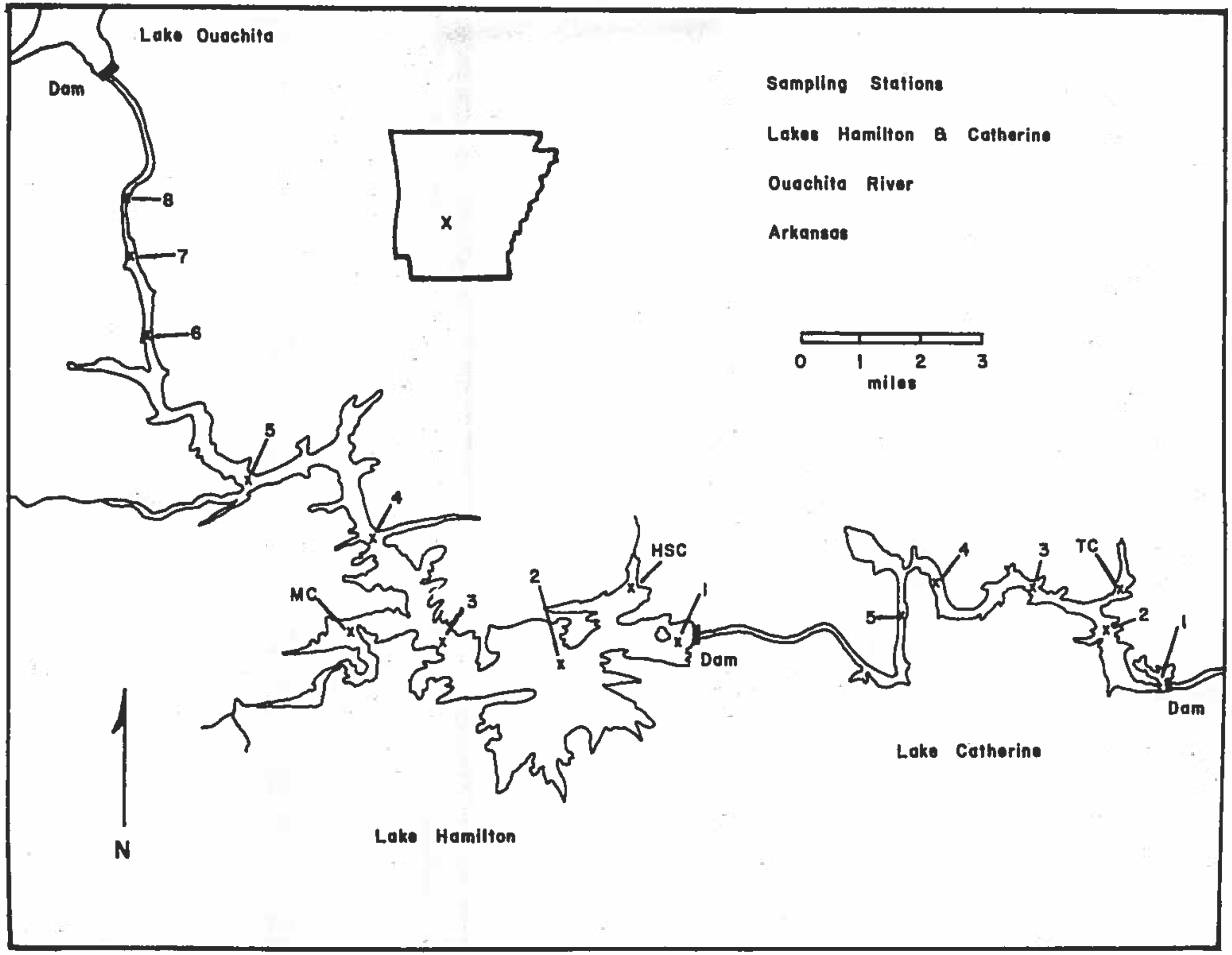

Sampling Stations
Lakes Hamilton & Catherine
Ouachita River
Arkansas
0 1 2 3
miles
Lake Ouachita
Dam
8
7
6
5
4
3
2
1
MC
HSC
Dam
5
4
3
TC
2
1
Dam
Lake Catherine
Lake Hamilton
N
X

Figure 3

pH Dependence of Extraction of Heavy Metals from Diethyldithiocarbamic Acid-Methyl Isobutyl Ketone System

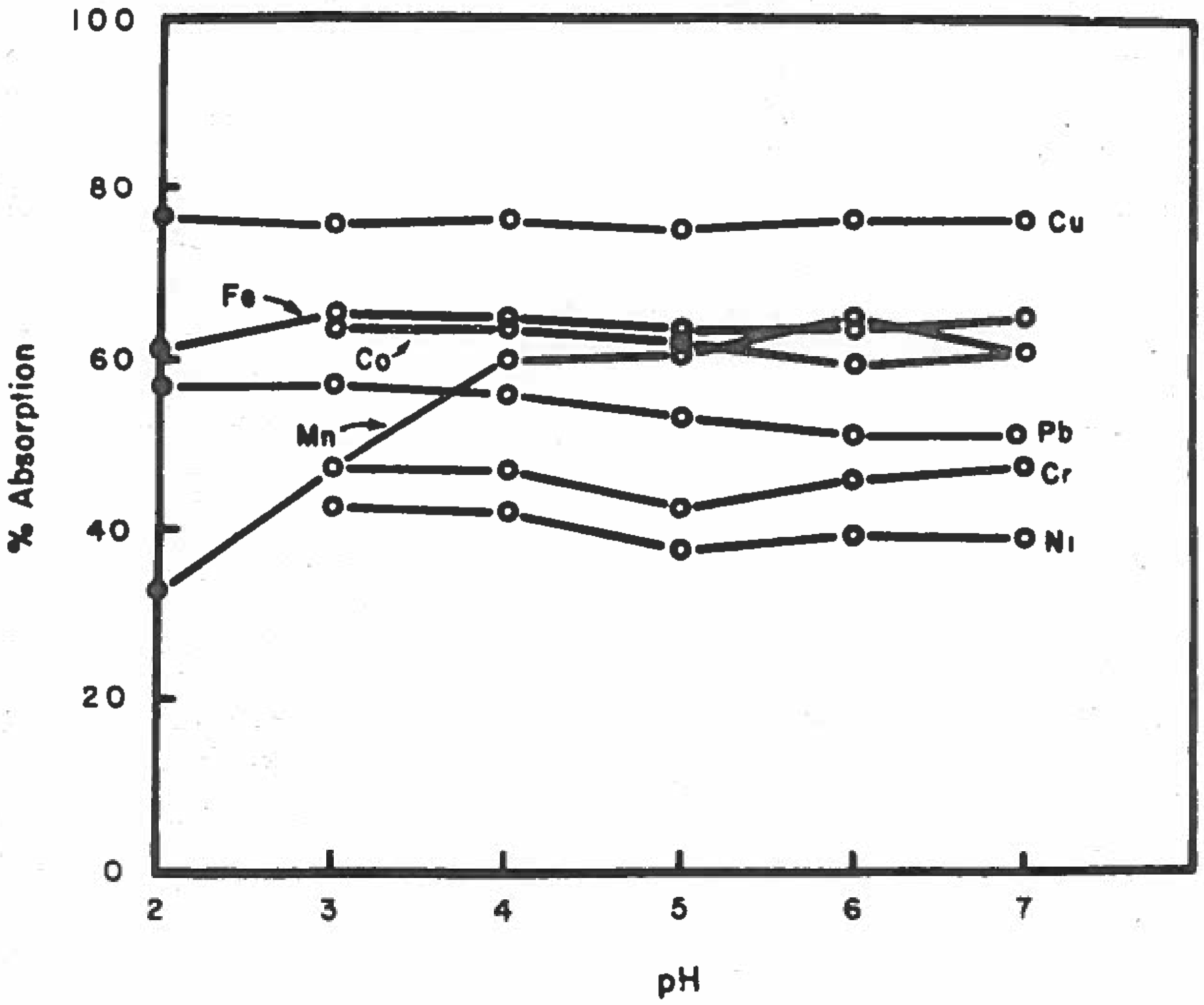

% Absorption
100
80
60
40
20
0
2
3
4
5
6
7
pH
Cu
Fe
Co
Mn
Pb
Cr
Ni

Figure 4

Stability of Extracted Heavy Metals (data for cobalt, nickel, chromium, lead, and zinc show no time dependence over the 400 minute period)

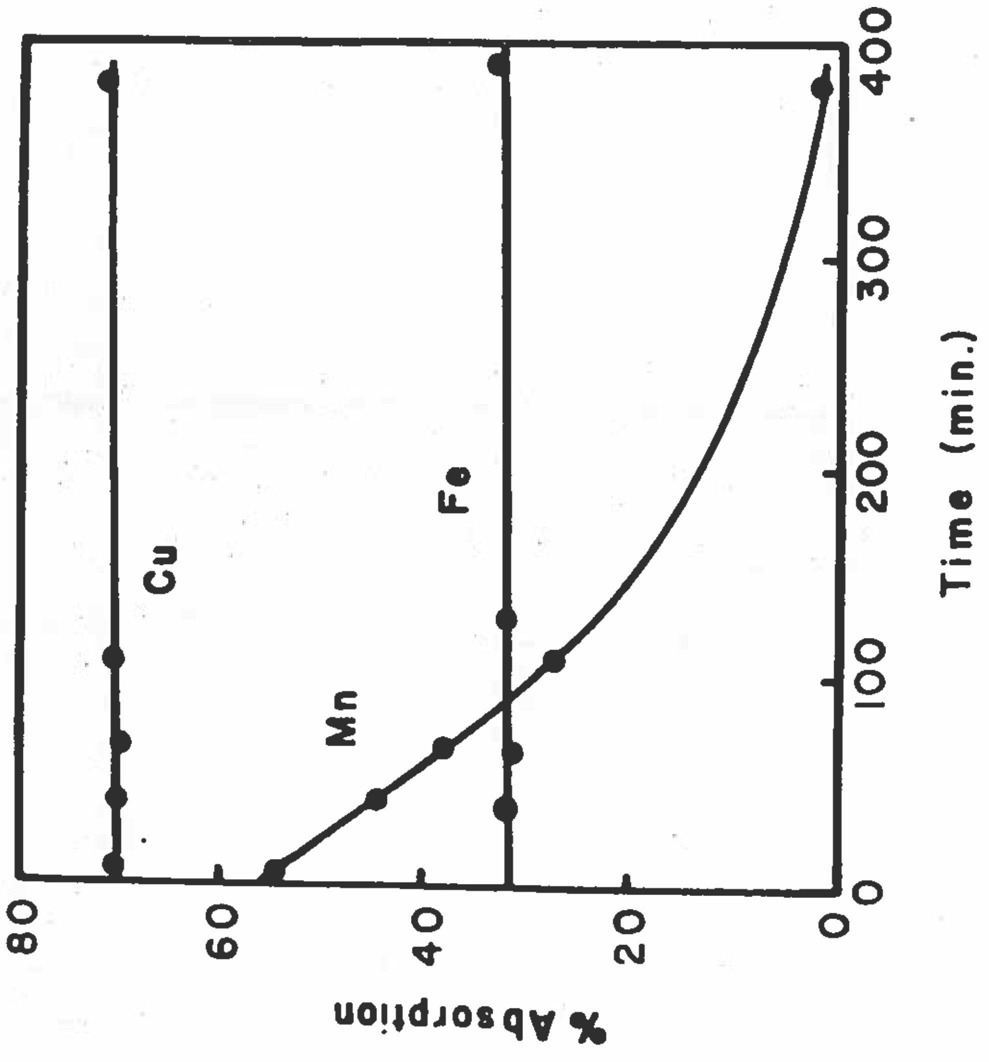
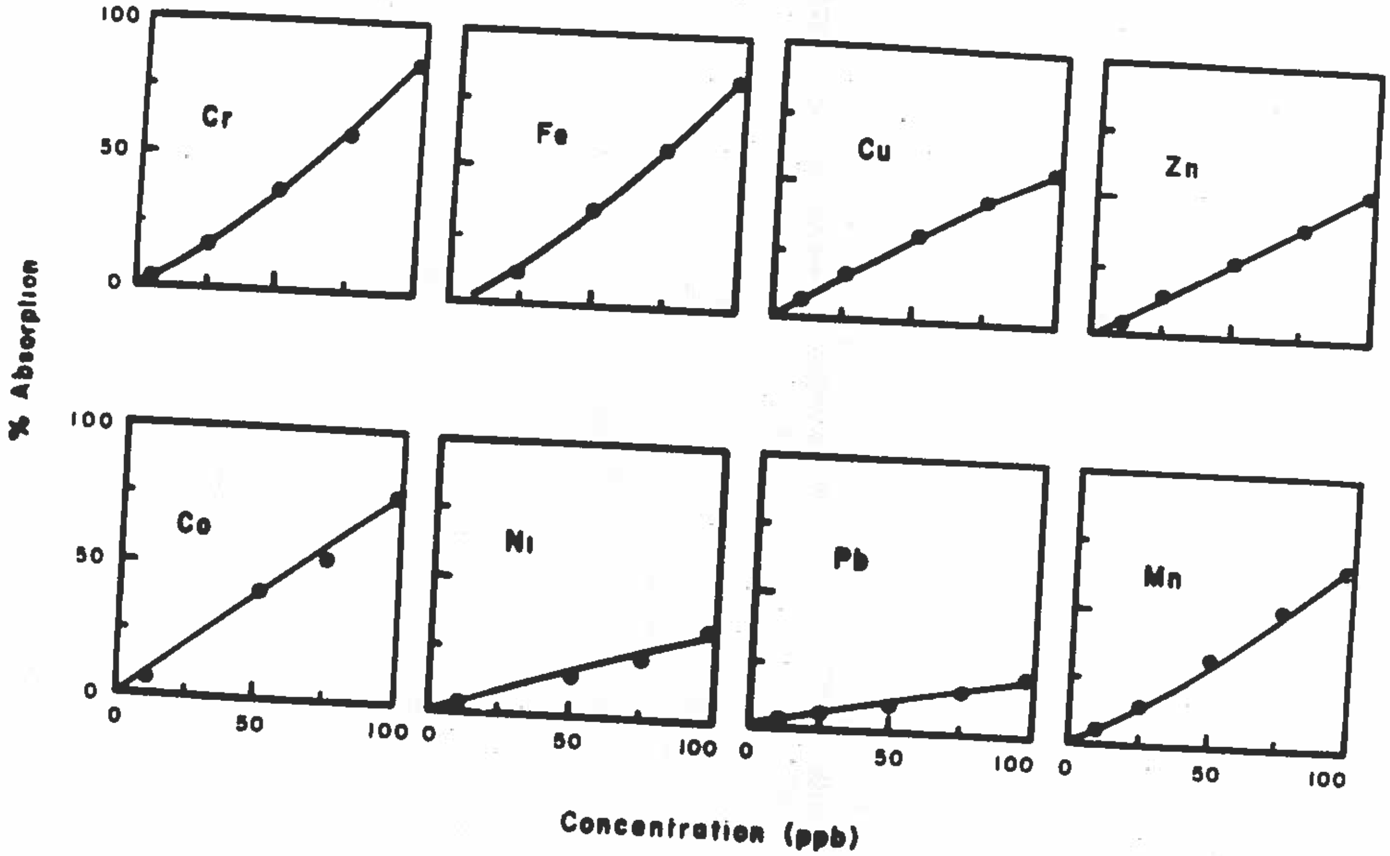

% Absorption
80
60
40
20
0
Time (min.)
0
100
200
300
400
Cu
Mn
Fe

Figure 5

Typical Calibration Curves for the Eight Heavy Metals

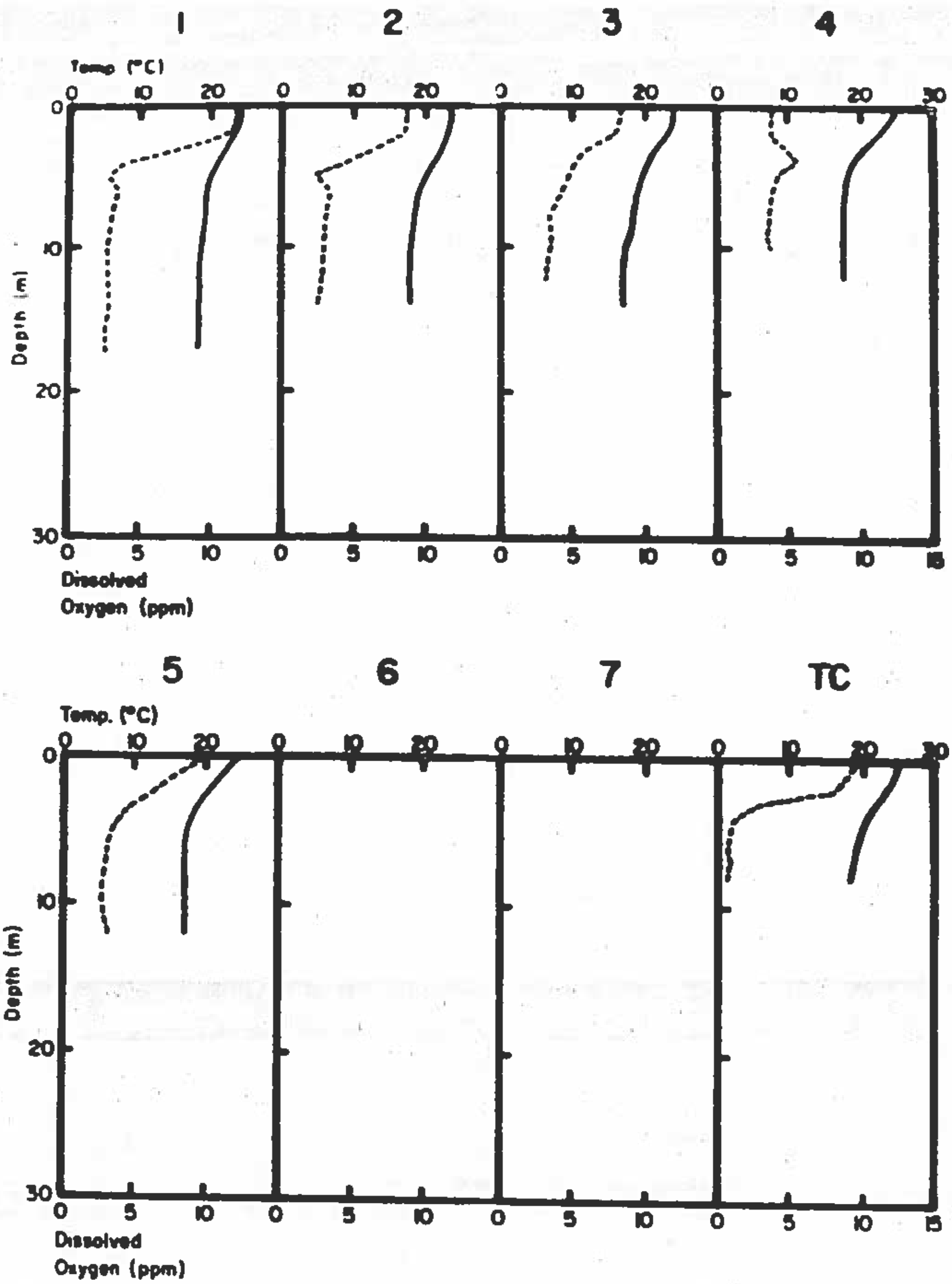


% Absorption
Cr
Fe
Cu
Zn
Co
Ni
Pb
Mn
100
50
0
100
50
0
0
50
100
0
50
100
0
50
100
0
50
100
Concentration (ppb)

Figure 6

Temperature Profile of Lakes Catherine, Hamilton, and Ouachita, July 1968

Catherine
9/14/68



Catherine
10/30/68

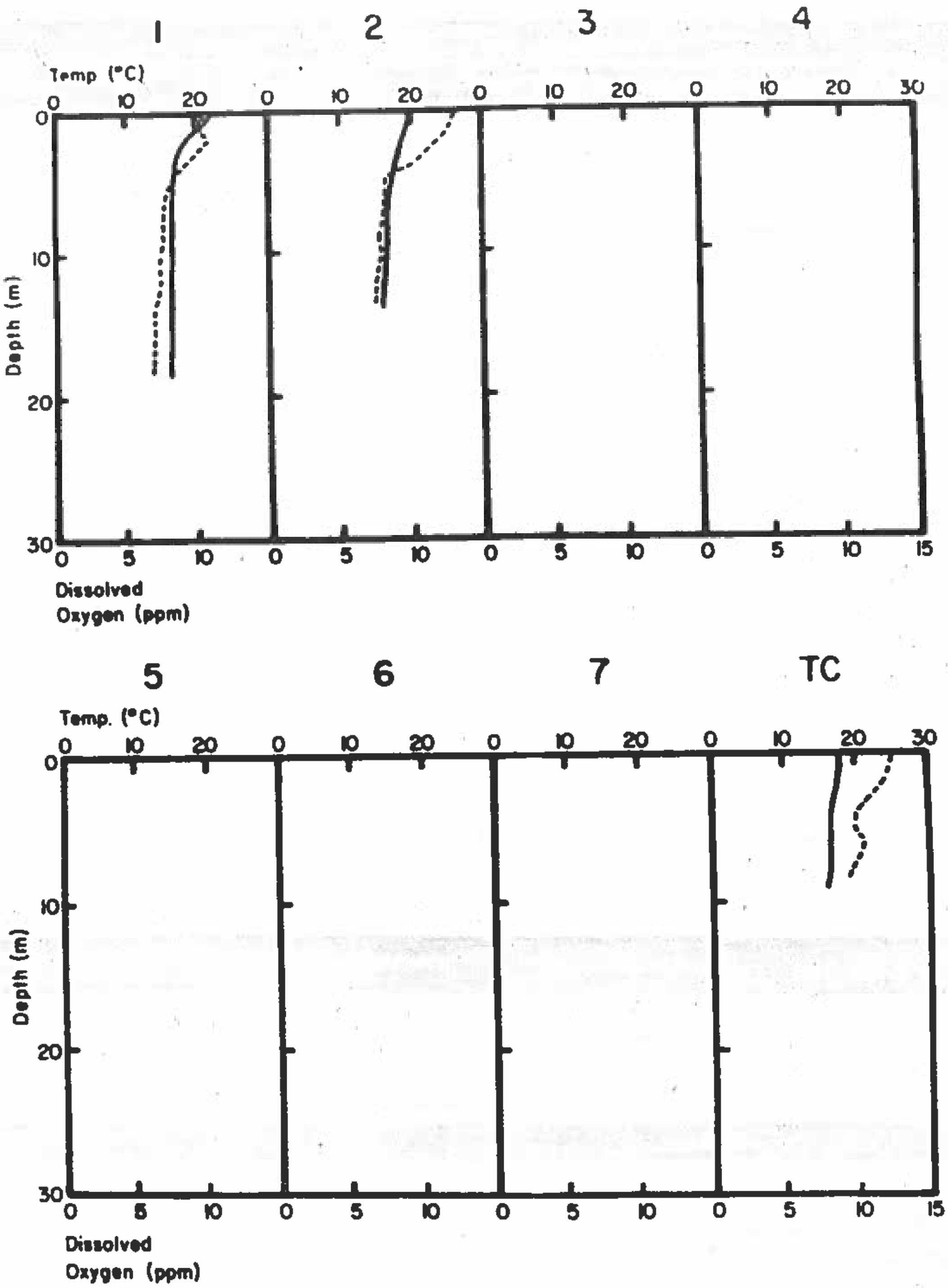
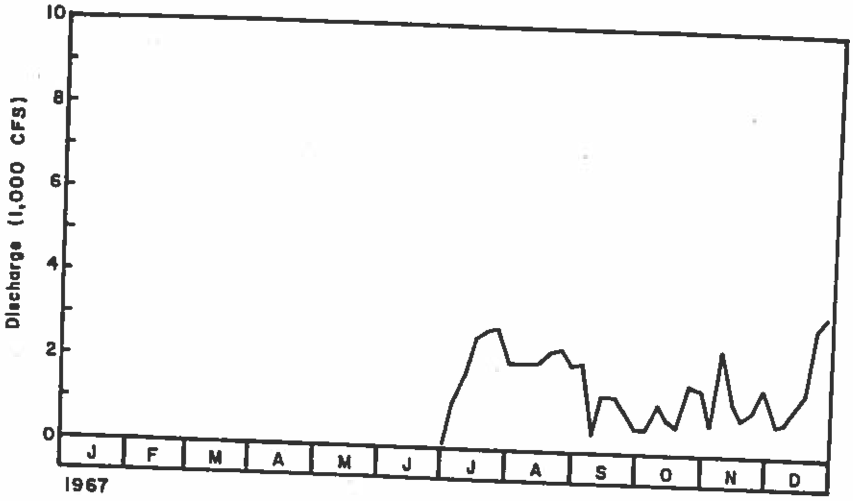
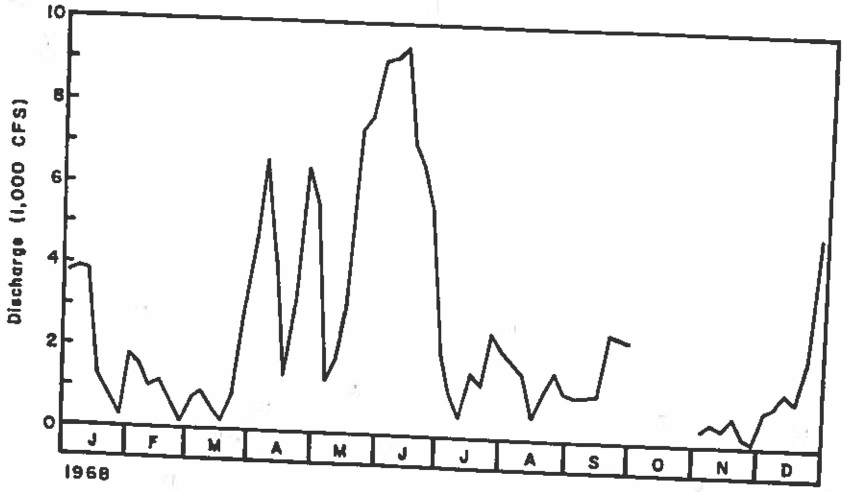
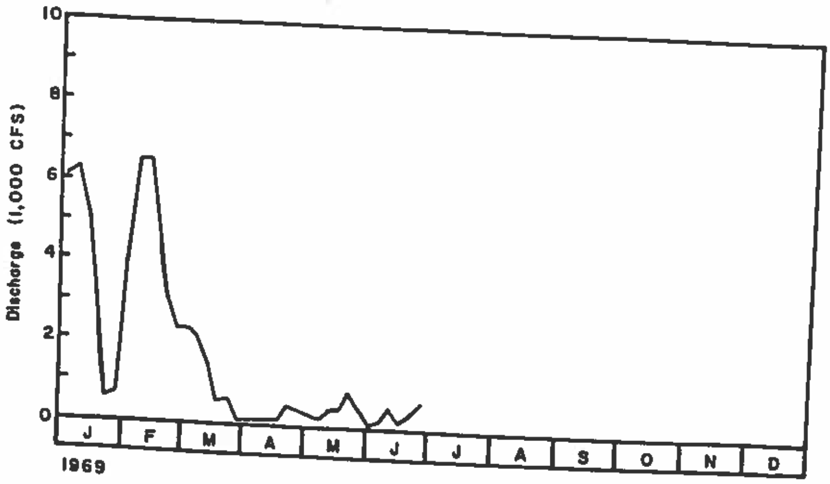


Figure 7

Five day averages of rate of release of water from Lake Ouachita, July 1967 through June 1969 (Reference No. 4)


Discharge (1,000 CFS)
10
8
6
4
2
0
J F M A M J J A S O N D
1967


Discharge (1,000 CFS)
10
8
6
4
2
0
J F M A M J J A S O N D
1968

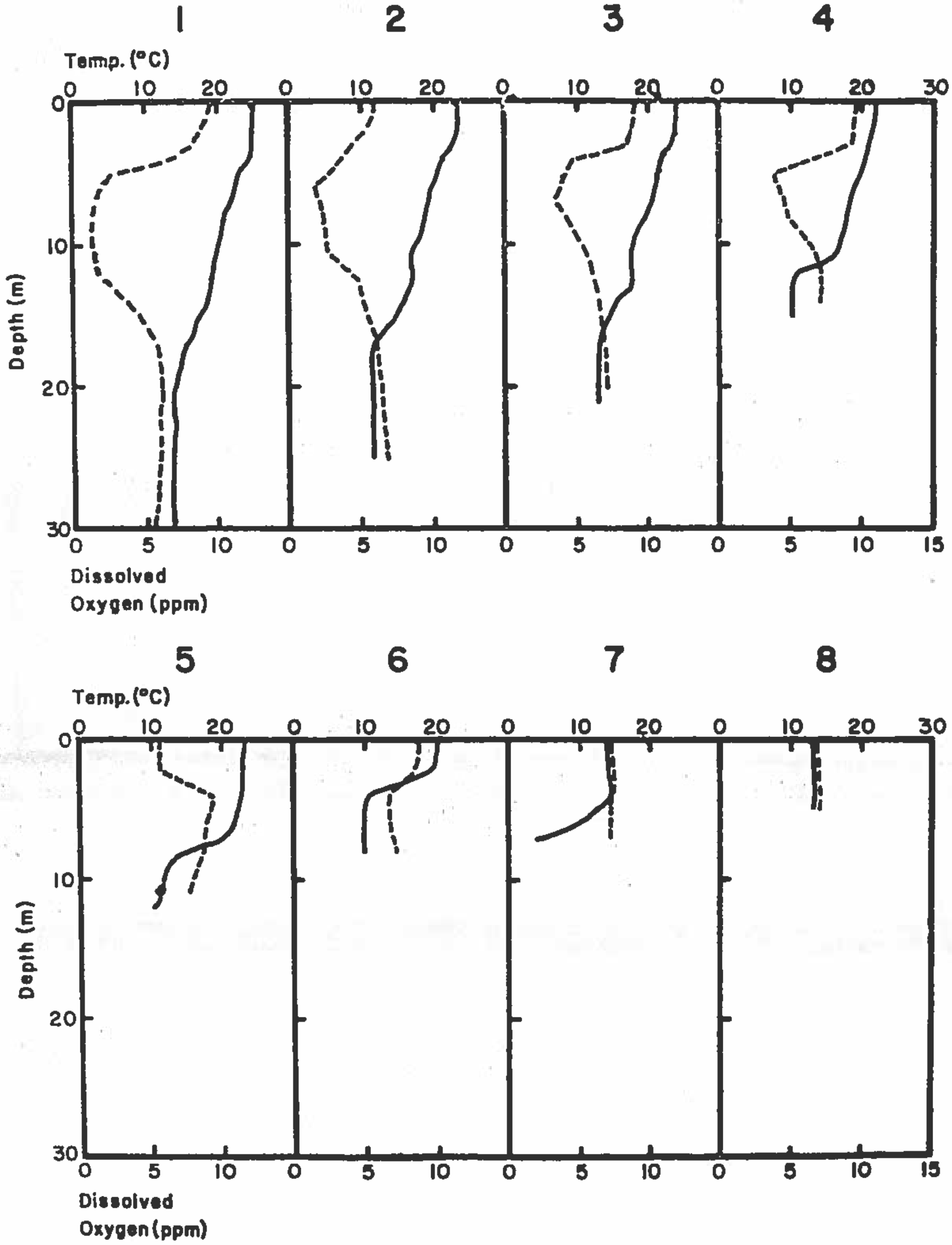

Discharge (1,000 CFS)
10
8
6
4
2
0
J F M A M J J A S O N D
1969

# Figure 8 through 36

Temperature and Dissolved Oxygen Distribution at Main Stem Stations in Lake Hamilton. The solid line represents temperature ($^{o}C$) and the dotted line the dissolved oxygen in ppm.

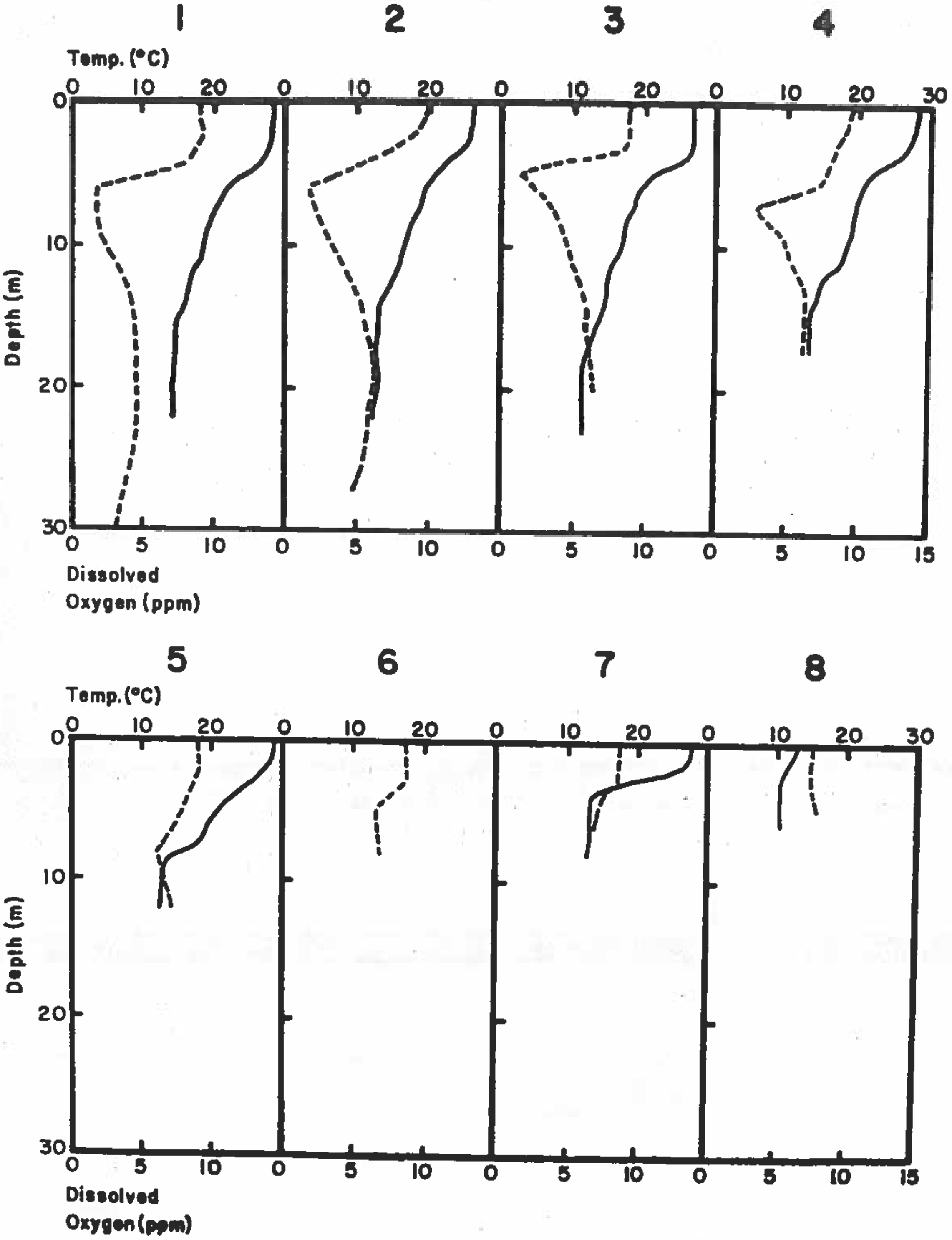
| Figure No. | Date | Figure No. | Date |
|---|---|---|---|
| 8 | 7/21/67 | 23 | 7/16/68 |
| 9 | 8/7/67 | 24 | 8/2/68 |
| 10 | 9/4/67 | 25 | 8/21/68 |
| 11 | 9/26/67 | 26 | 8/30/68 |
| 12 | 10/28/67 | 27 | 9/20/68 |
| 13 | 11/24/67 | 28 | 9/28/68 |
| 14 | 1/27/68 | 29 | 10/19/68 |
| 15 | 3/1/68 | 30 | 11/2/68 |
| 16 | 4/1/68 | 31 | 11/23/68 |
| 17 | 4/28/68 | 32 | 1/11/69 |
| 18 | 5/23/68 | 33 | 3/15/69 |
| 19 | 5/30/68 | 34 | 6/4/69 |
| 20 | 6/14/68 | 35 | 6/18/69 |
| 21 | 6/21/68 | 36 | 6/26/69 |
| 22 | 6/27/68 | | |

Hamilton
7/21/67



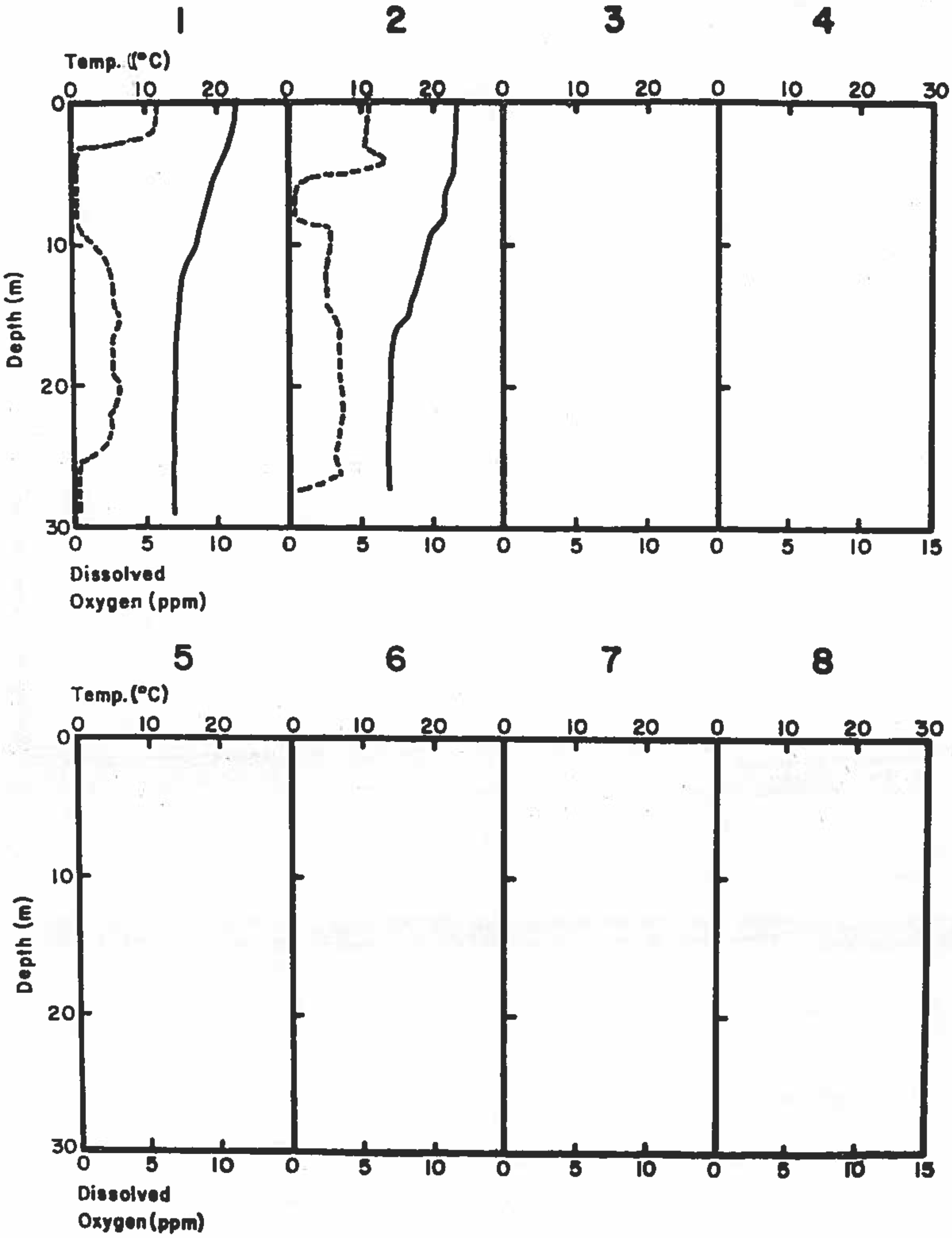
**Hamilton**

8/7/67

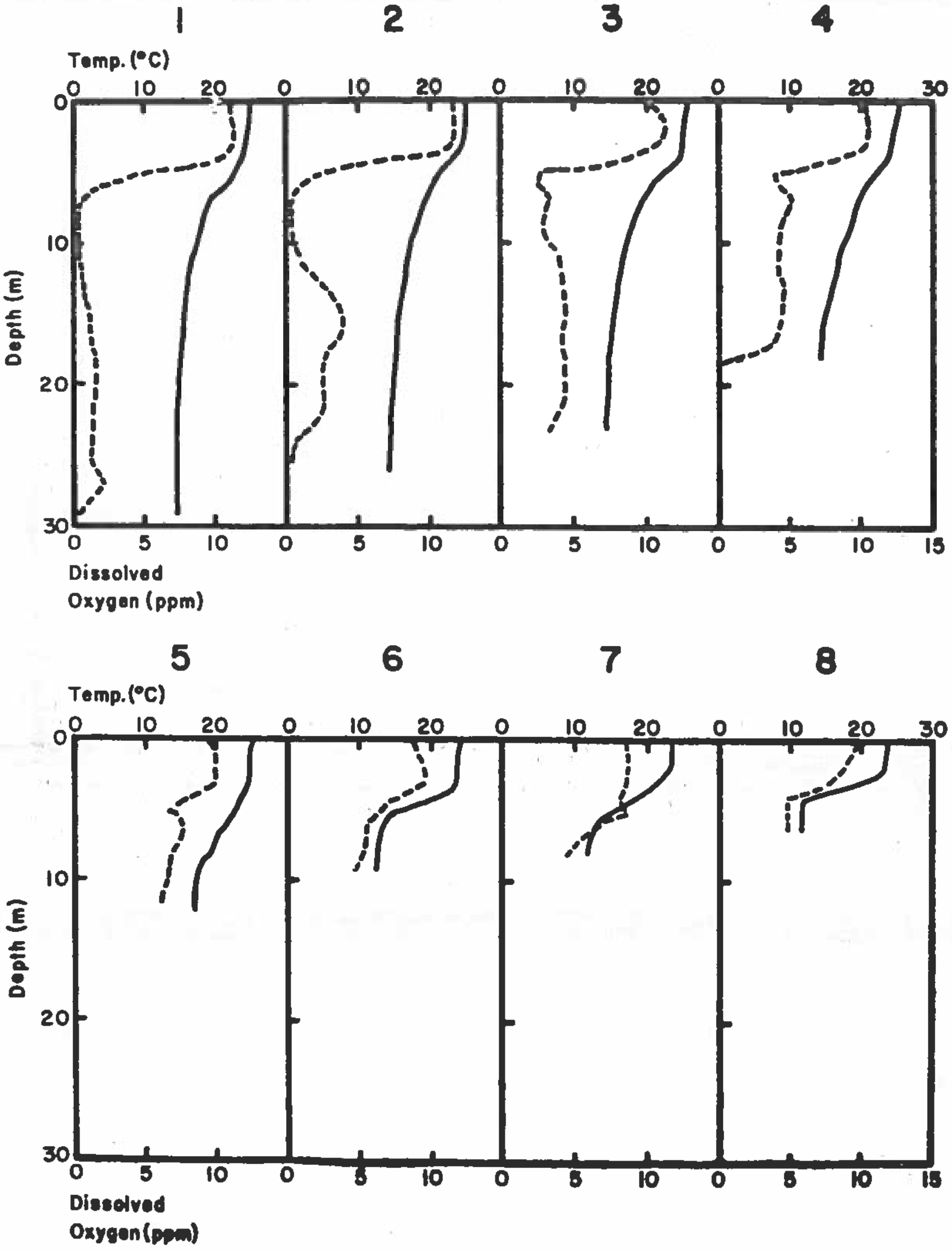


**Hamilton**

9/4/67

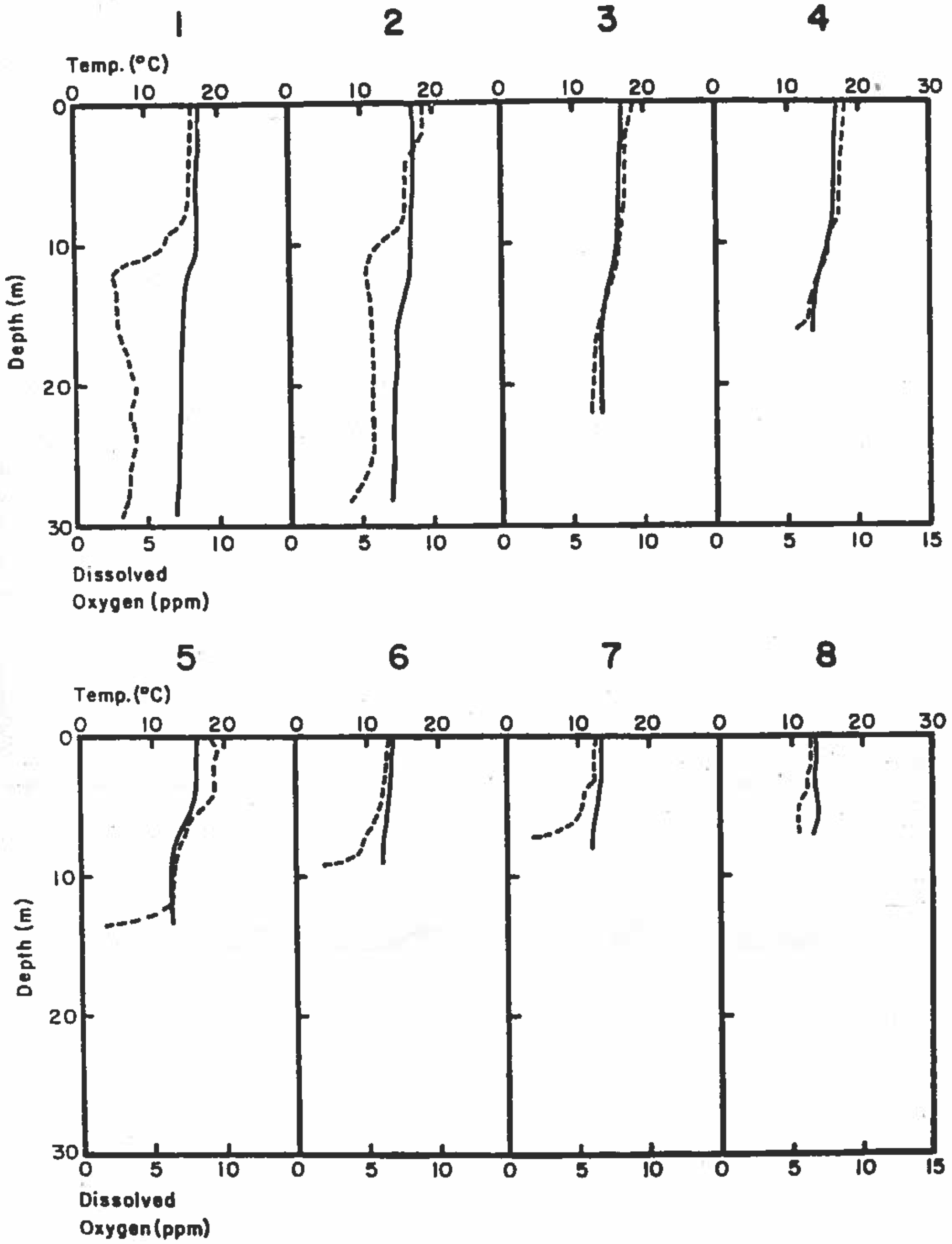


Hamilton
9/26/67



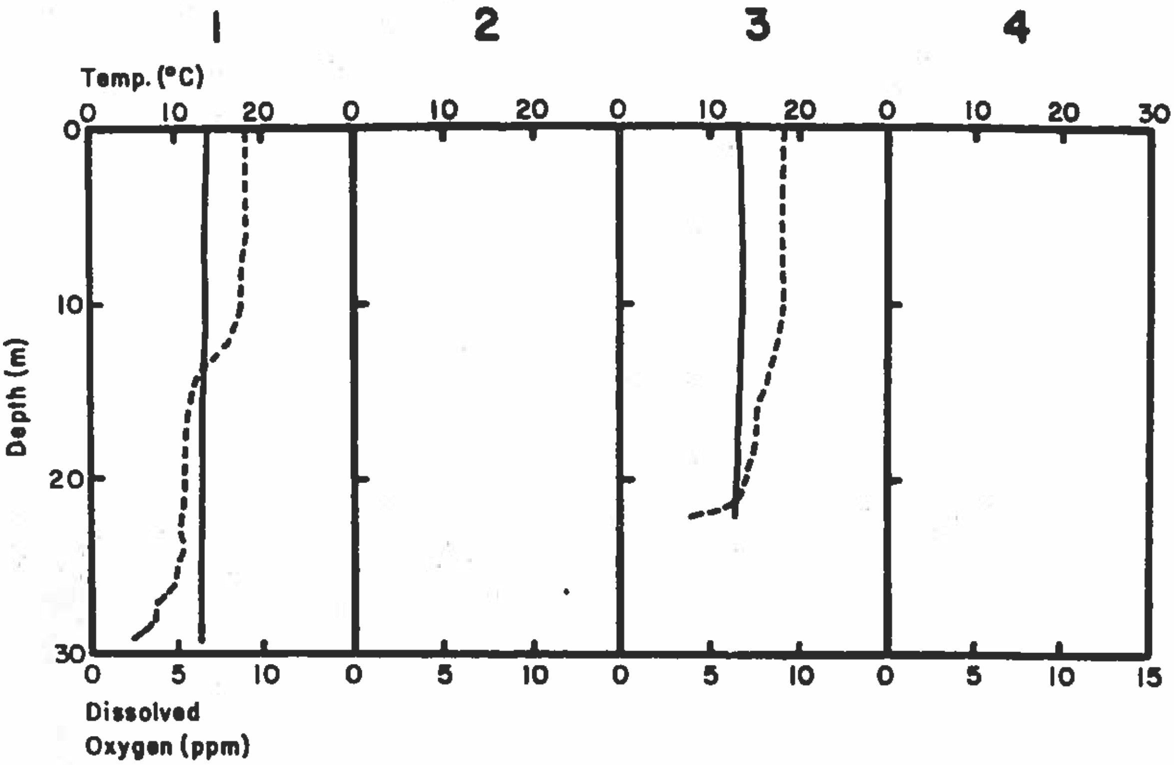
Hamilton

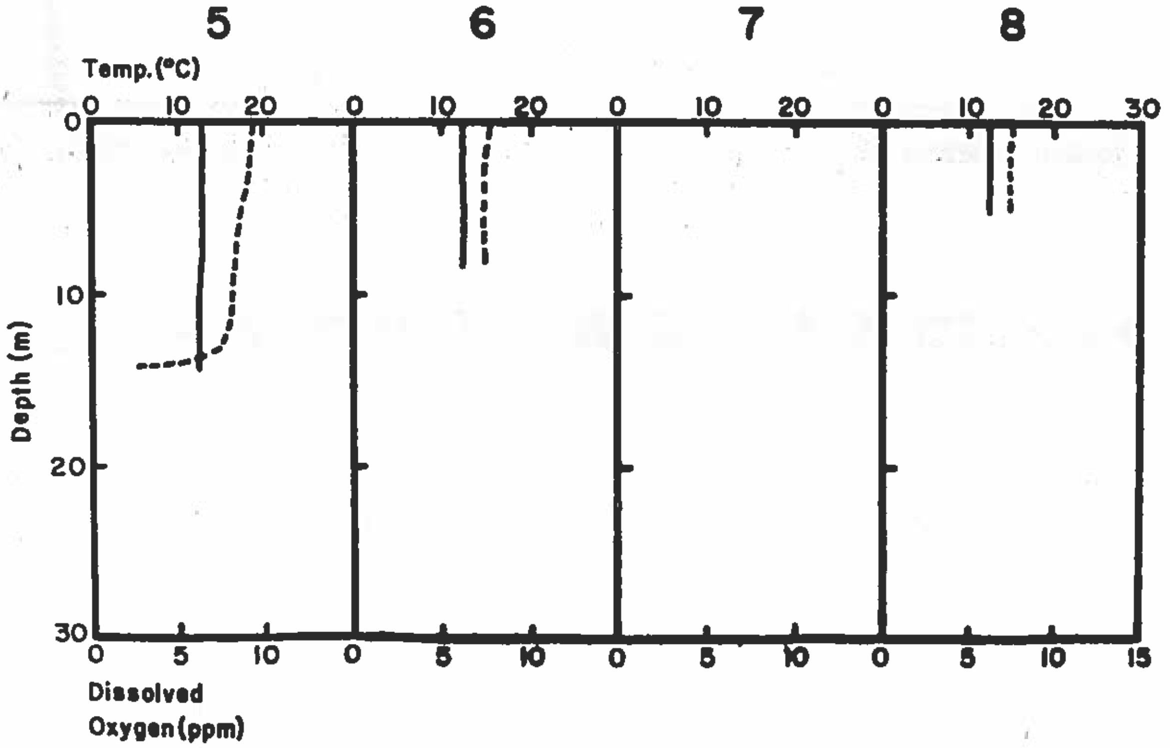
10/28/67



Hamilton

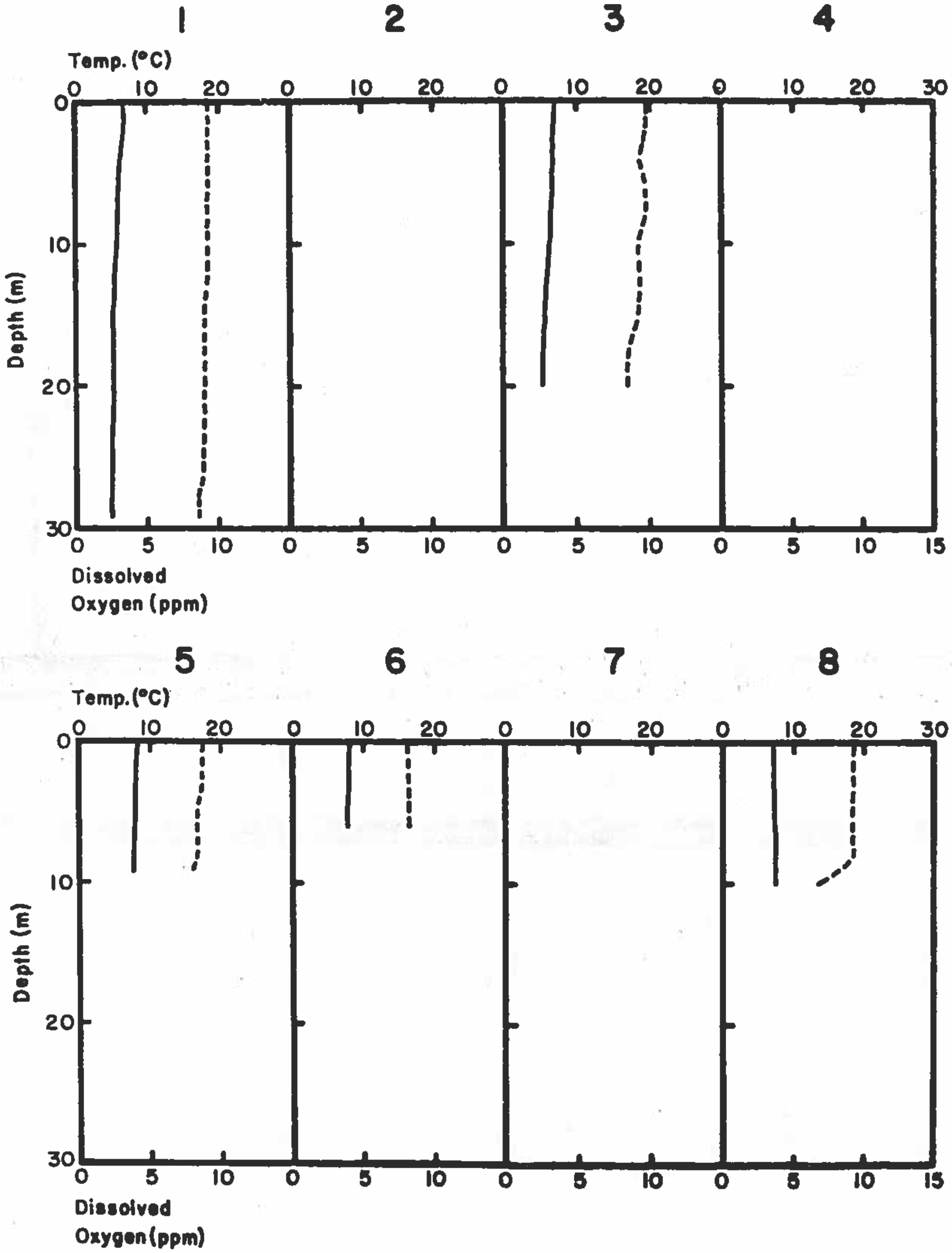
11/24/67





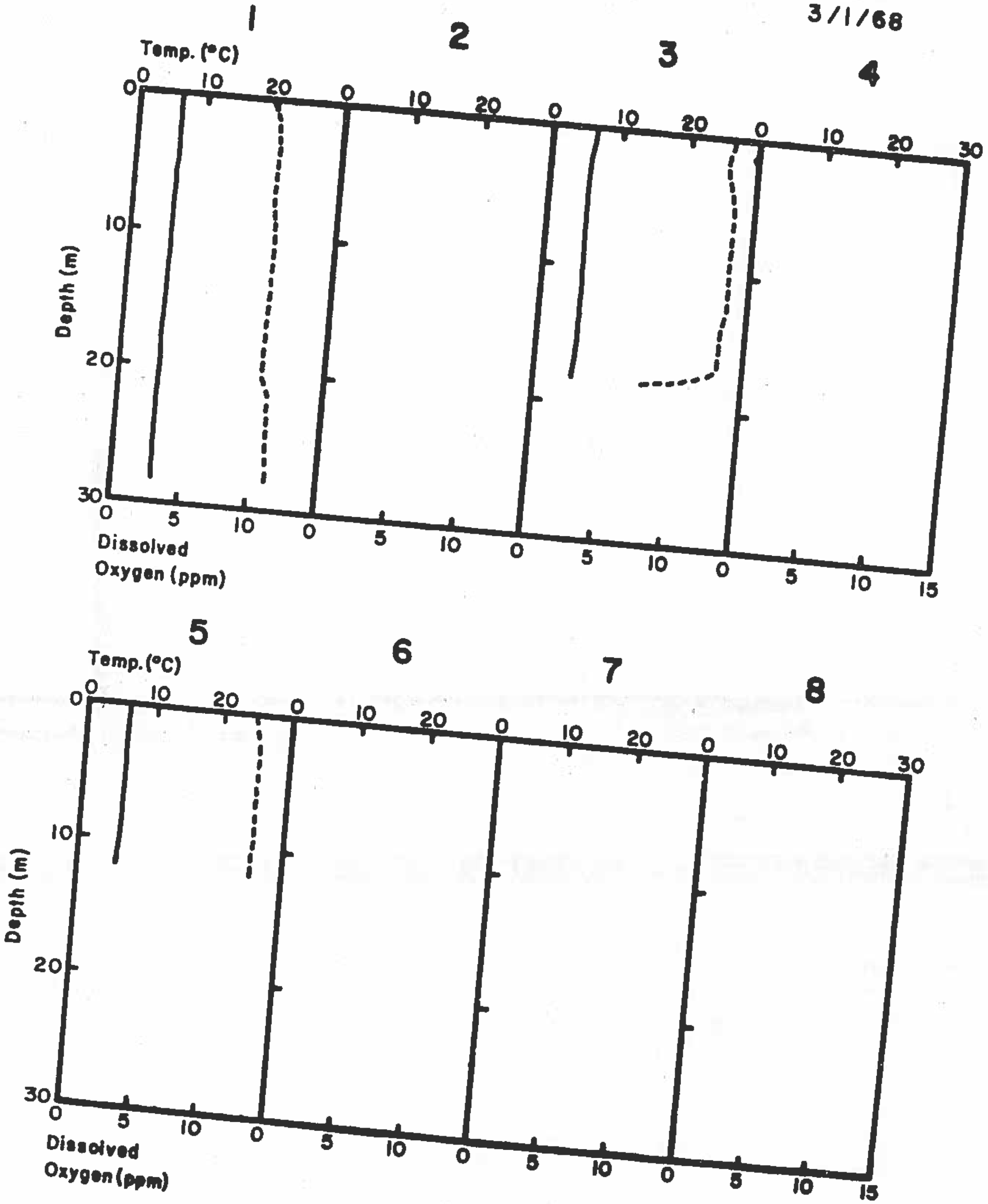
Hamilton

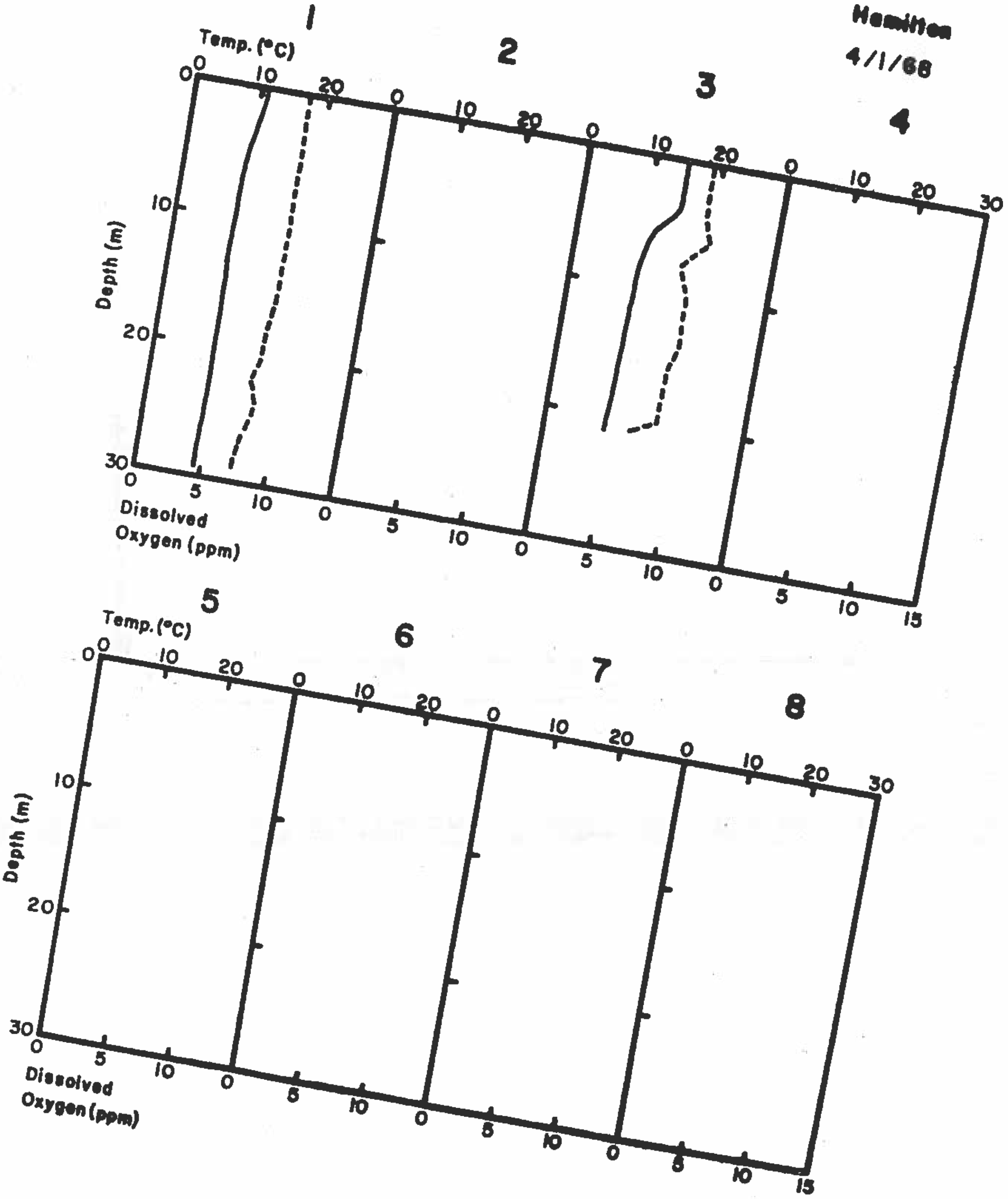
1/27/68



Hamilton

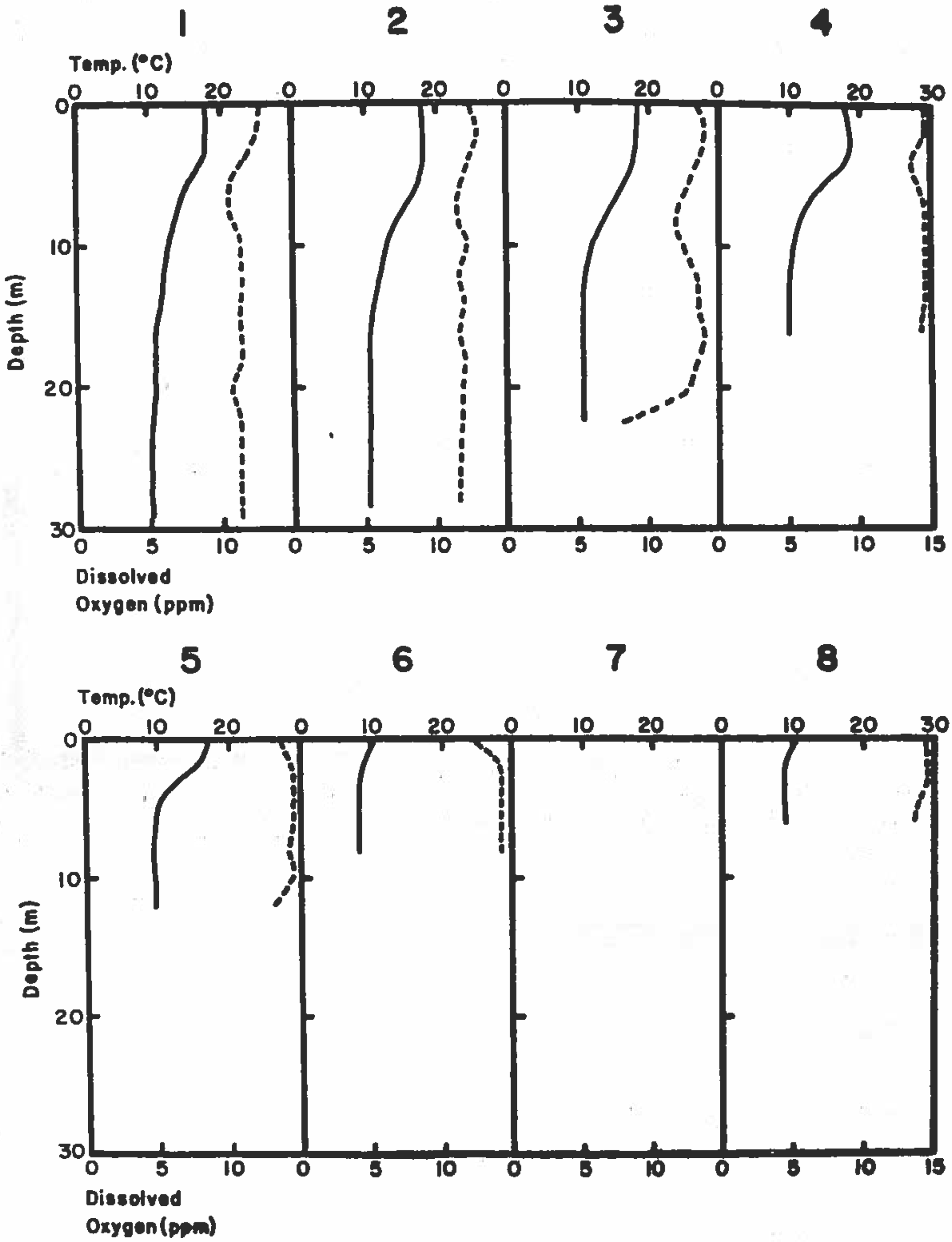
3/1/68




Hamilton
4/1/68
1
2
3
4
5
6
7
8
Temp. (°C)
0
10
20
30
Depth (m)
0
10
20
30
Dissolved Oxygen (ppm)
0
5
10
15

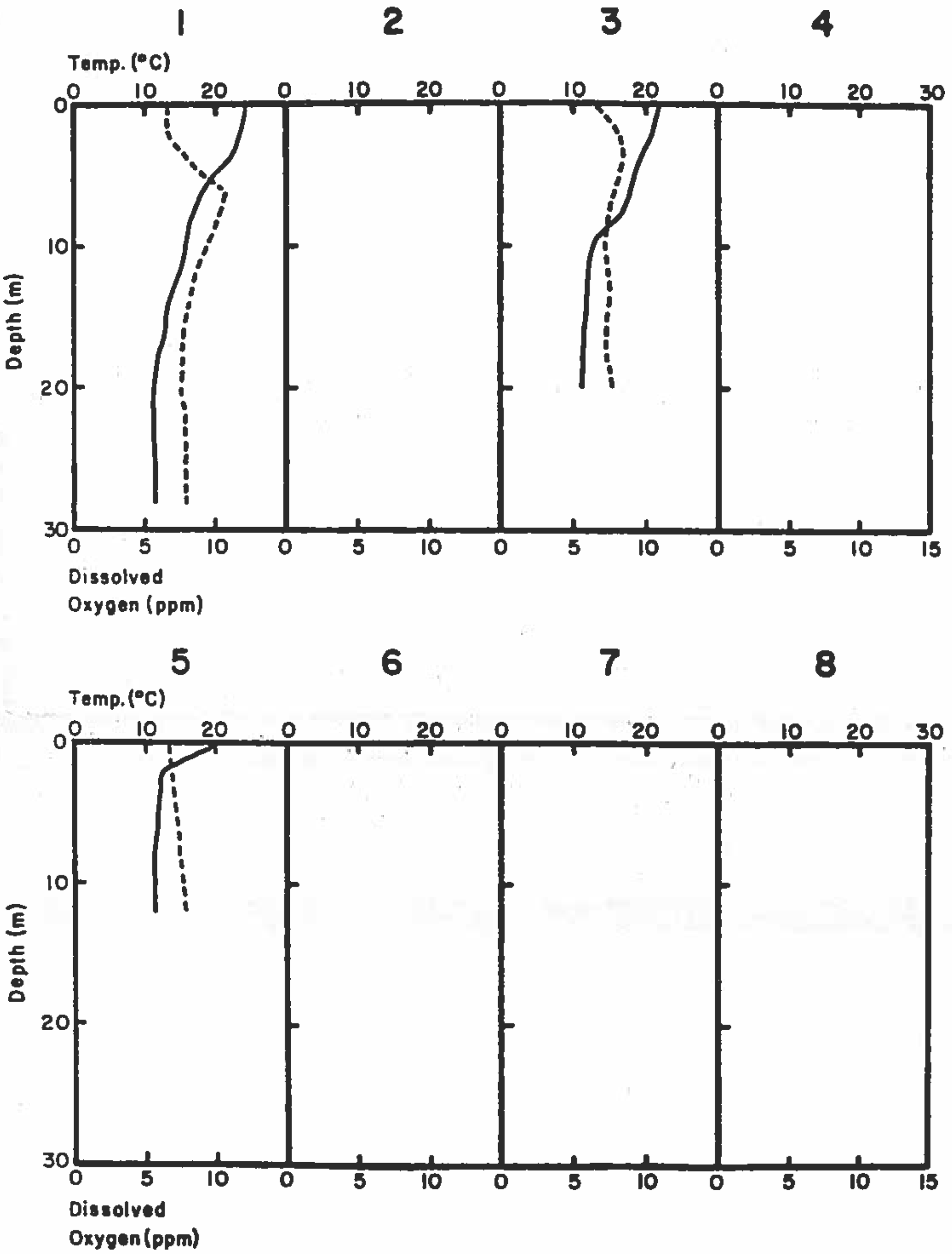
Hamilton

4/28/68



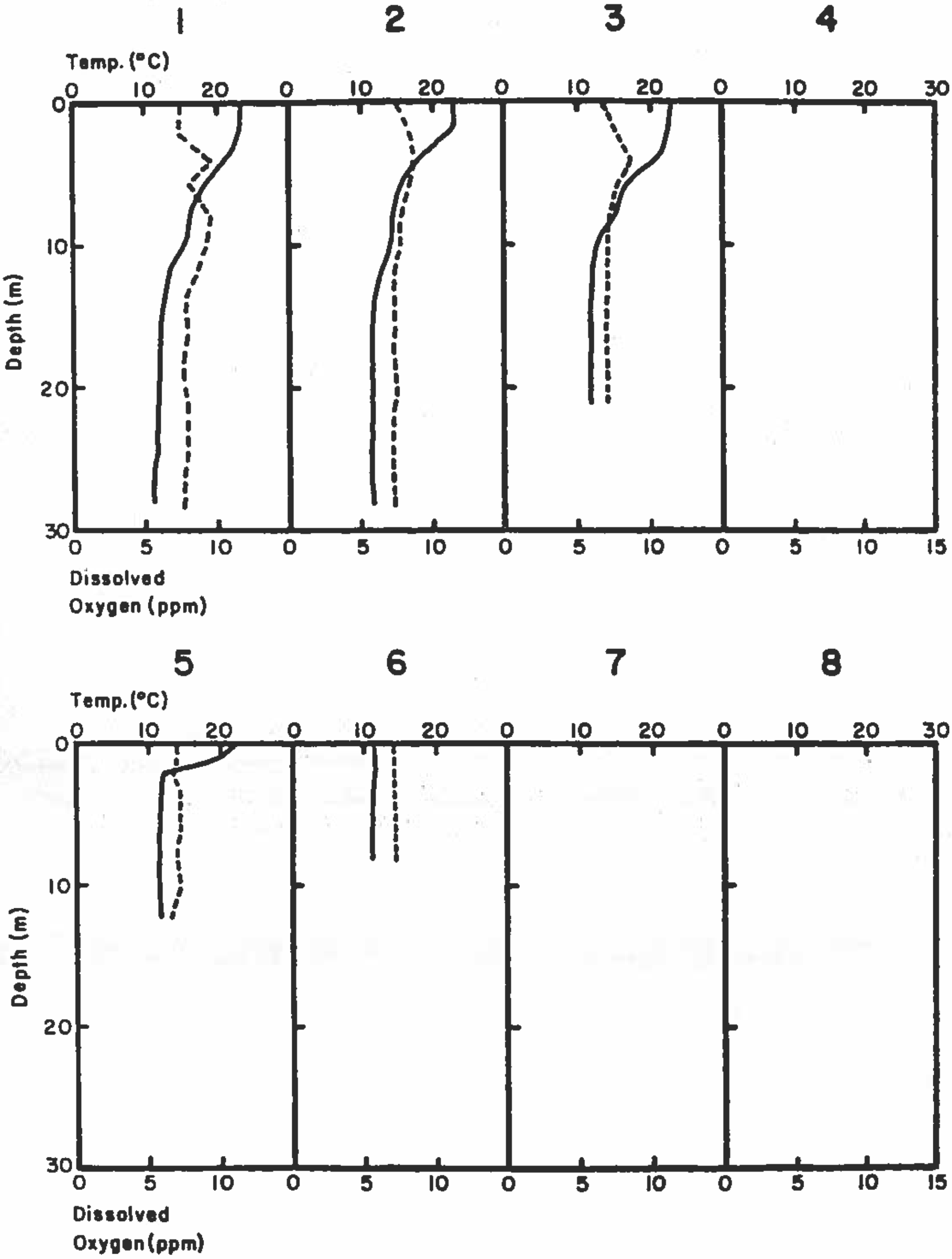
**Hamilton**

**5/23/68**

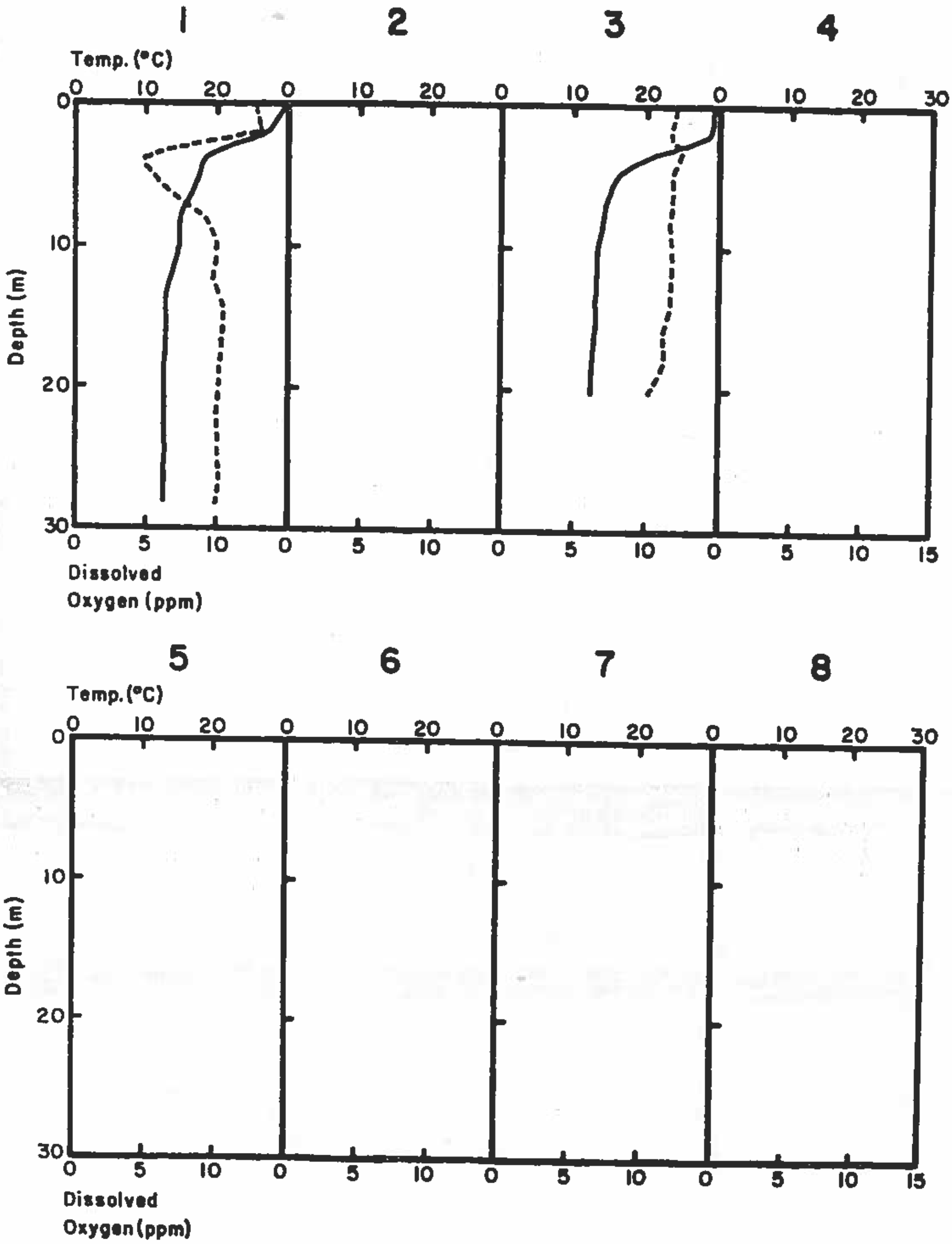


Hamilton

5/30/68

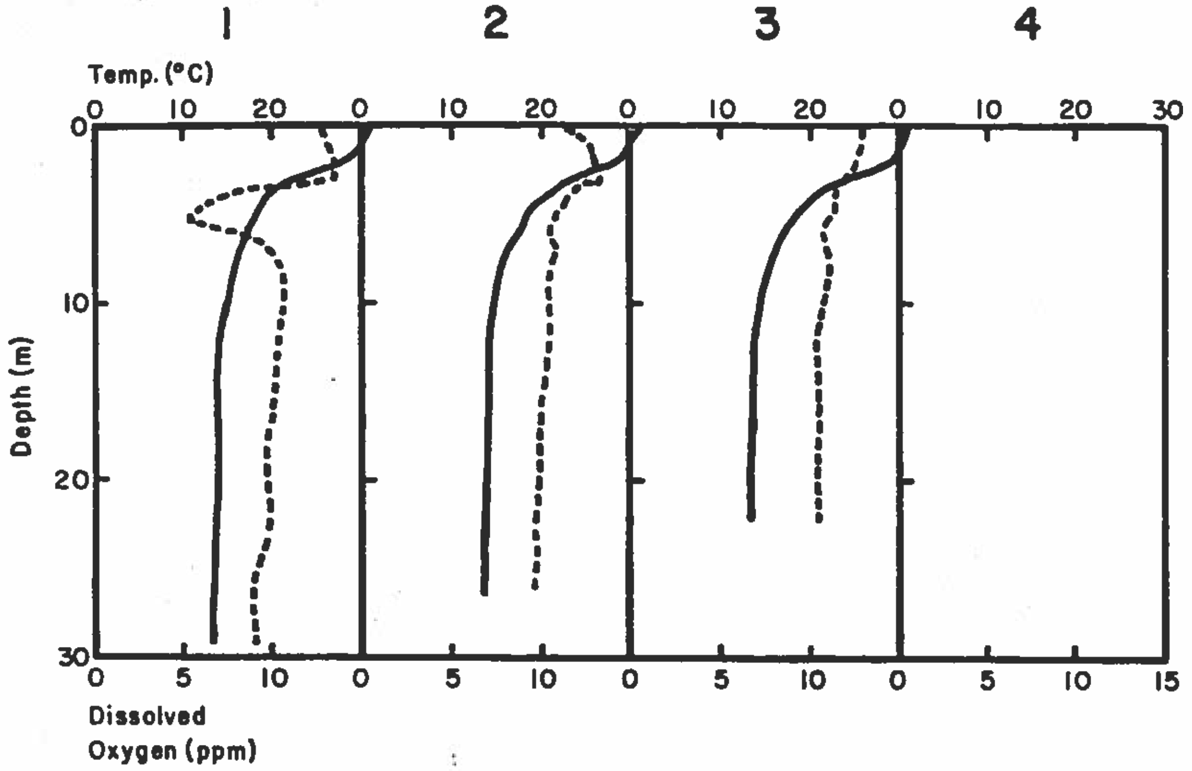


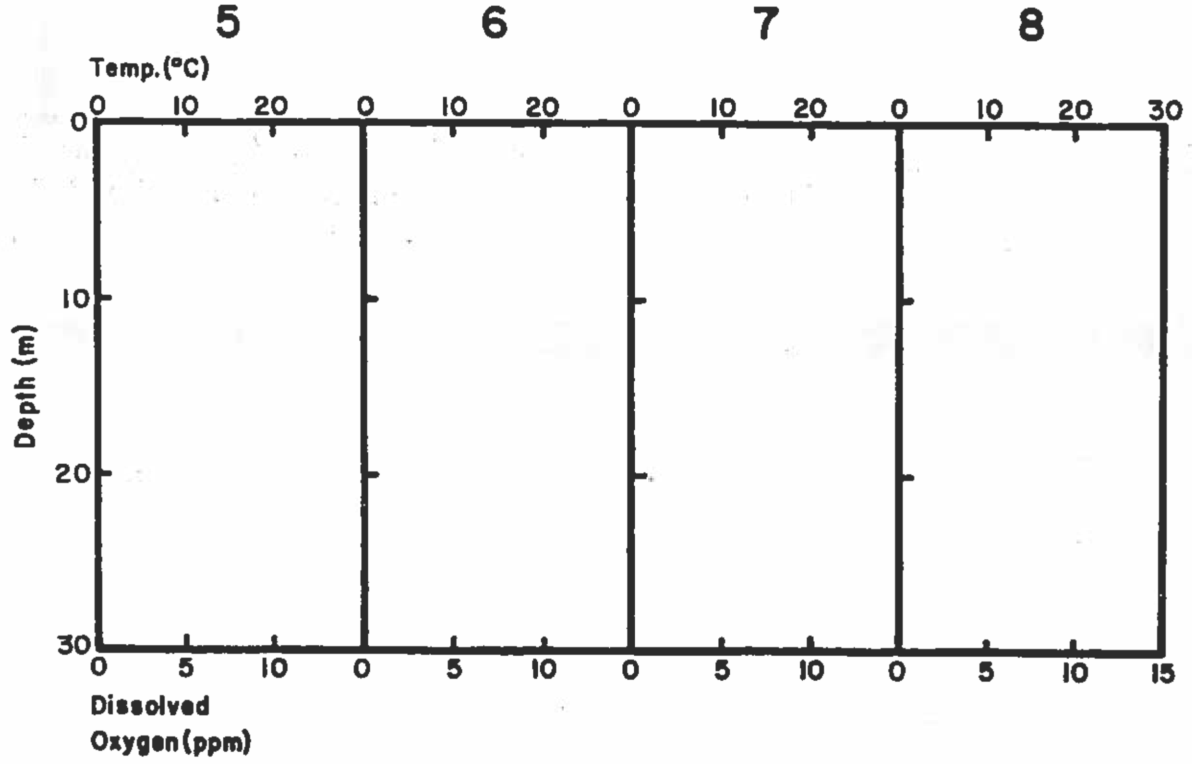
Hamilton
6/14/68



Hamilton

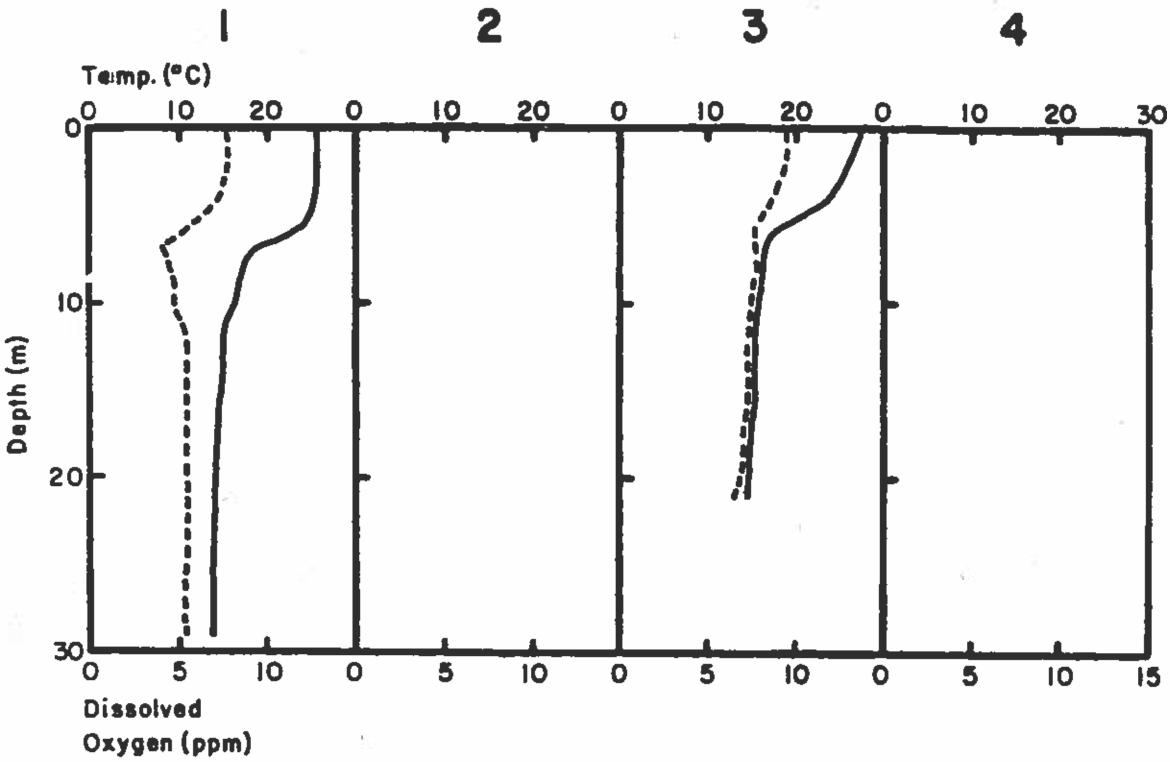
6/21/68

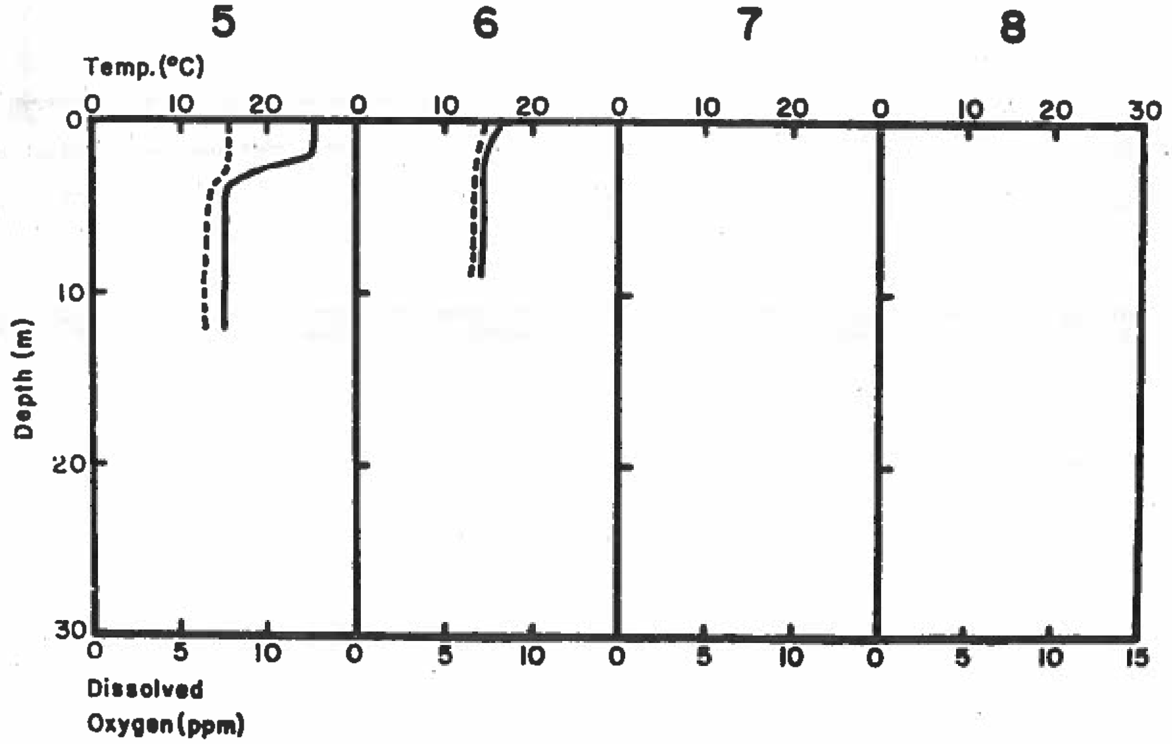




Hamilton

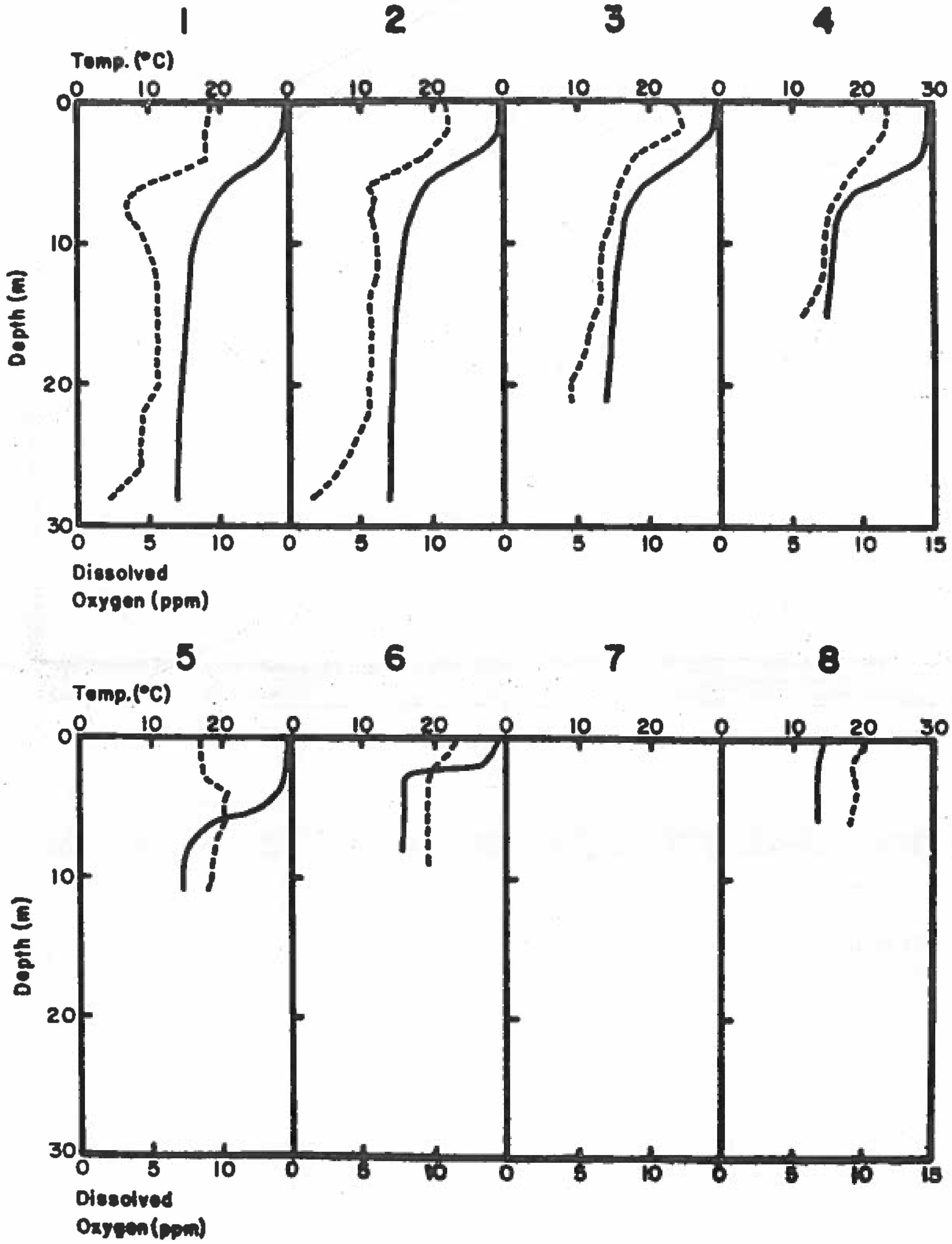
6/27/68





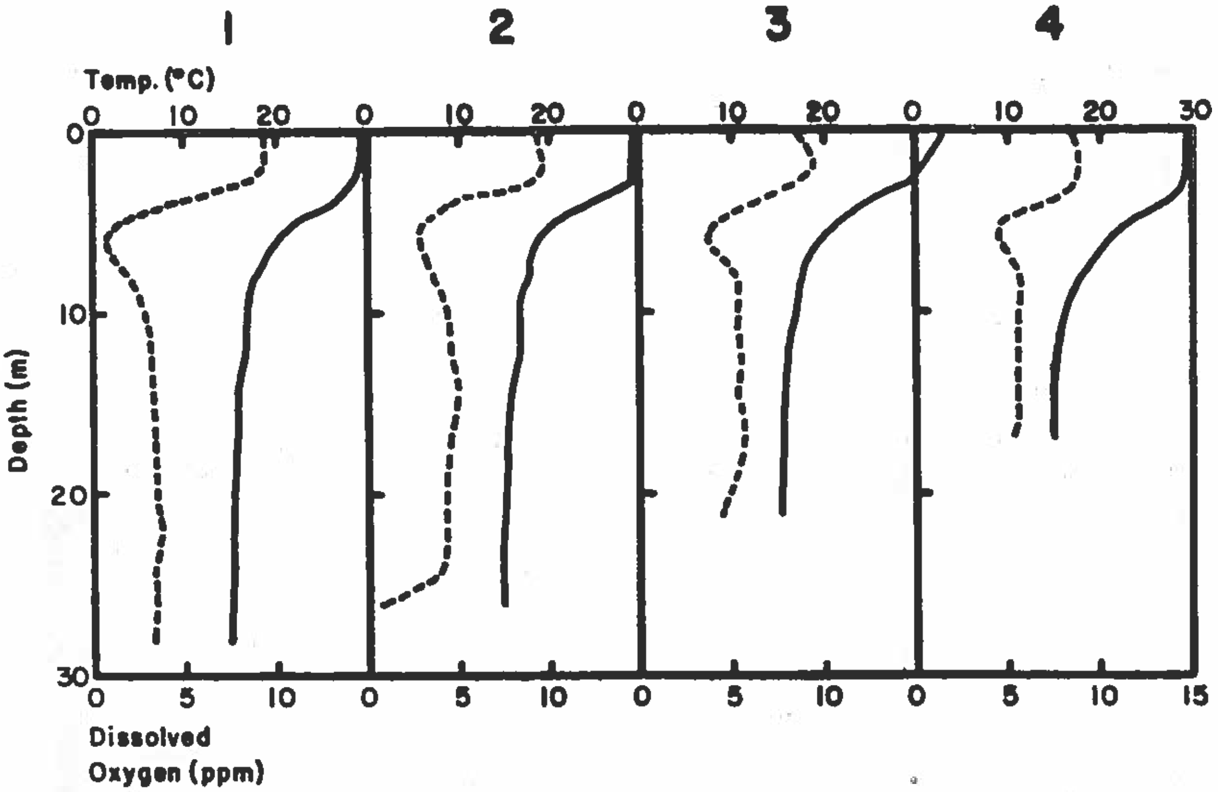
Hamilton

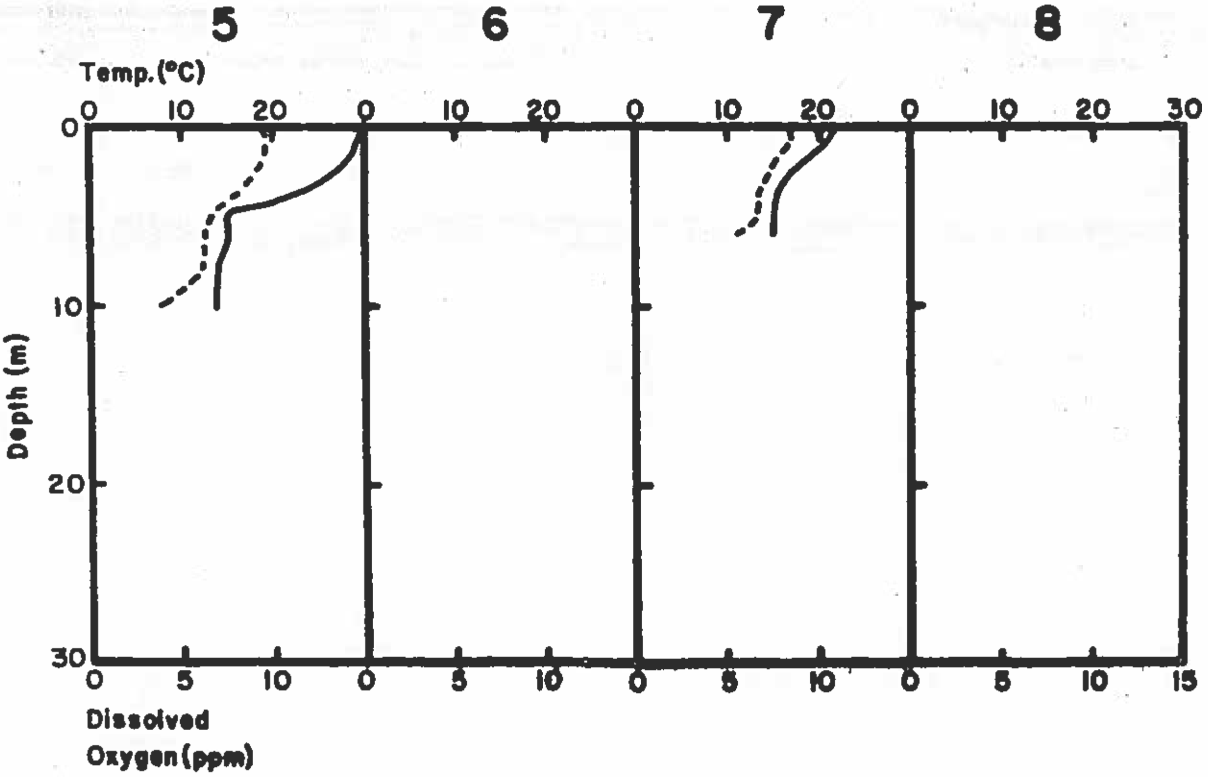
7/16/68



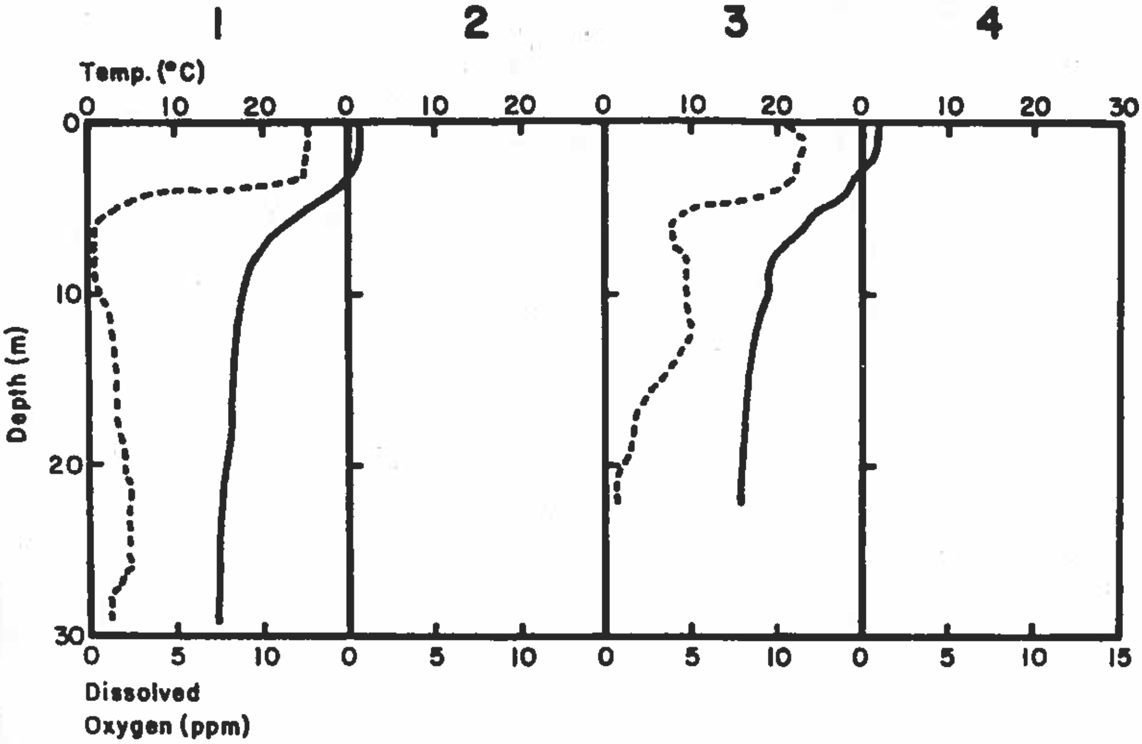
Hamilton

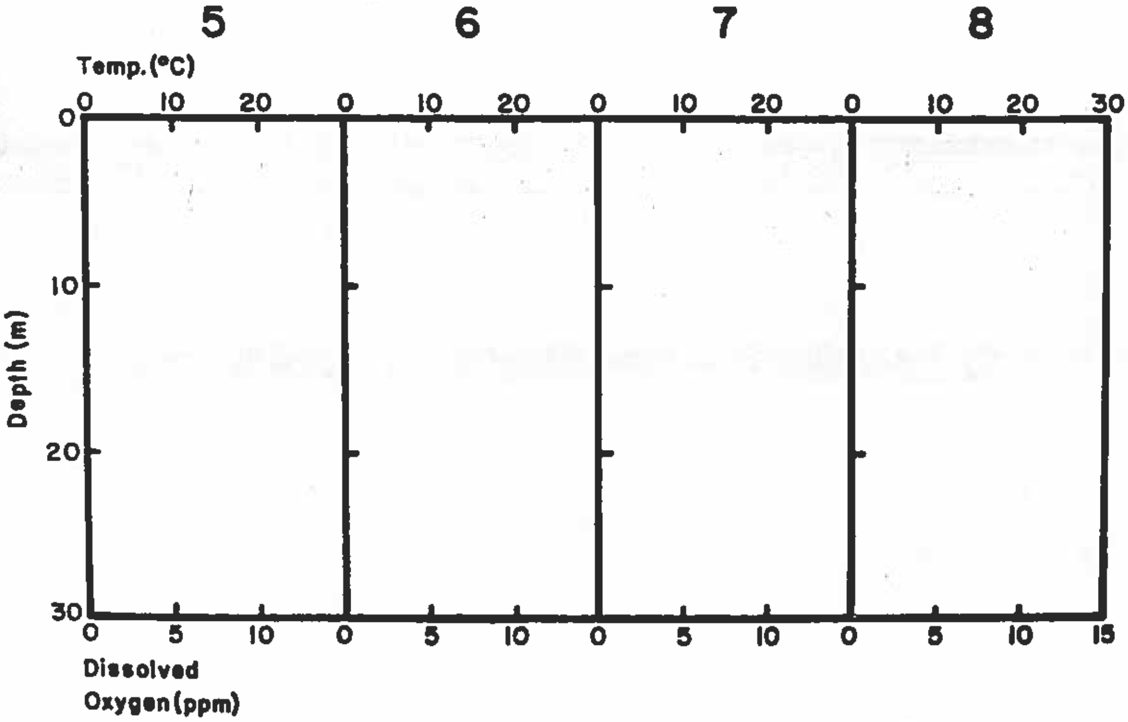
8/2/68





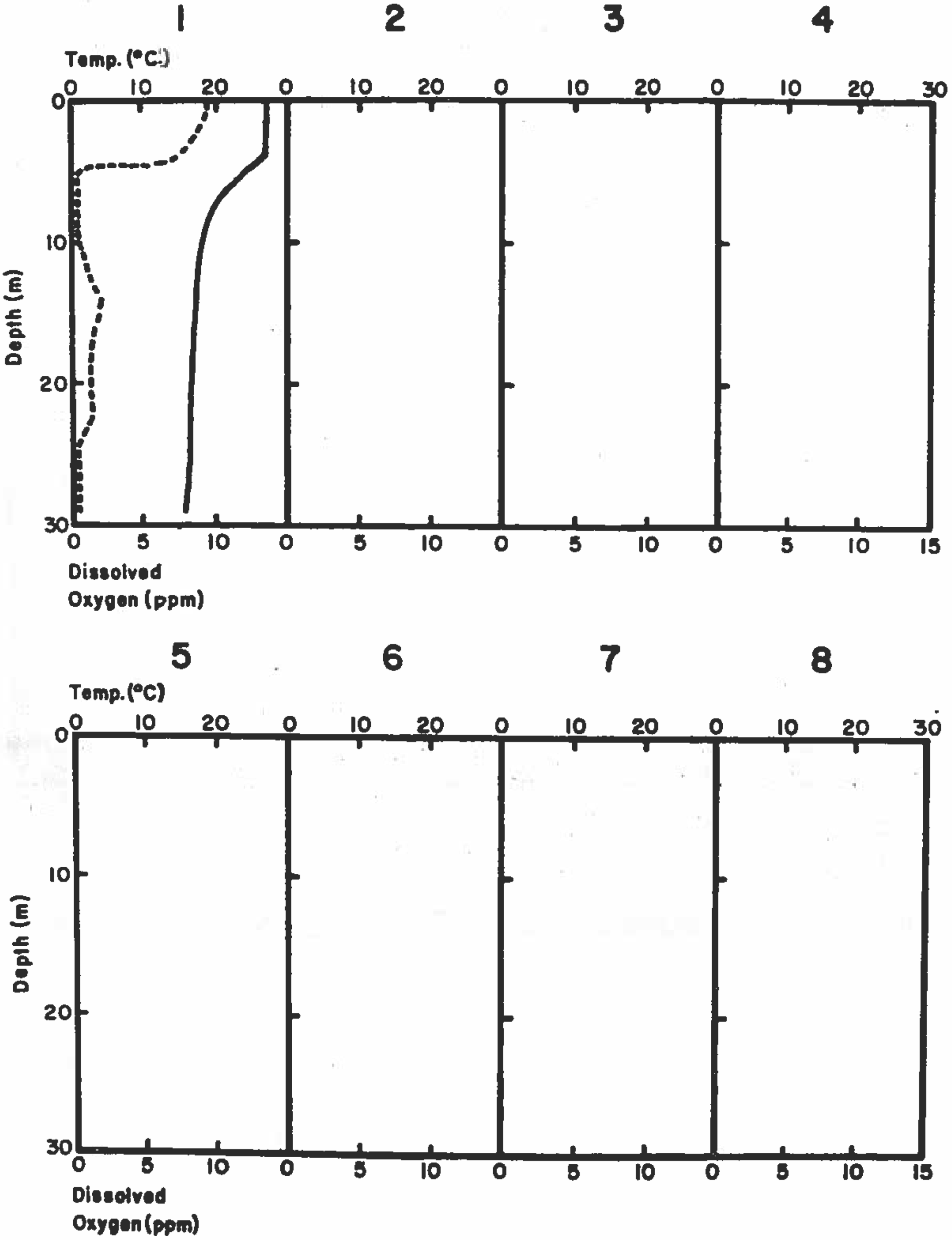
**Hamilton**
**8/21/68**





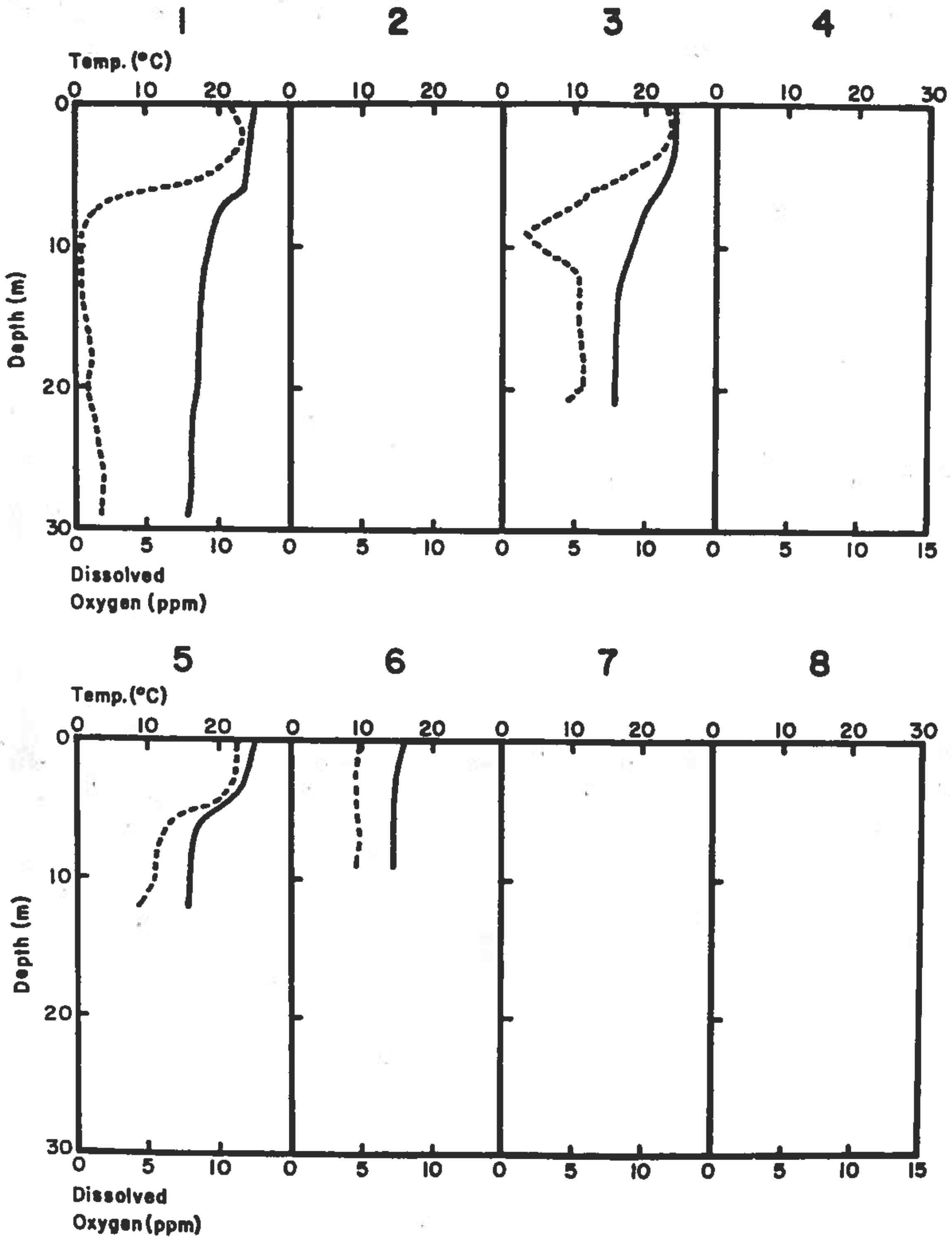
Hamilton

8/30/68

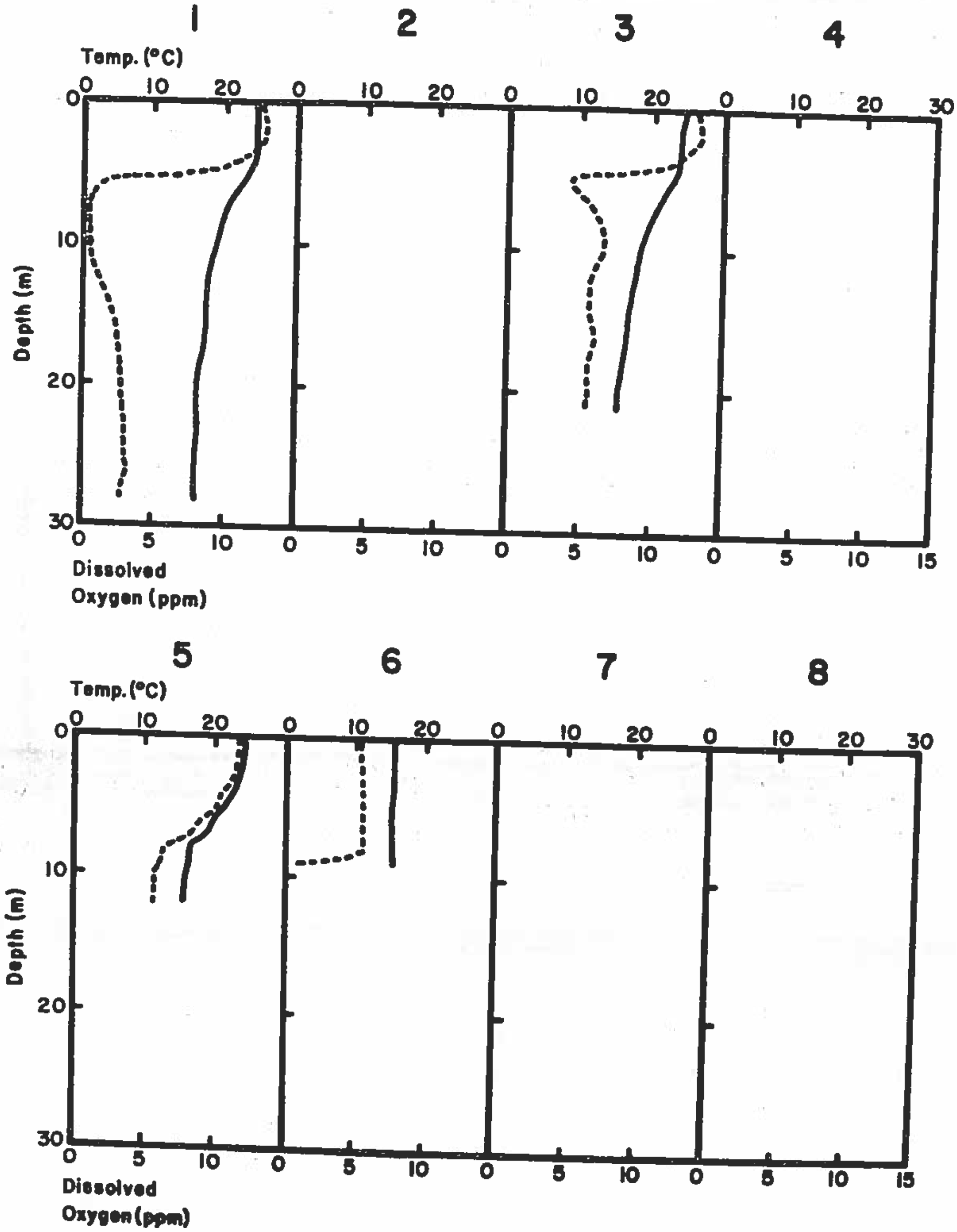


**Hamilton**

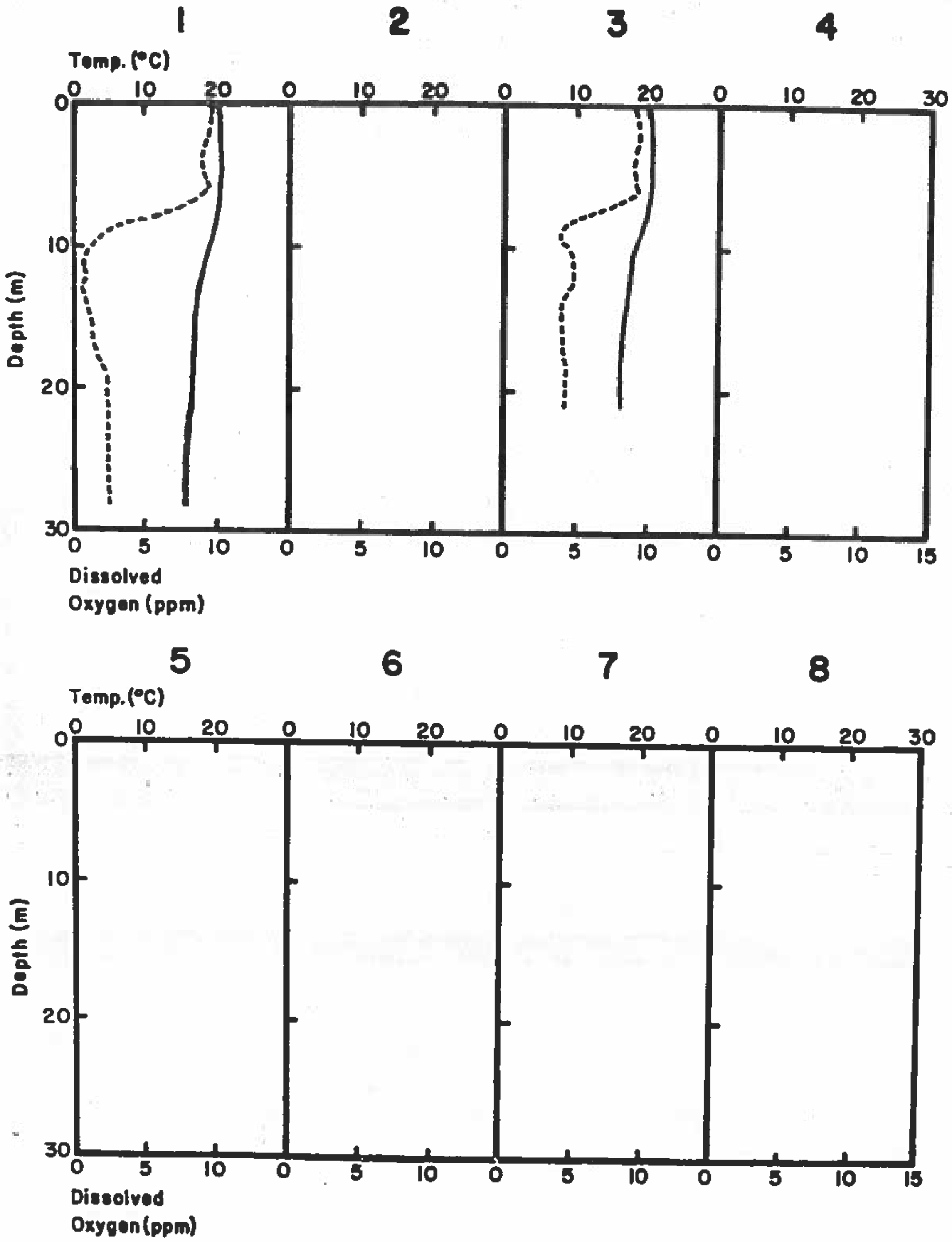
**9/20/68**



Hamilton
9/28/68

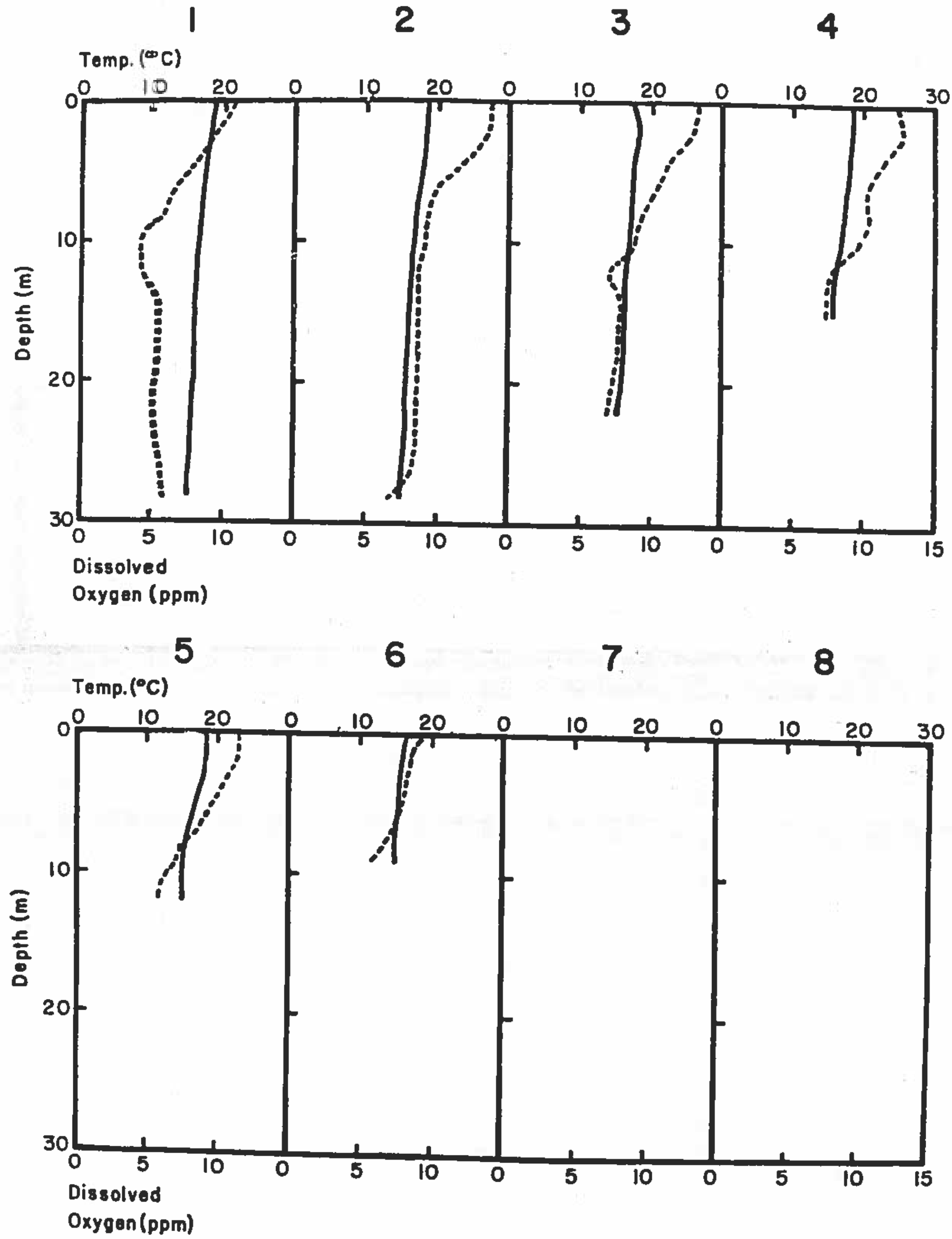


Hamilton
10/19/68



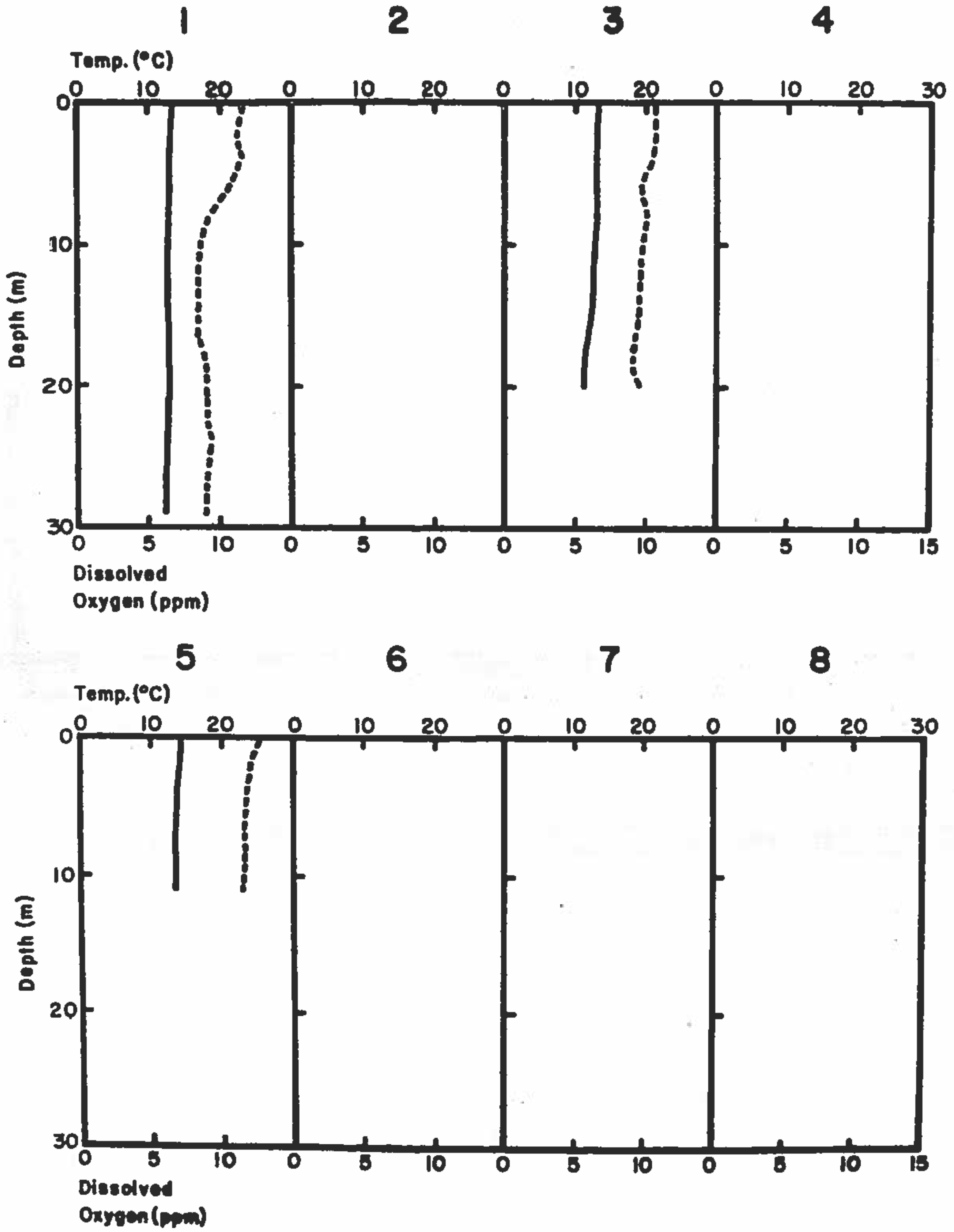
Hamilton

11/2/68



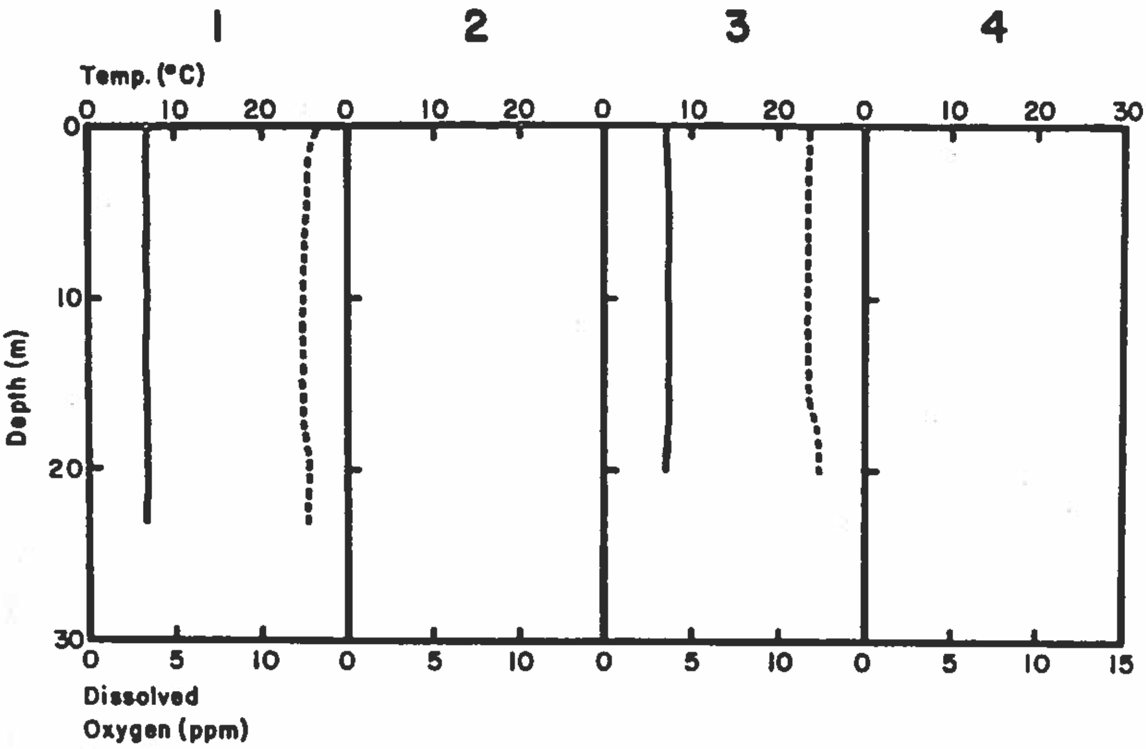
Hamilton

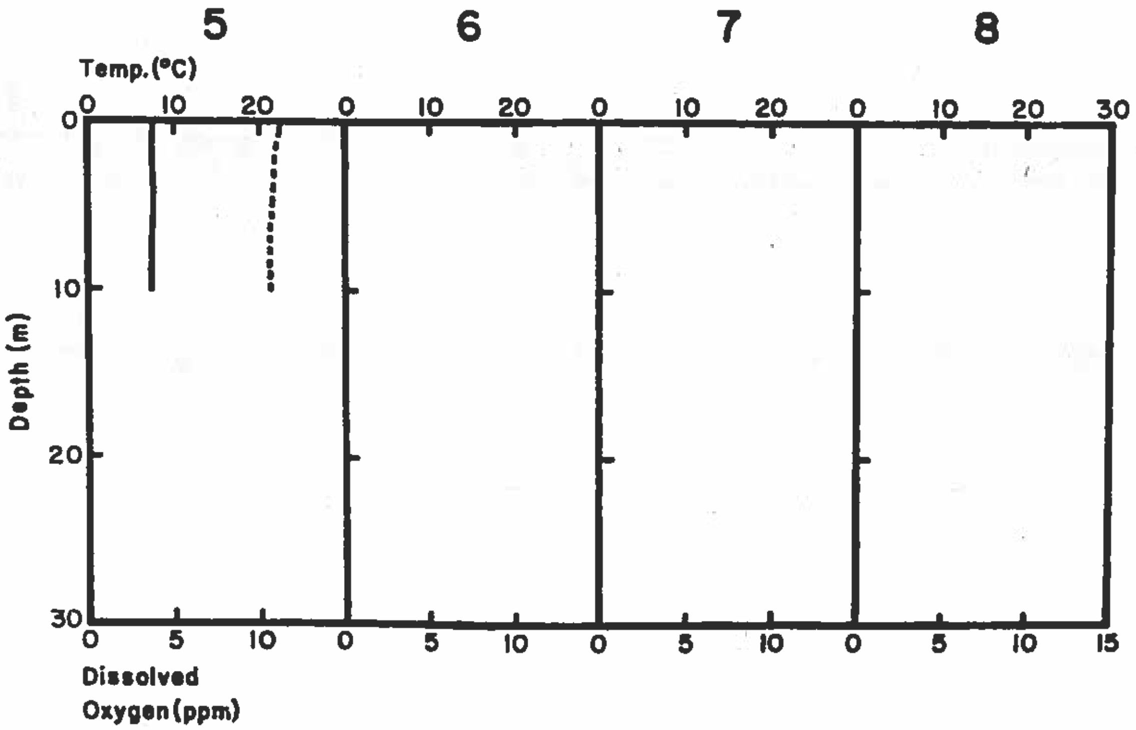
11/23/68



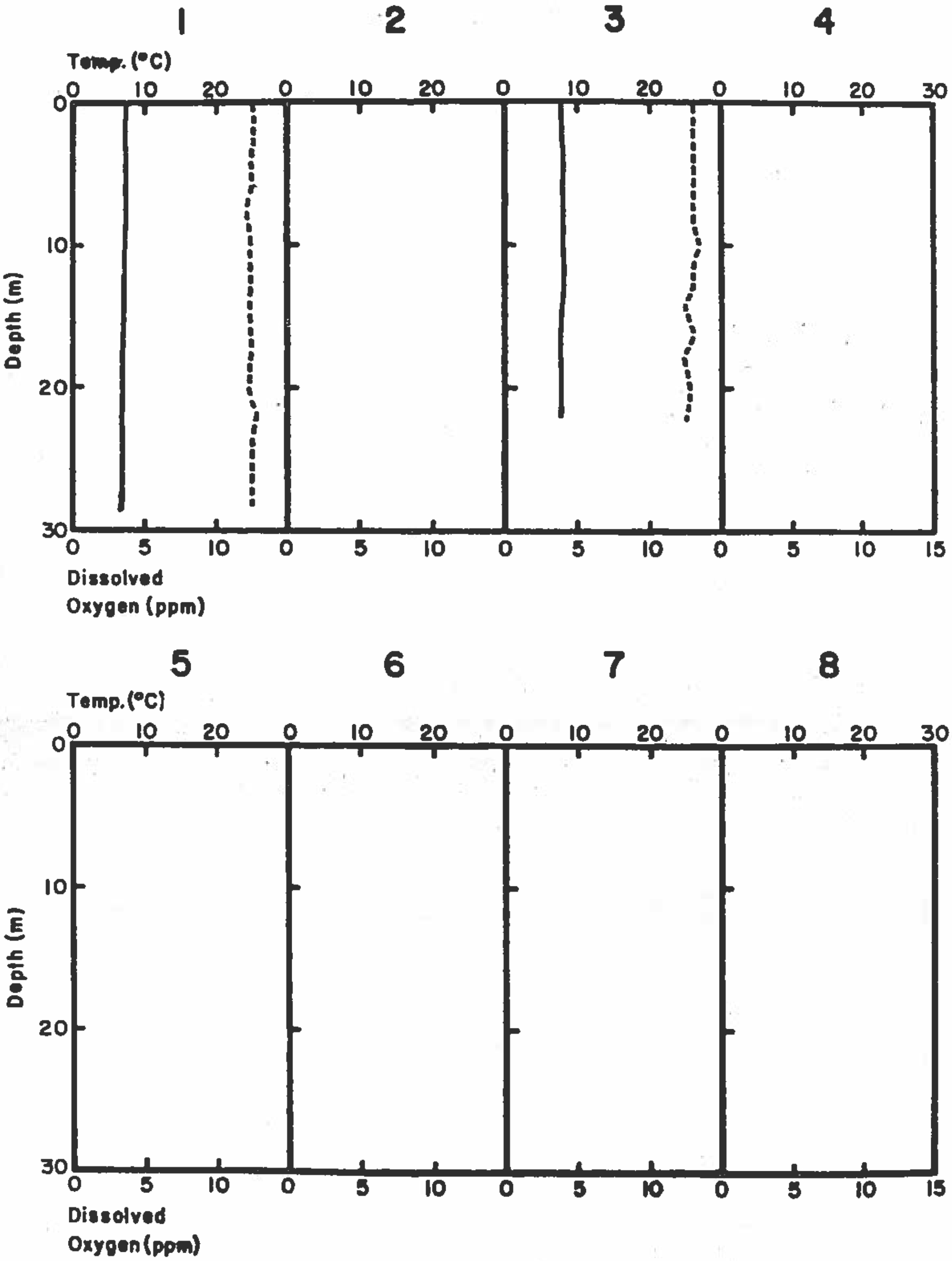
**Hamilton**

**1/11/69**

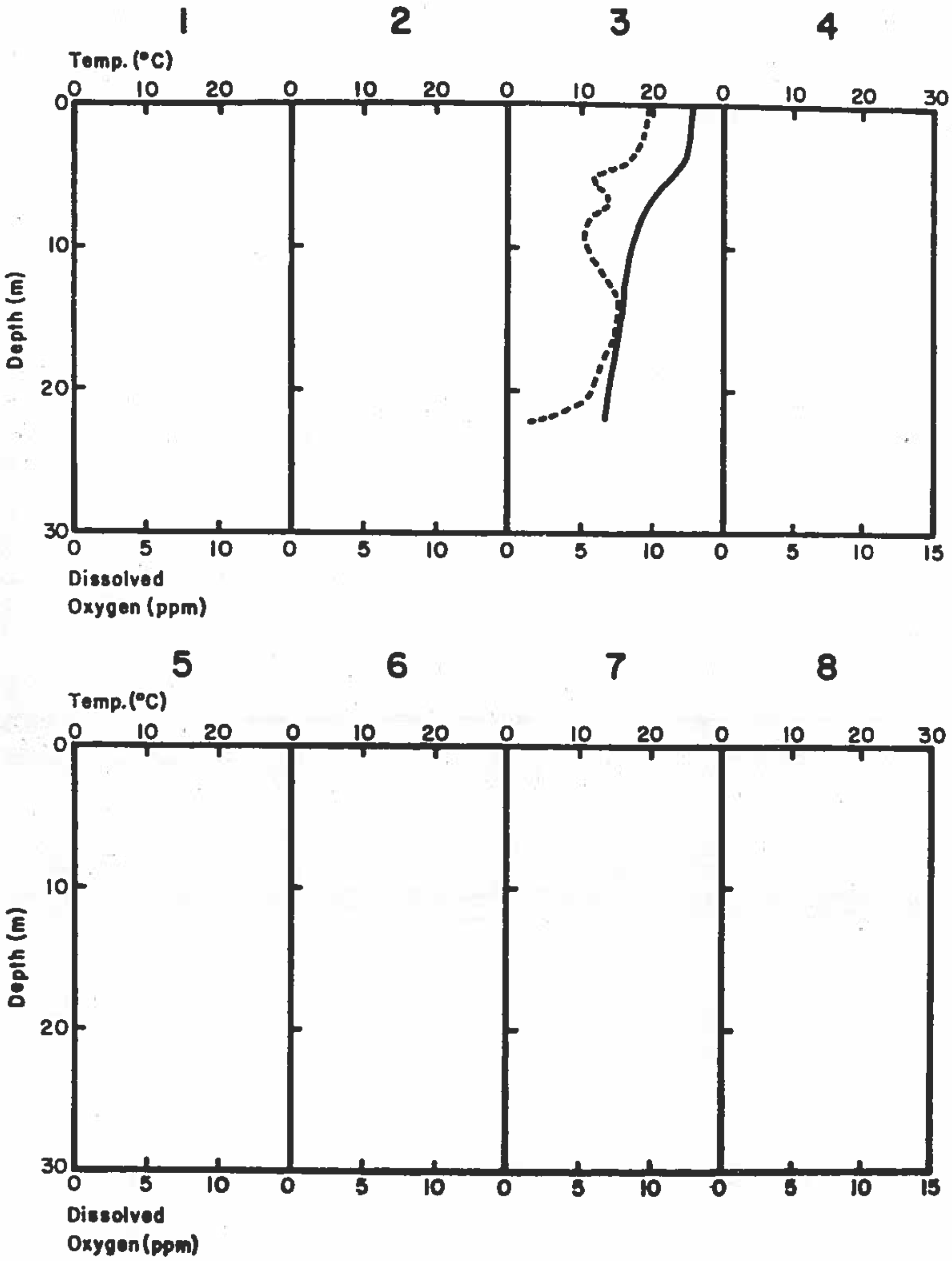




Hamilton
3/15/69



Hamilton
6/4/69



Hamilton

6/18/69

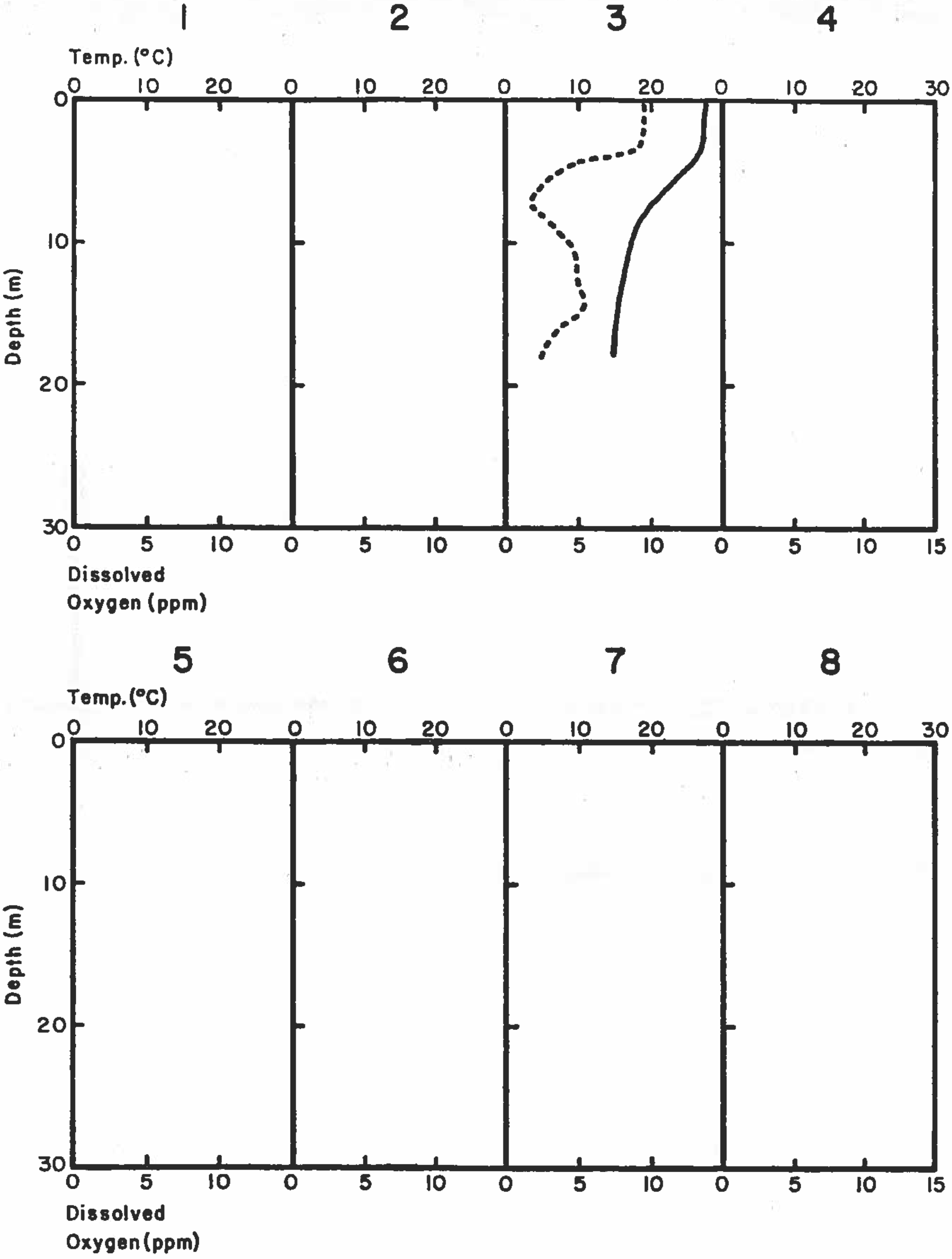


Figure 43

Phosphate concentration at Station 1 on Lake Hamilton during 1968

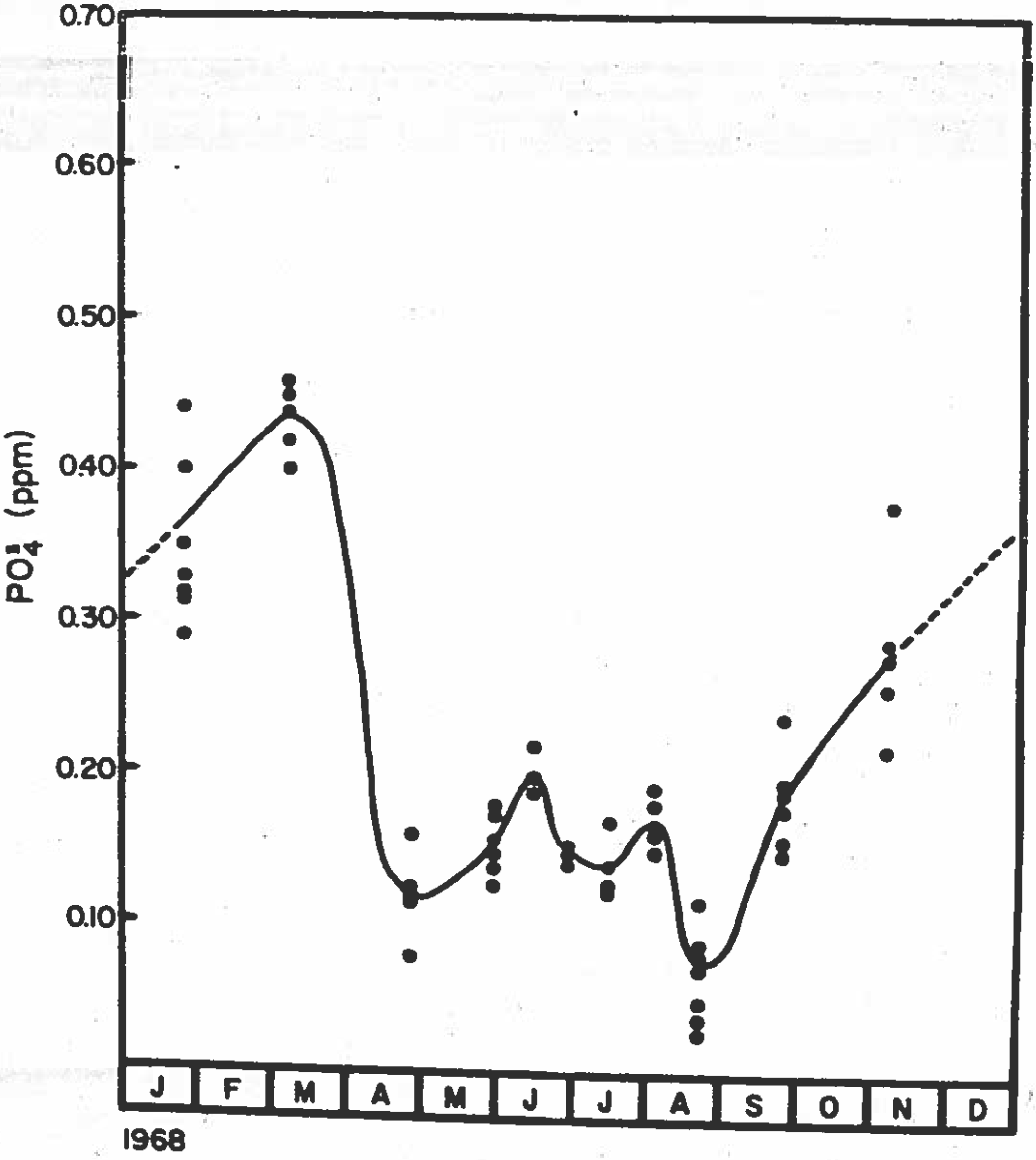

0.70
0.60
0.50
0.40
0.30
0.20
0.10
PO$_4^{\equiv}$ (ppm)
J
F
M
A
M
J
J
A
S
O
N
D
1968

Figure 44

Dissolved Oxygen distribution at Station MC, Lake Hamilton

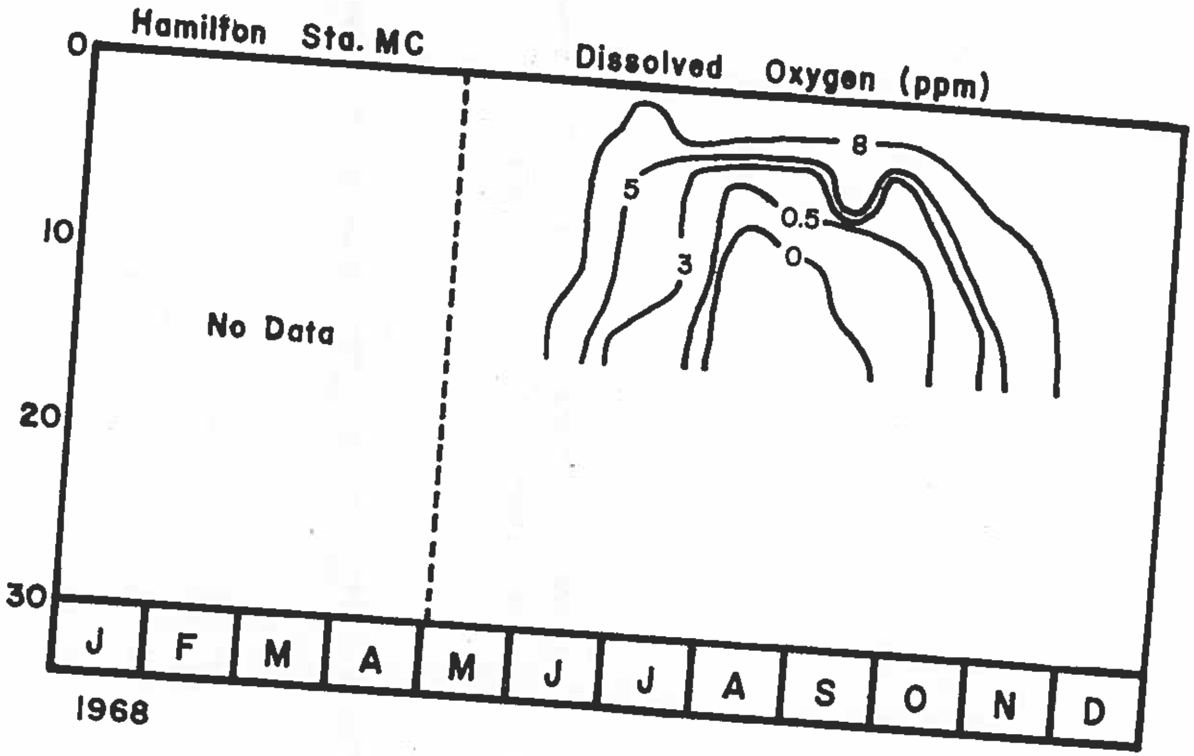

Hamilton Sta. MC
Dissolved Oxygen (ppm)
No Data
0
10
20
30
8
5
3
0.5
0
J
F
M
A
M
J
J
A
S
O
N
D
1968

Figure 45

Iron distribution at Station MC, Lake Hamilton

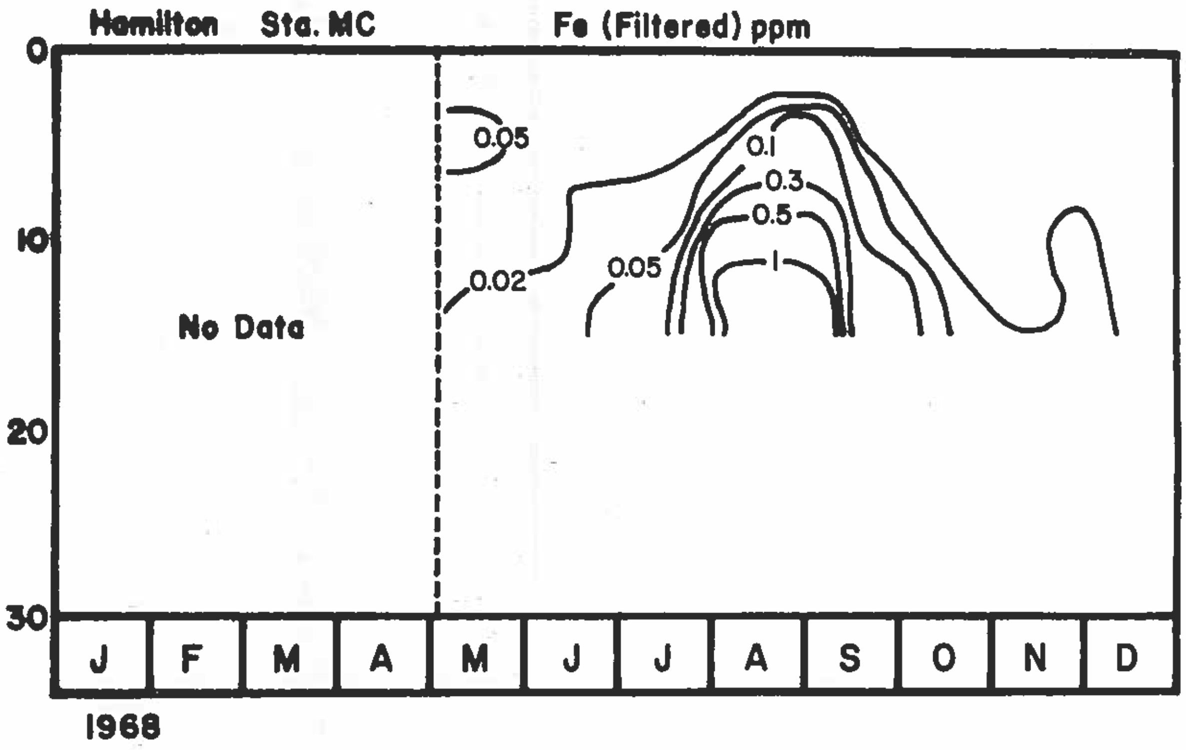

Hamilton Sta. MC
Fe (Filtered) ppm
0
10
20
30
No Data
0.05
0.02
0.05
0.1
0.3
0.5
1
J
F
M
A
M
J
J
A
S
O
N
D
1968

Figure 46

Manganese distribution at Station MC, Lake Hamilton

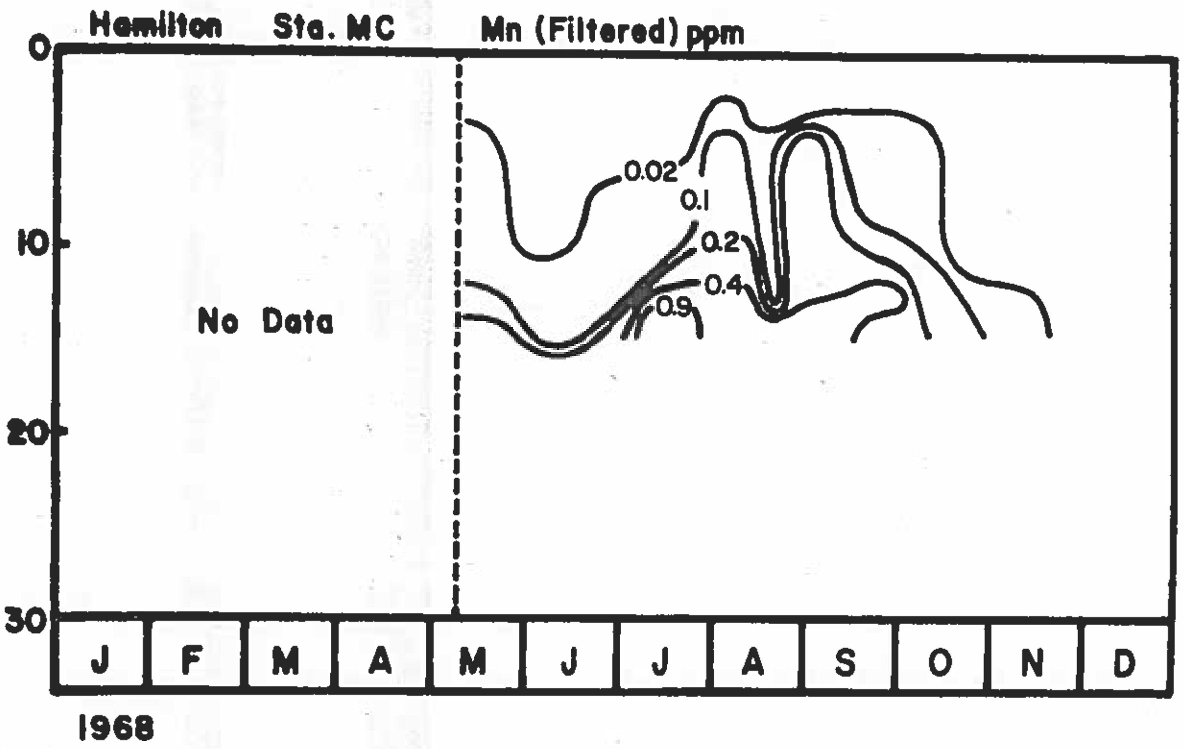
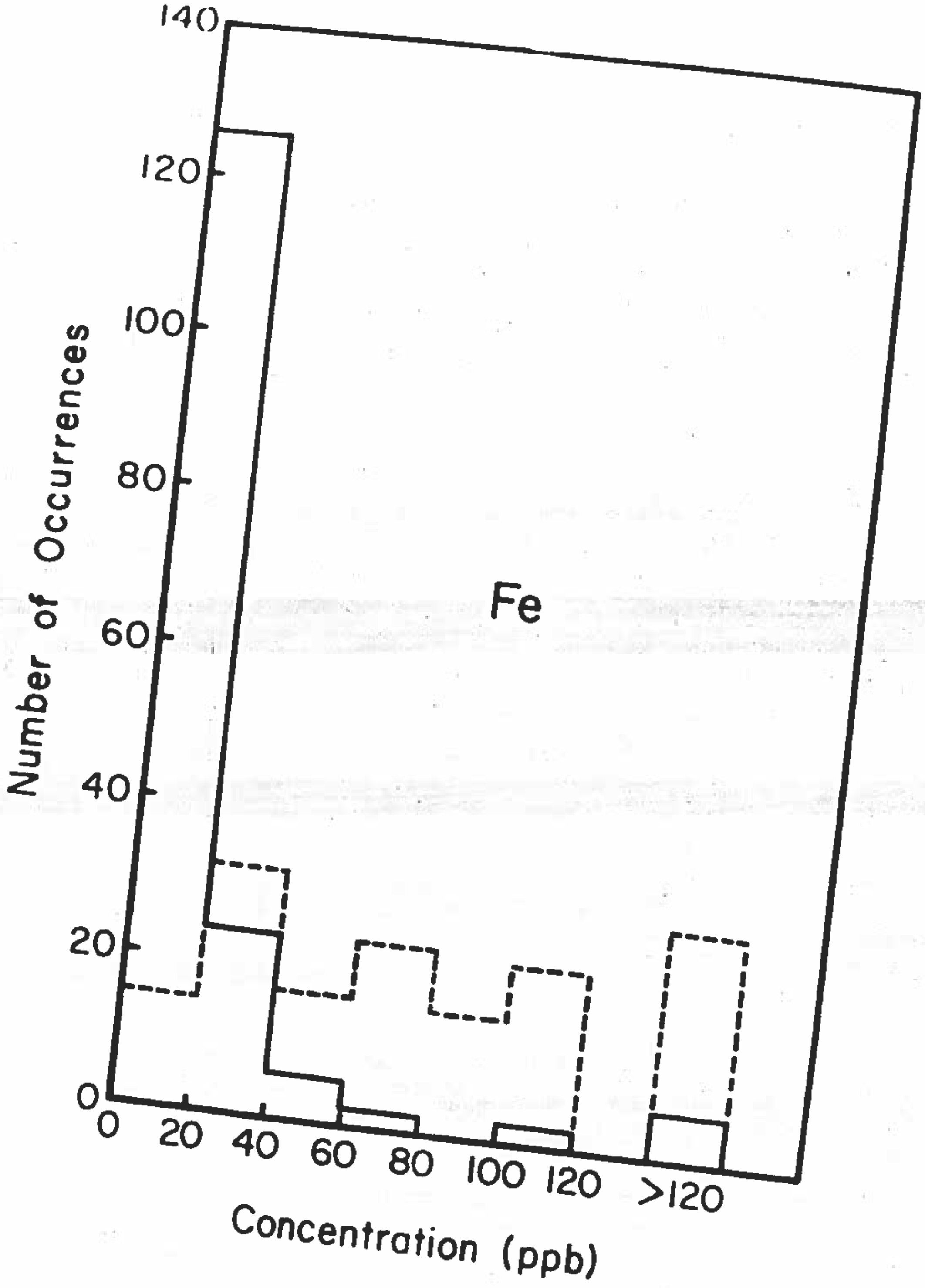

Hamilton
Sta. MC
Mn (Filtered) ppm
0
10
20
30
No Data
0.02
0.1
0.2
0.4
0.9
J
F
M
A
M
J
J
A
S
O
N
D
1968

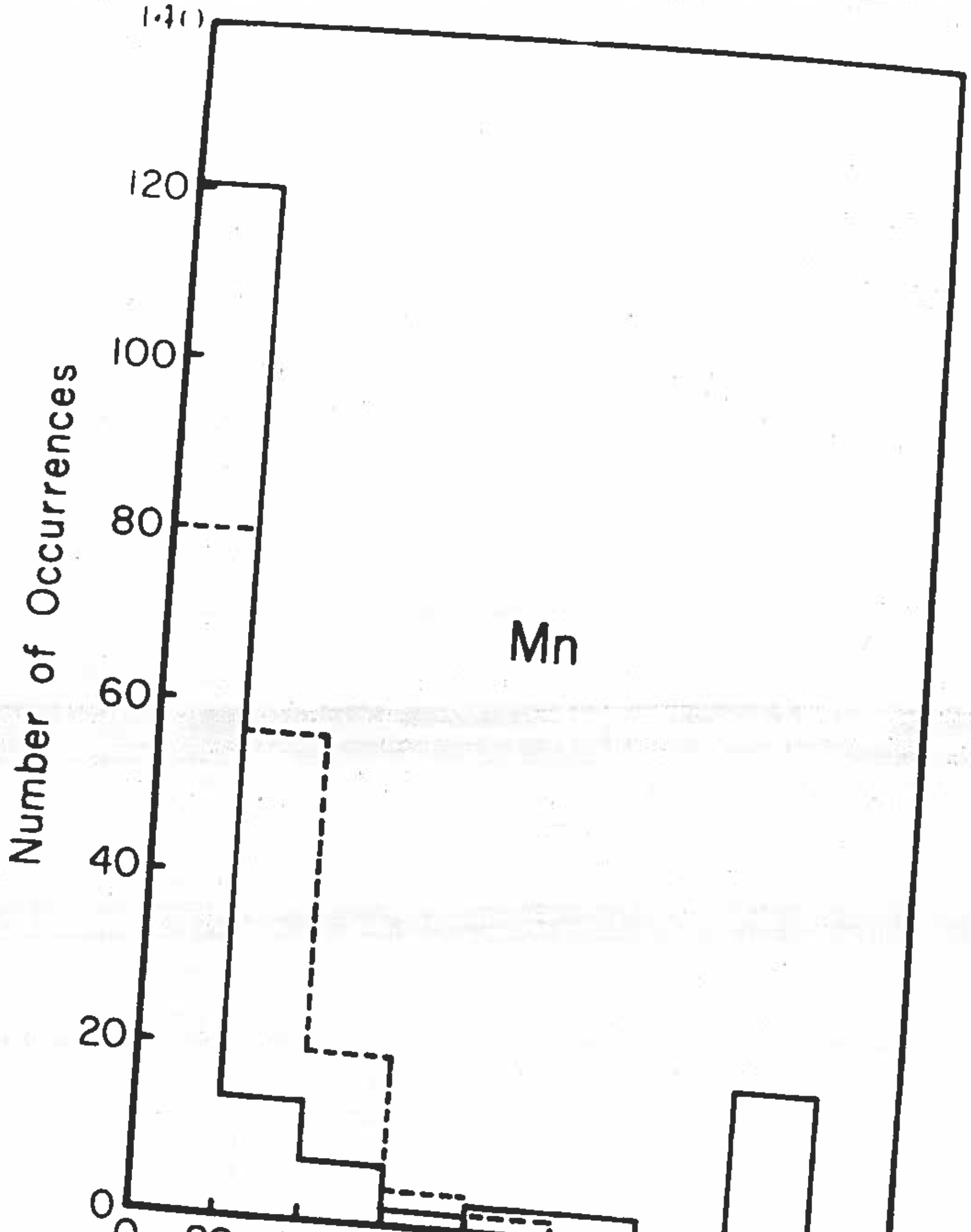
Figure 47 through 54

Plot of concentration of heavy metals vs the number of occurrences at stations in Lake Hamilton. The solid line represents metals in the filtered fraction while the dotted line represents the metal present in the particulate fraction.

| Figure No. | Element |
|---|---|
| 47 | Iron |
| 48 | Manganese |
| 49 | Copper |
| 50 | Nickel |
| 51 | Cobalt |
| 52 | Lead |
| 53 | Zinc |
| 54 | Chromium |



140
120
100
80
60
40
20
0
Number of Occurrences
Fe
0
20
40
60
80
100
120
>120
Concentration (ppb)


140
120
100
80
60
40
20
0
Number of Occurrences
Mn
0
20
40
60
80
100
120
>120
Concentration (ppb)

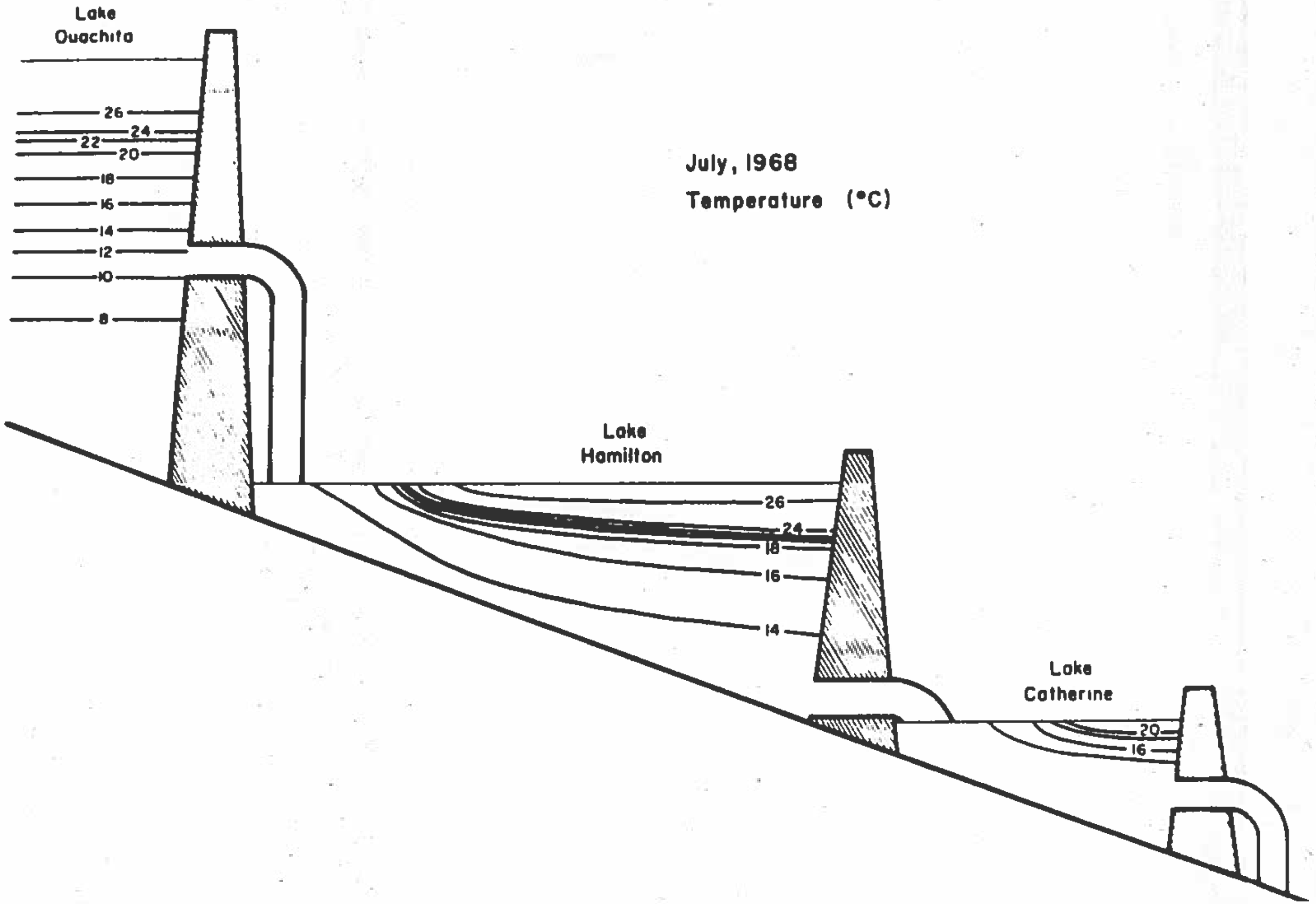

July, 1968
Temperature (°C)

Figure 37

Temperature and Dissolved Oxygen Profiles at Station MC on Lake Hamilton. The solid line represents the temperature (°C) and the dotted line the dissolved oxygen in ppm.

Hamilton
Sta. MC

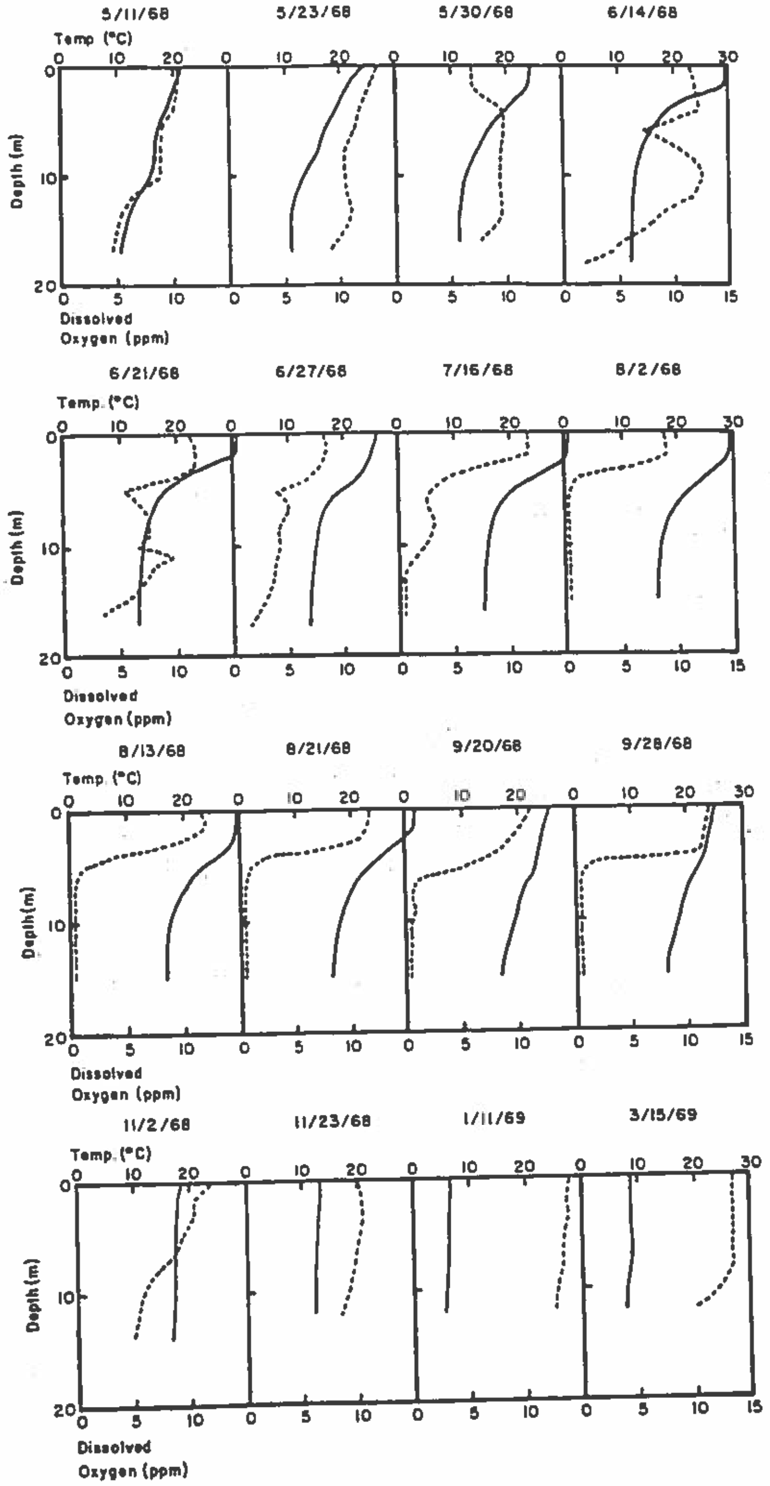
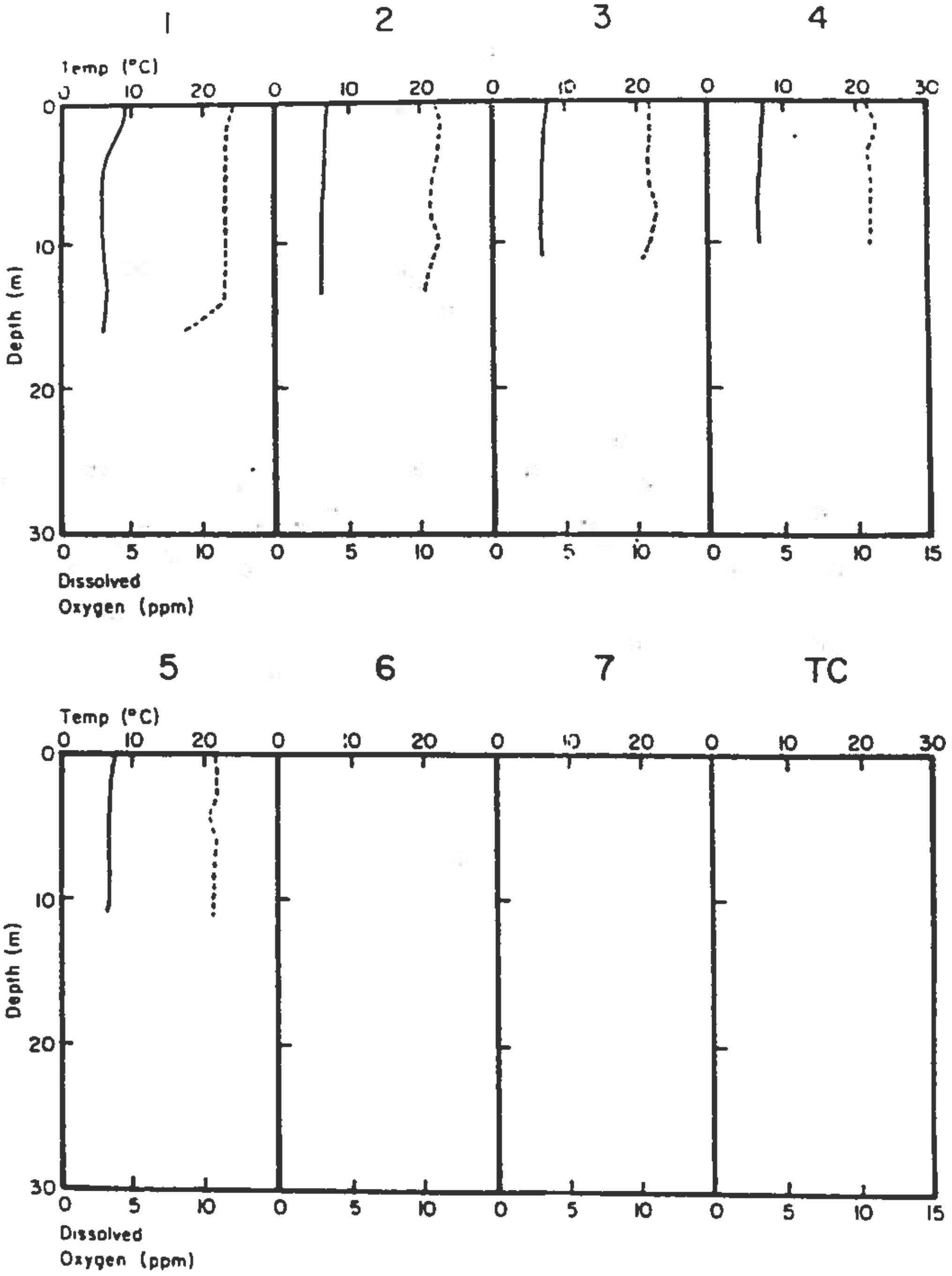


Figure 38 through 42

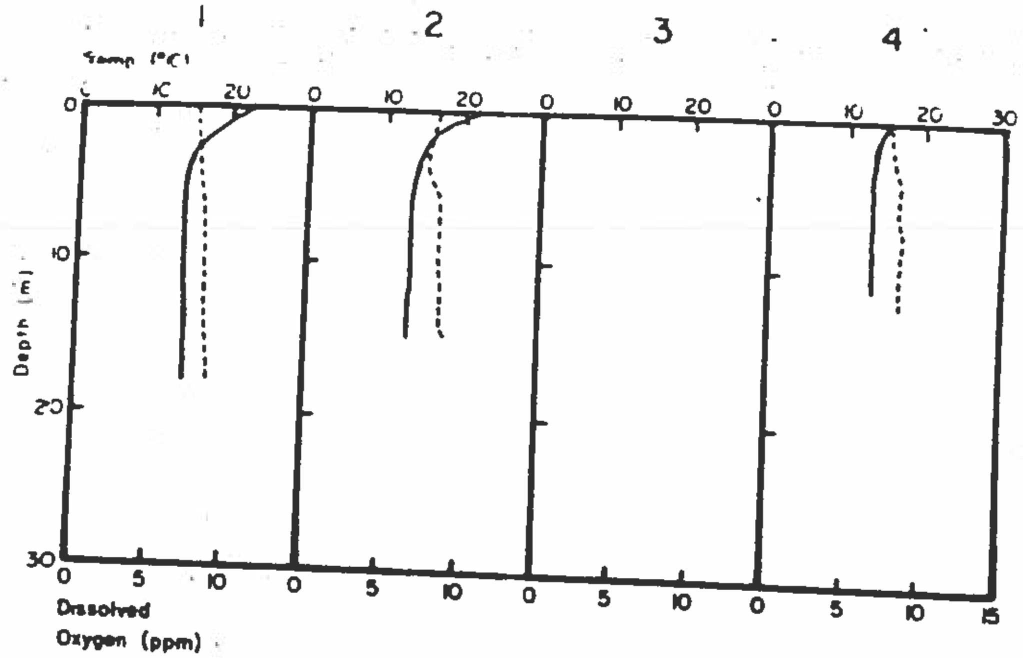
Temperature and dissolved oxygen profiles for Lake Catherine at Main Stem Station and Station TC. The solid line represents temperature (°C) and the dotted line the dissolved oxygen in ppm.

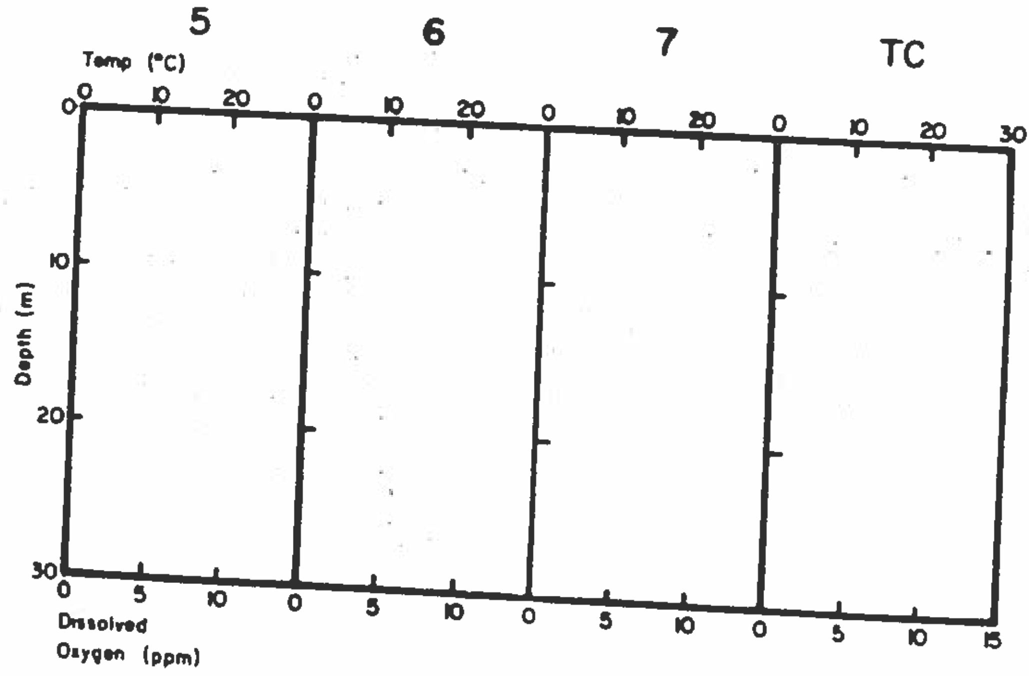
| Figure No. | Date |
|---|---|
| 38 | 2/10/68 |
| 39 | 6/7/68 |
| 40 | 7/26/68 |
| 41 | 9/14/68 |
| 42 | 10/30/68 |

Catherine
2/10/68

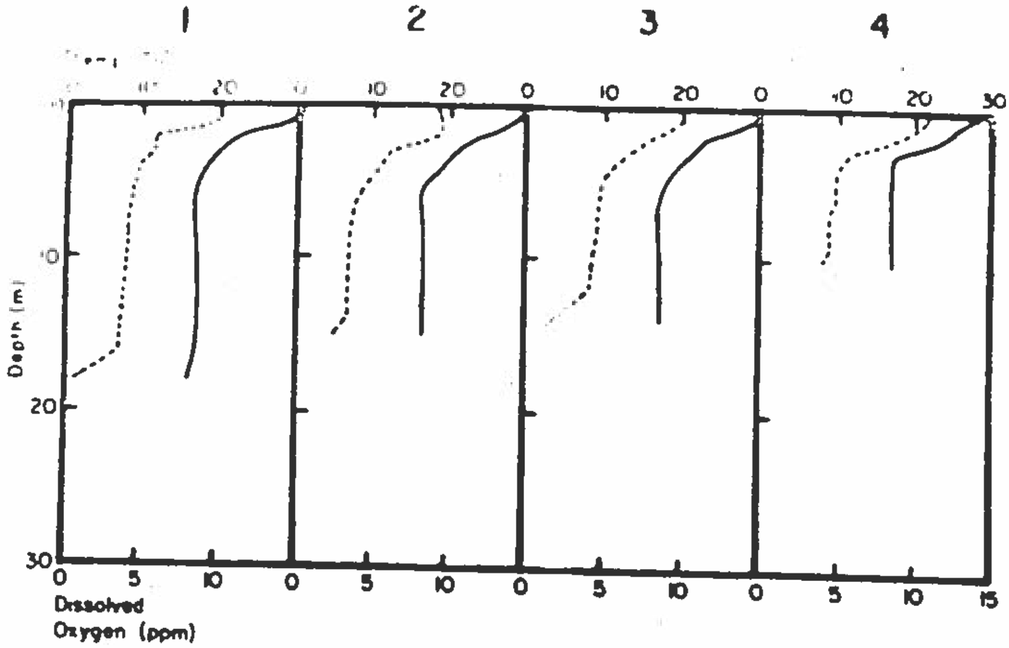


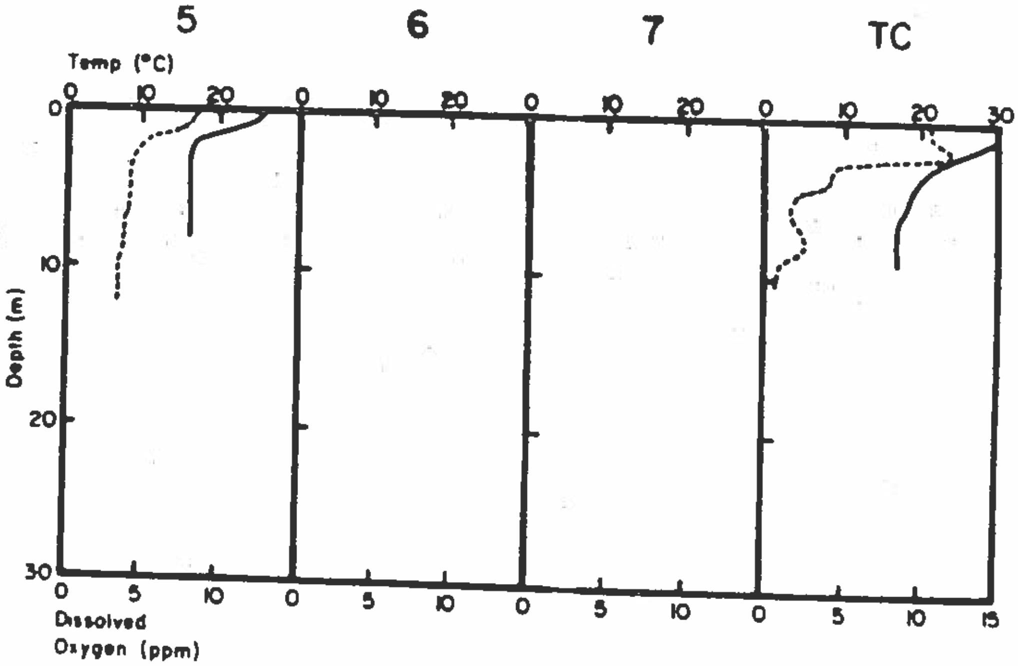
Catherine
6/7/68

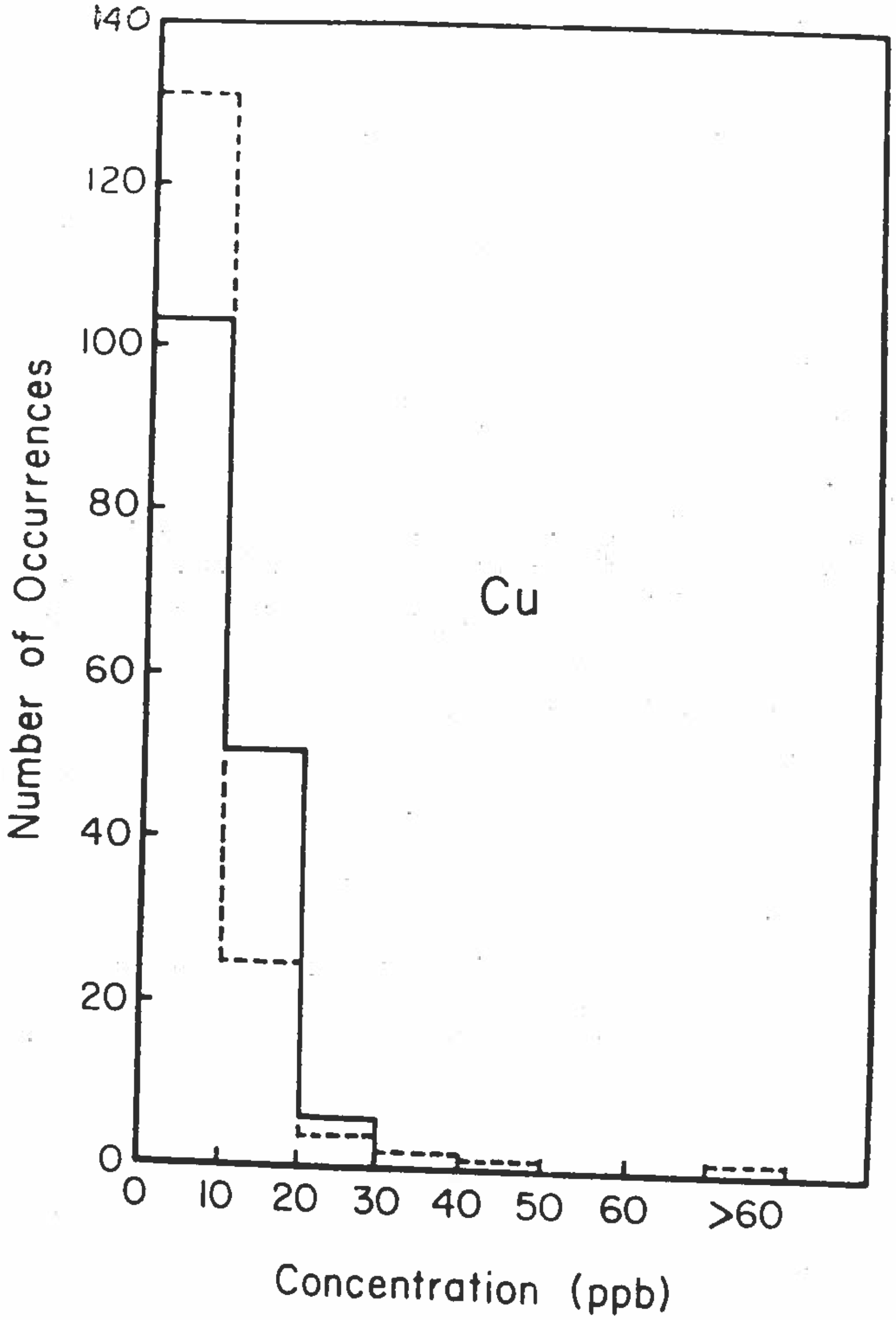


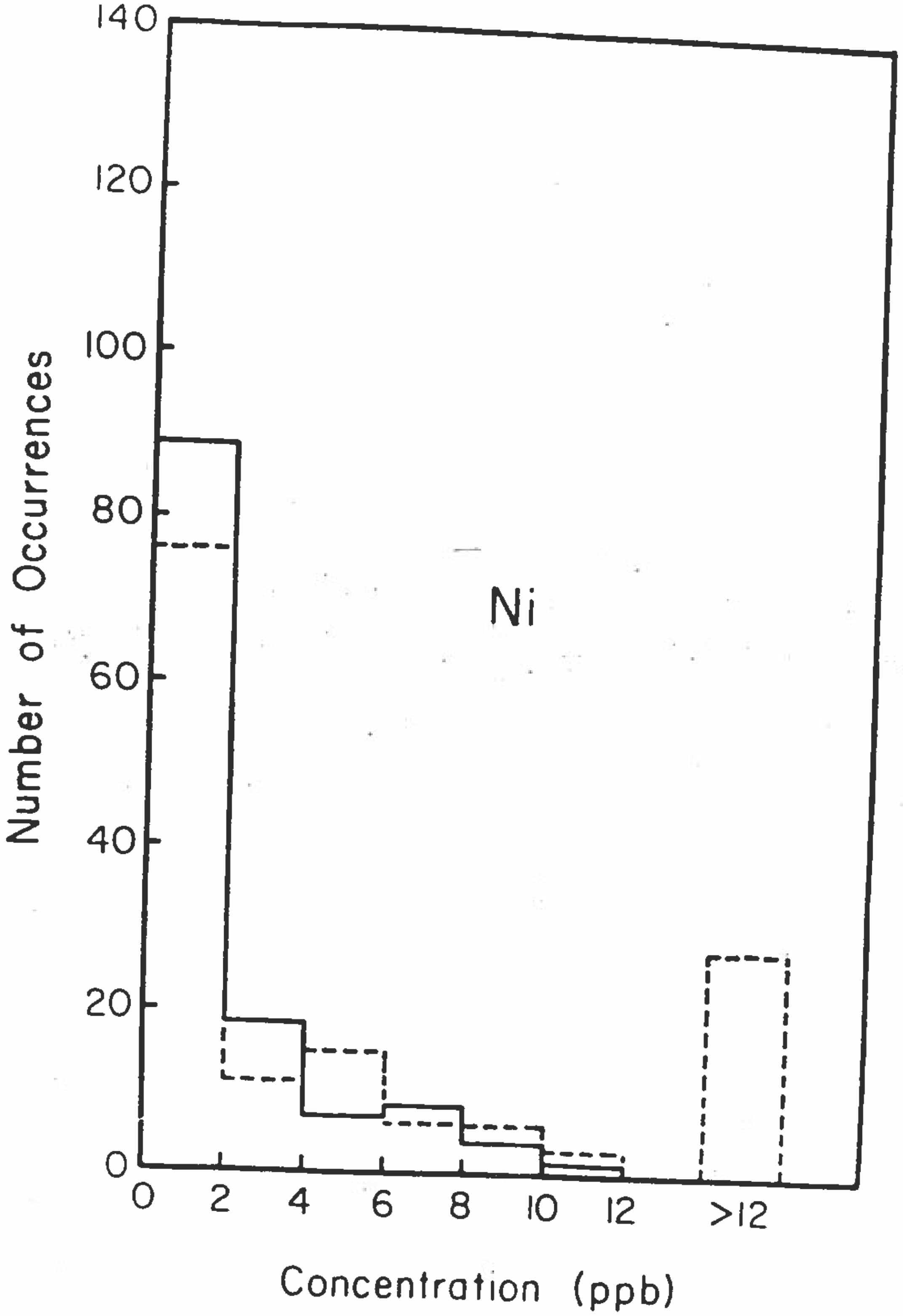


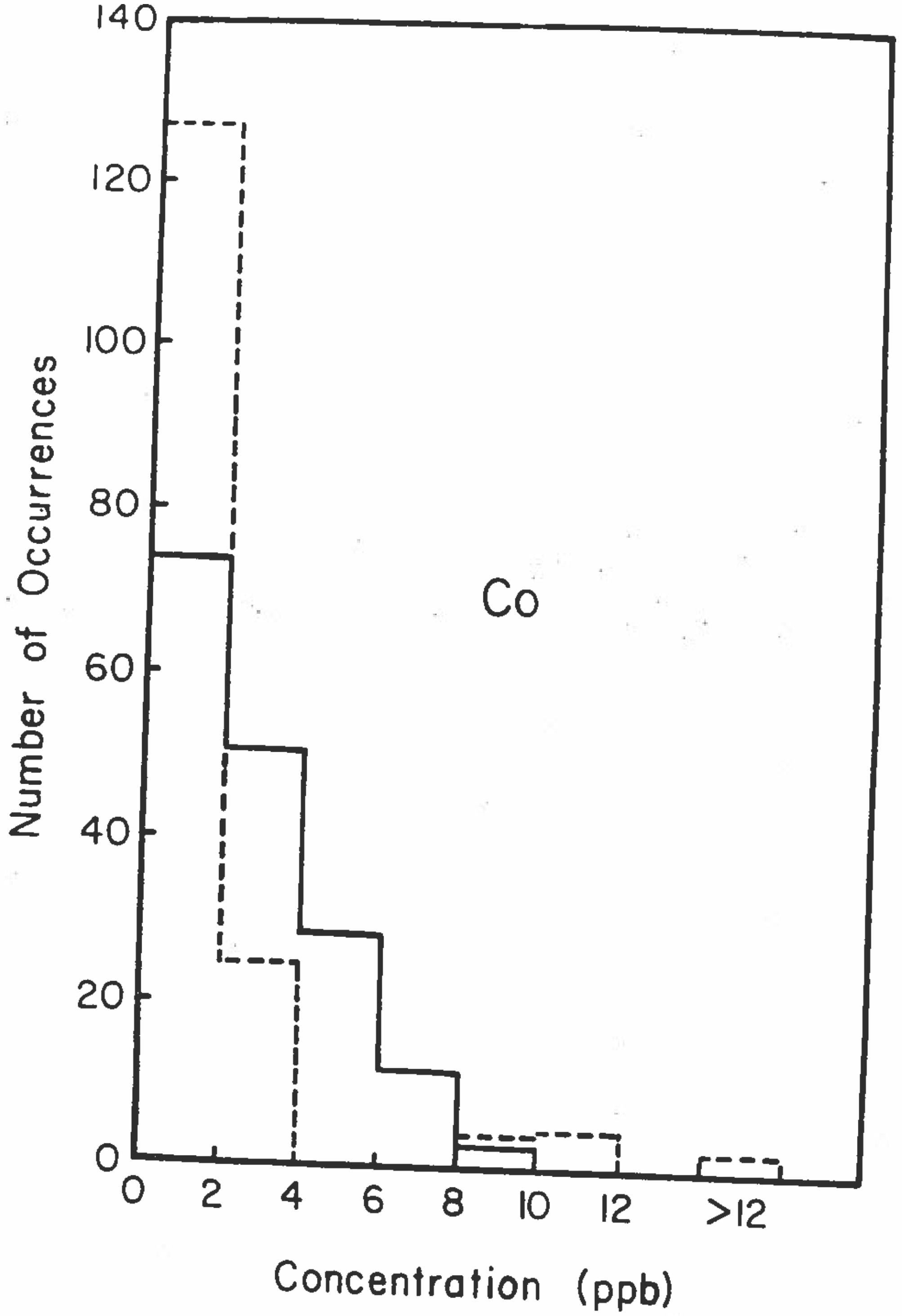
Catherine
7/26/76,H

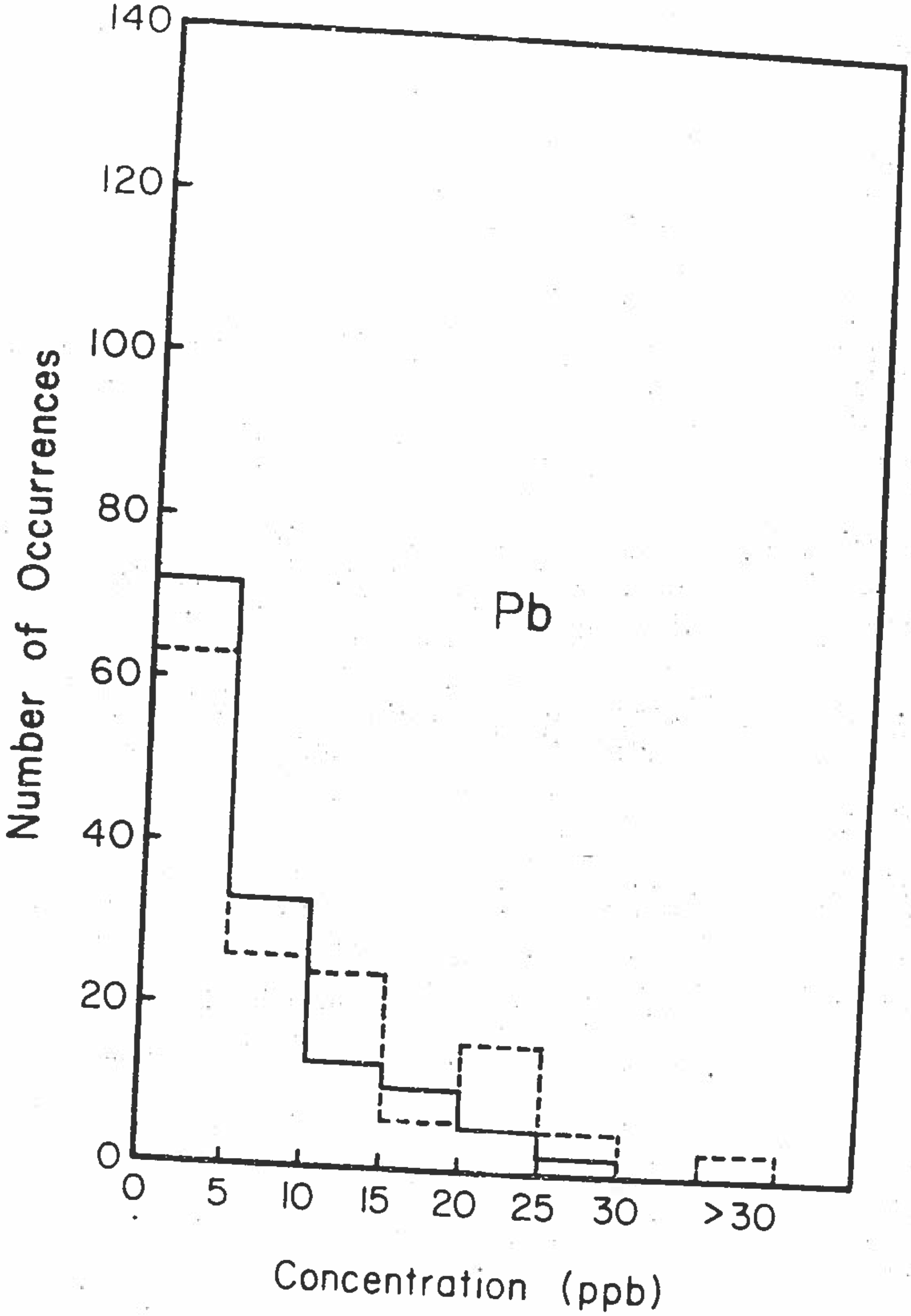


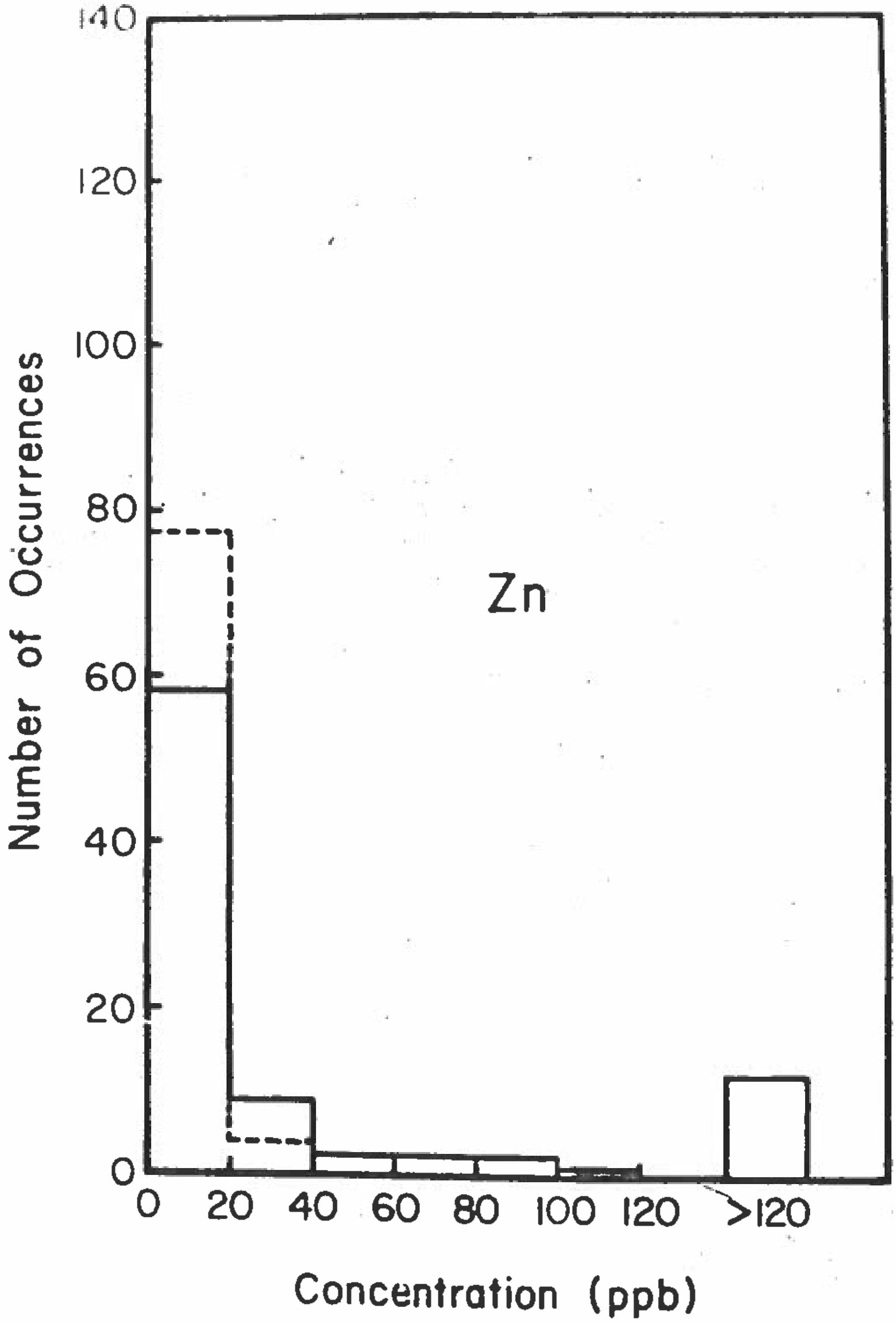



140
120
100
80
60
40
20
0
Number of Occurrences
Cu
0
10
20
30
40
50
60
>60
Concentration (ppb)


Ni
Number of Occurrences
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
>12
Concentration (ppb)


Co
Number of Occurrences
Concentration (ppb)
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
>12


Pb
Number of Occurrences
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30
>30
Concentration (ppb)



140
120
100
80
60
40
20
0
Number of Occurrences
Zn
0
20
40
60
80
100
120
>120
Concentration (ppb)

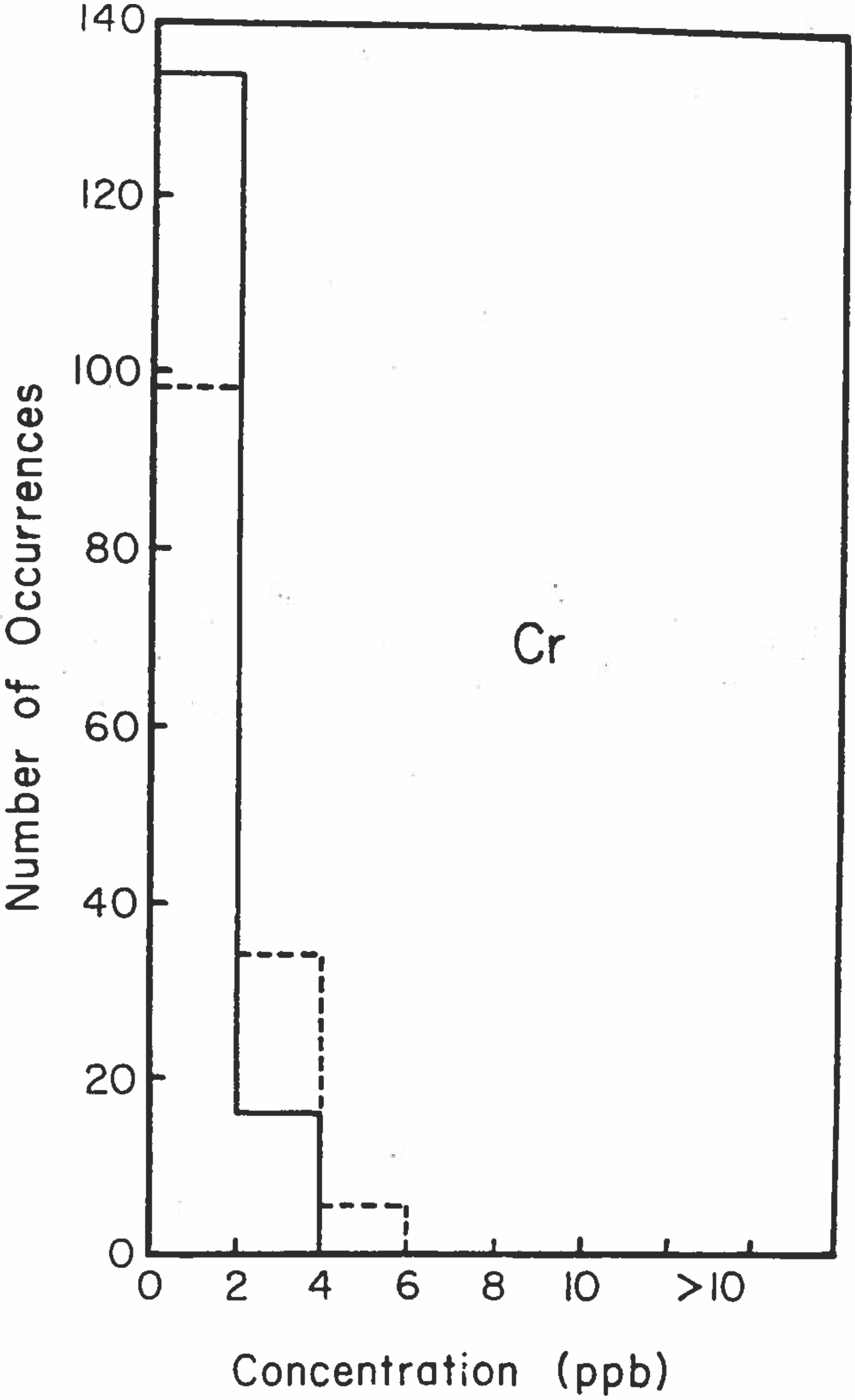

140
120
100
80
60
40
20
0
Number of Occurrences
Cr
0
2
4
6
8
10
>10
Concentration (ppb)

Figure 55

Chemical nature of interflow observed between 5 and 10 meters at Station 3, Lake Hamilton on June 4, 1969

Hamilton
Station No. 3
June 4, 1969

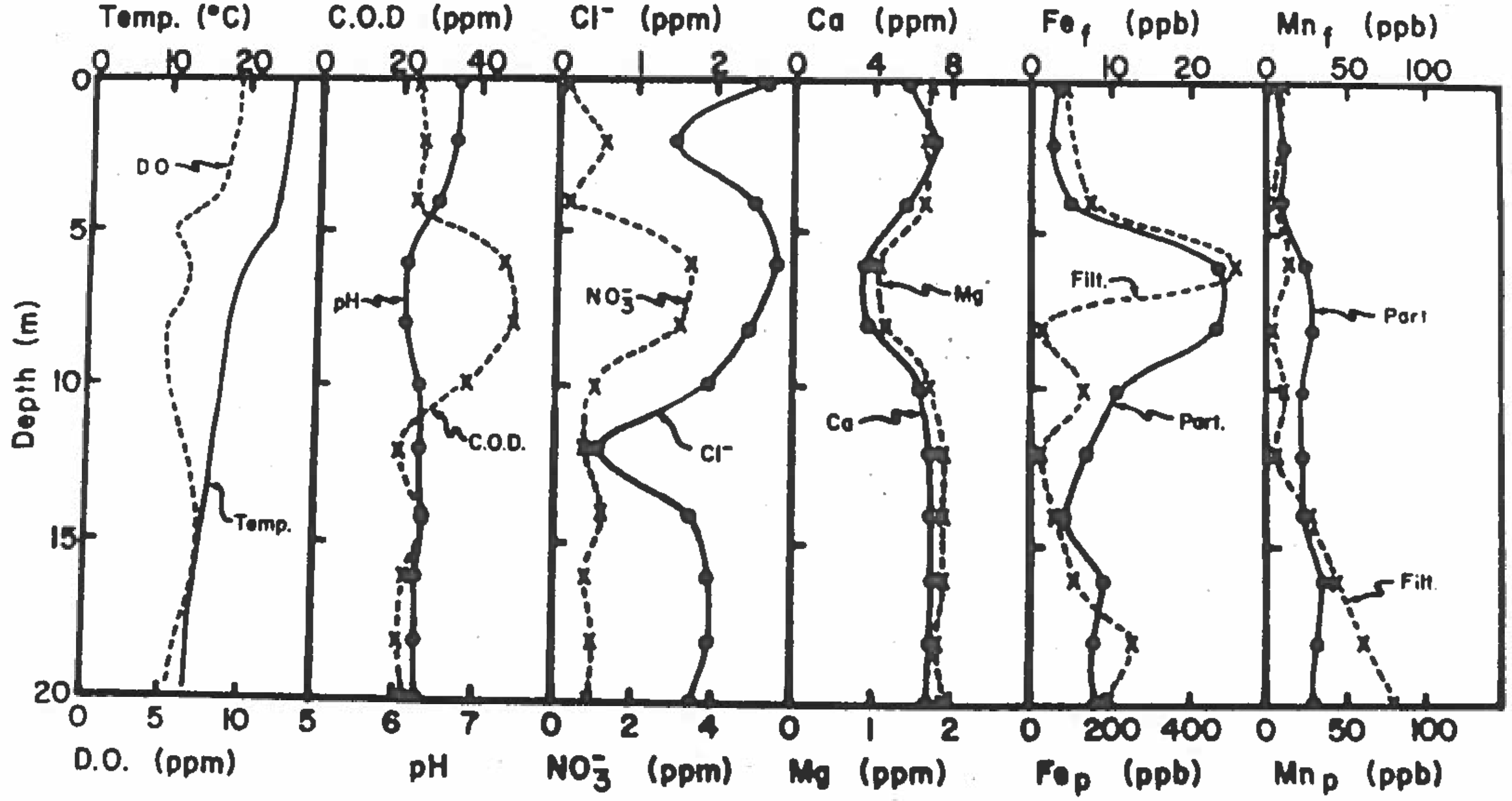
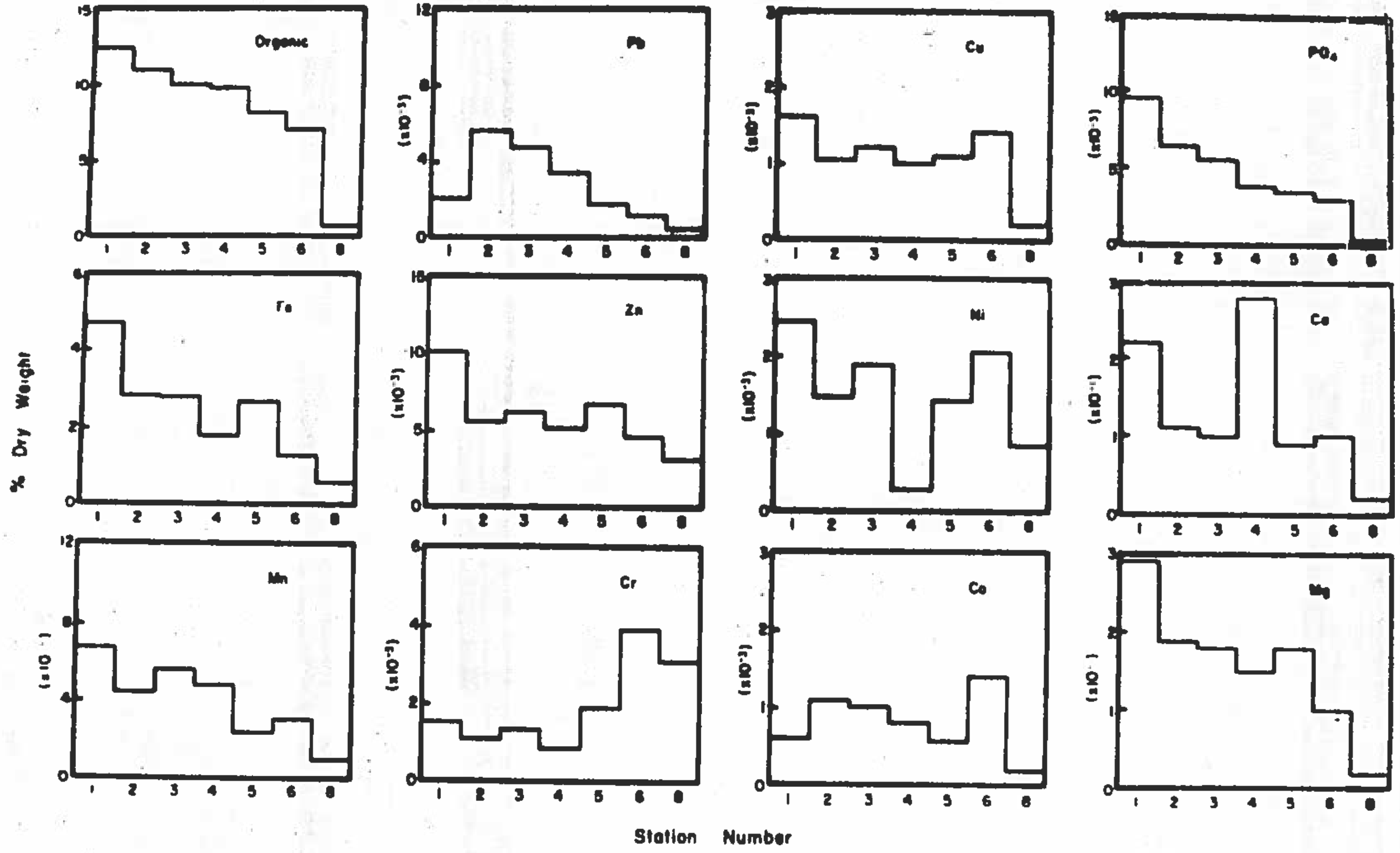


Figure 56

Water quality profile observed at Station 3, Lake Hamilton on June 26, 1969

Figure 57

Results of mud analysis for stations on Lake Hamilton



Organic
Pb
Cu
PO4
Fe
Zn
Ni
Ca
Mn
Cr
Co
Mg
$(x10^{-3})$
$(x10^{-1})$
$(x10^{-2})$
% Dry Weight
Station Number
1 2 3 4 5 6 8

Figure 58

Dissolved oxygen distribution in tank under stratified conditions

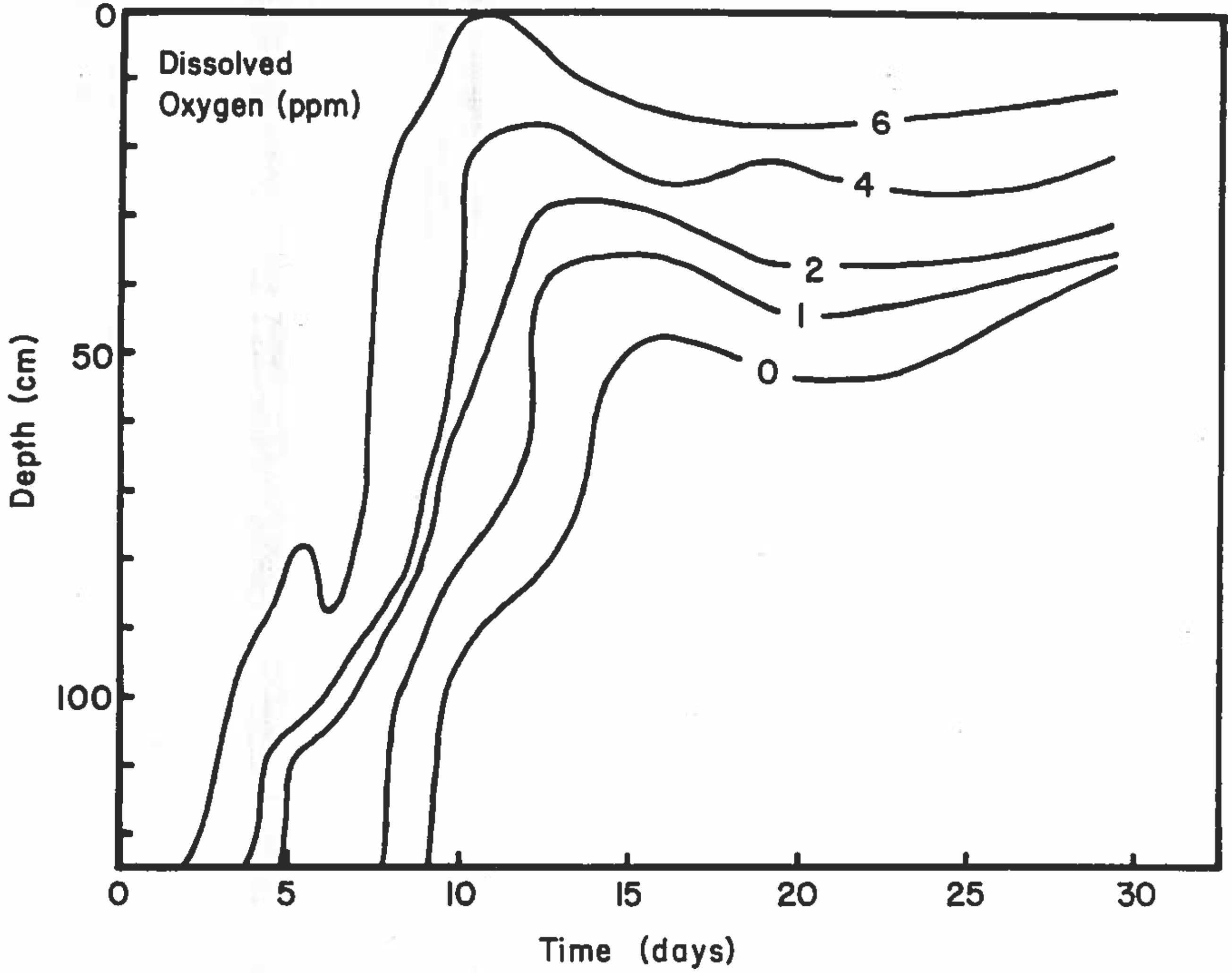
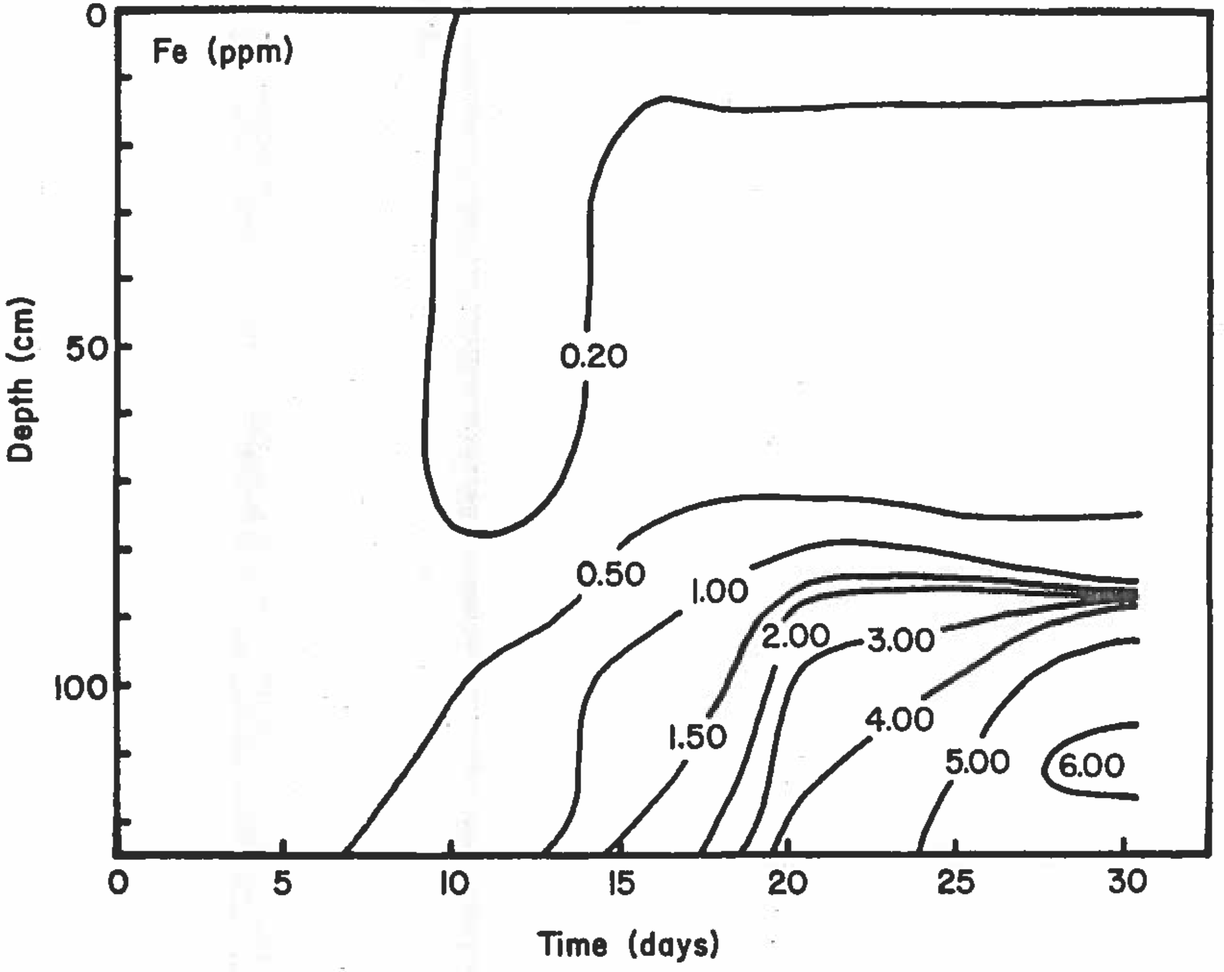
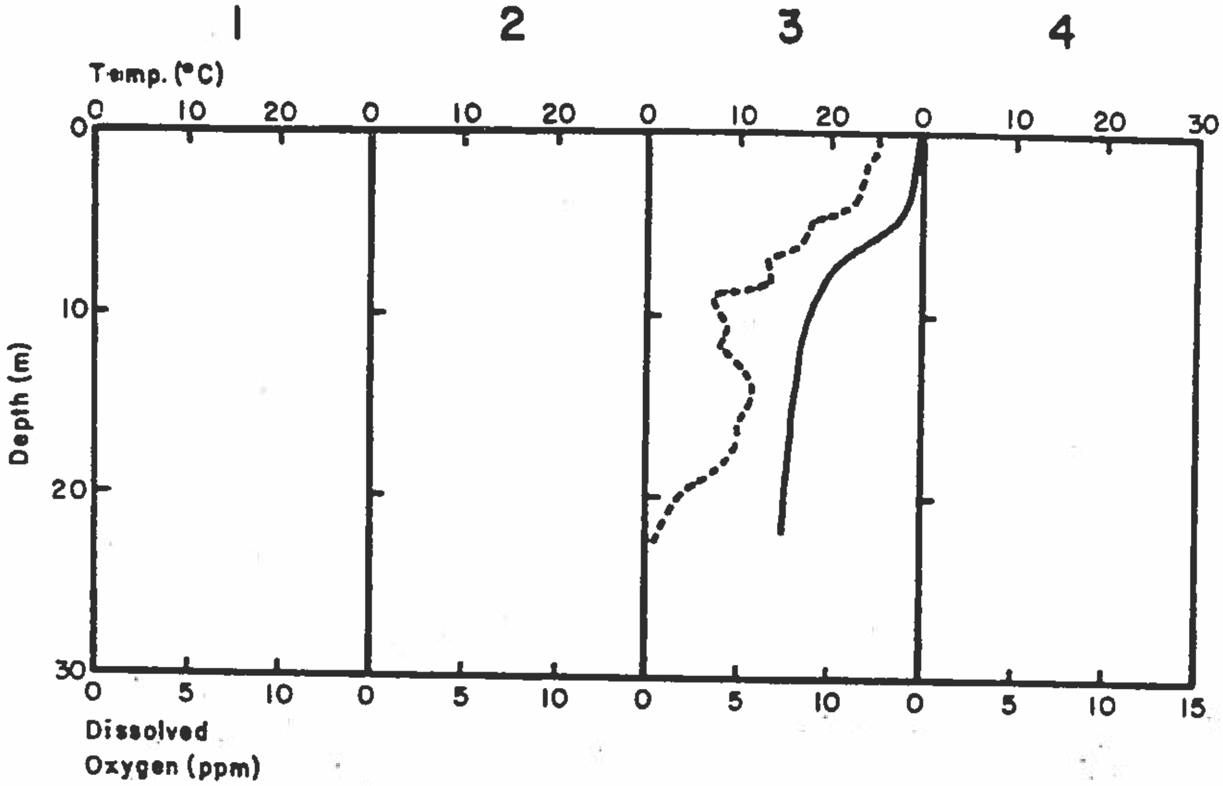

Dissolved
Oxygen (ppm)
6
4
2
1
0
Depth (cm)
0
50
100
Time (days)
0
5
10
15
20
25
30

Figure 59

Iron distribution in tank under stratified conditions


Fe (ppm)
Depth (cm)
0
50
100
Time (days)
0
5
10
15
20
25
30
0.20
0.50
1.00
1.50
2.00
3.00
4.00
5.00
6.00

Hamilton
6/26/69



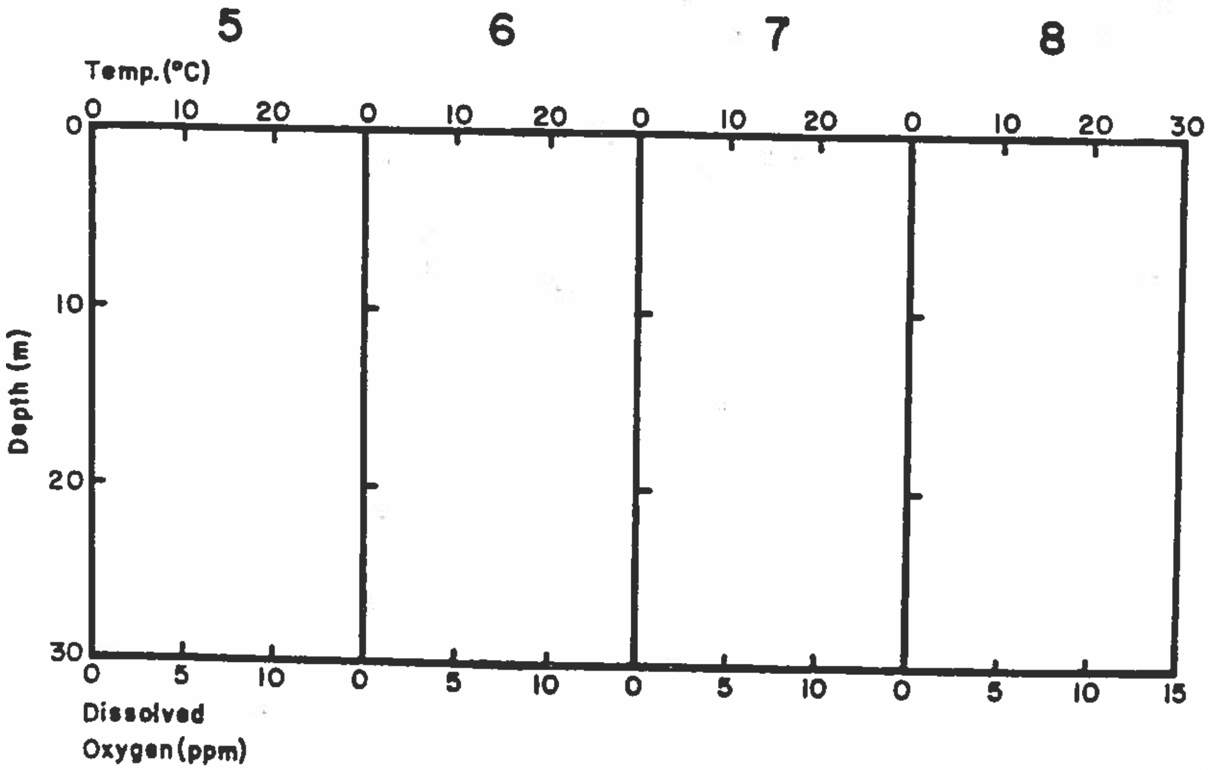


Figure 60

Manganese distribution in tank under stratified conditions

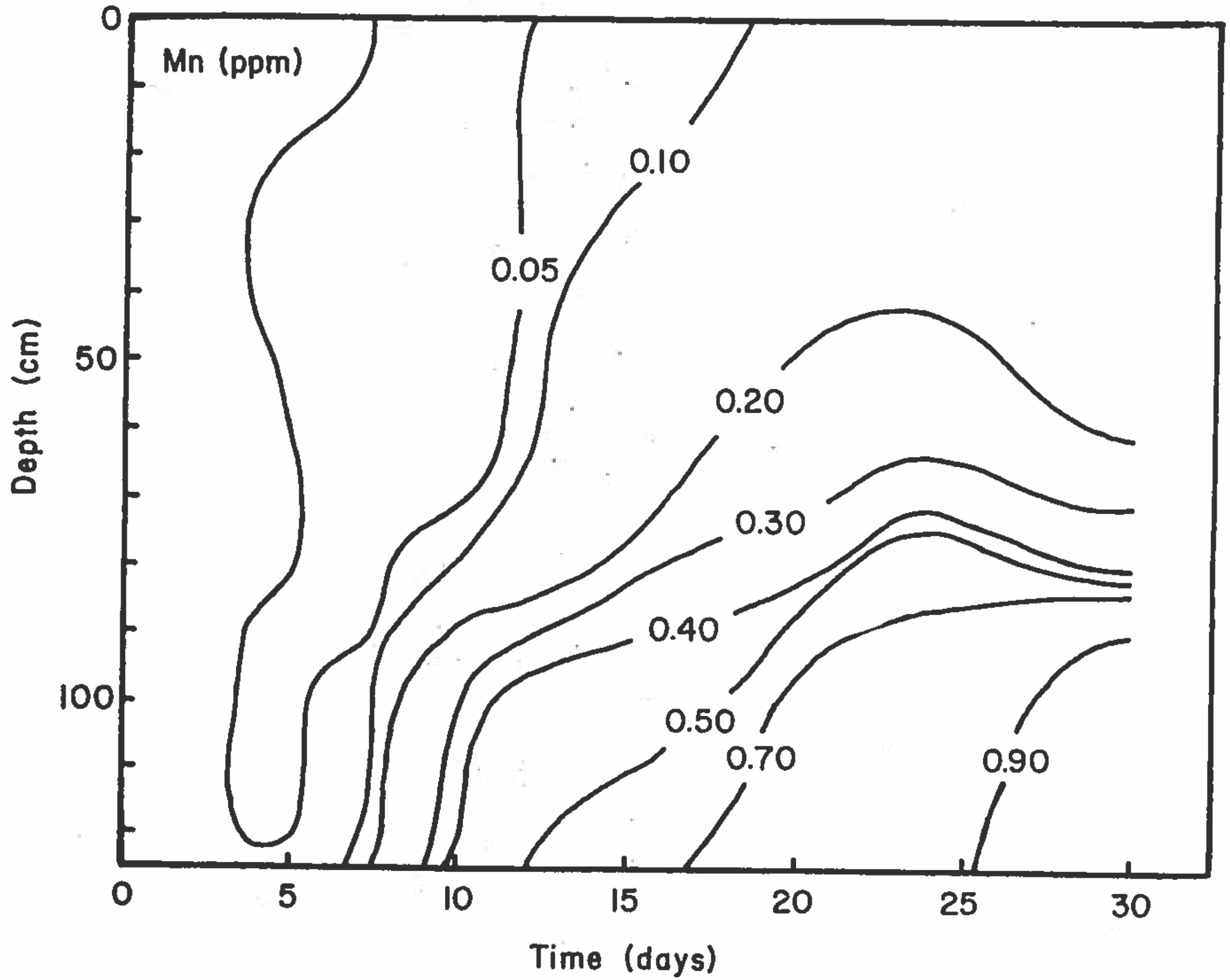
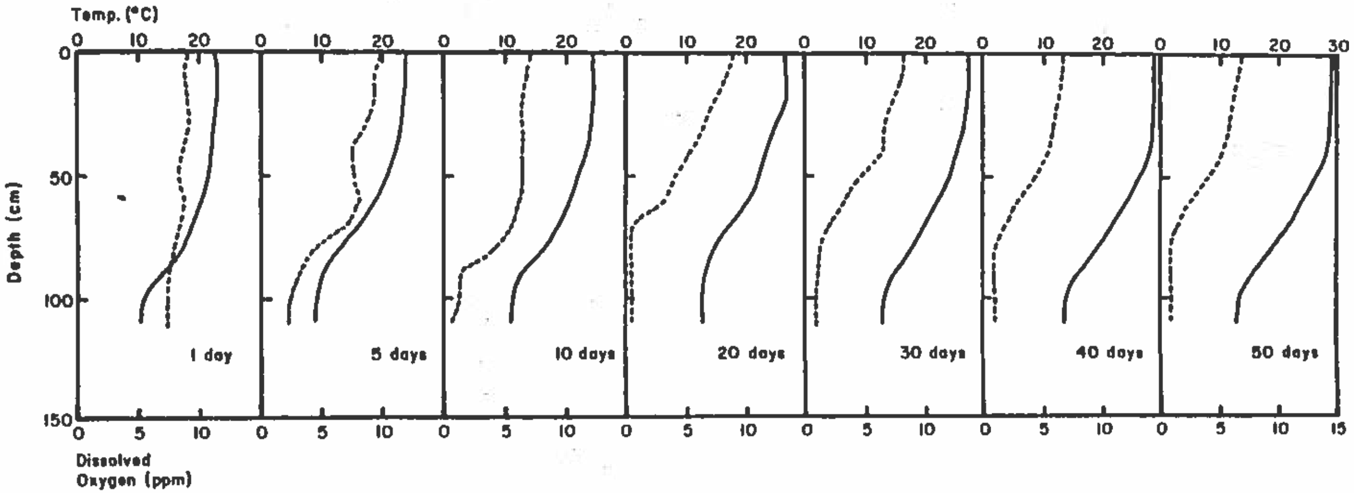

Mn (ppm)
0.05
0.10
0.20
0.30
0.40
0.50
0.70
0.90
Depth (cm)
0
50
100
Time (days)
0
5
10
15
20
25
30

Figure 61

Temperature, dissolved oxygen, and cobalt distribution in tank under stratified conditions. Tank was originally charged with a solution containing 0.50 ppm cobalt.


Temp. (°C)
0
10
20
30
Depth (cm)
0
50
100
150
1 day
5 days
10 days
20 days
30 days
40 days
50 days
0
5
10
15
Dissolved
Oxygen (ppm)

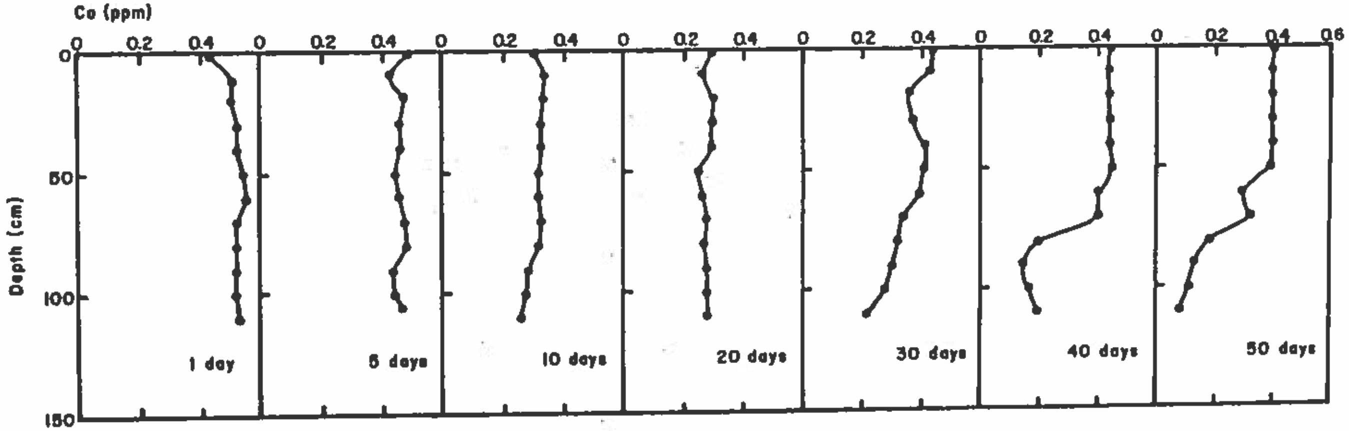

Co (ppm)
0
0.2
0.4
0.6
Depth (cm)
0
50
100
150
1 day
5 days
10 days
20 days
30 days
40 days
50 days

Figure 62

Results of analysis of samples taken at stations located on the Ouachita River below Lake Catherine on September 5, 1968. Station locations are shown in Figure 1.

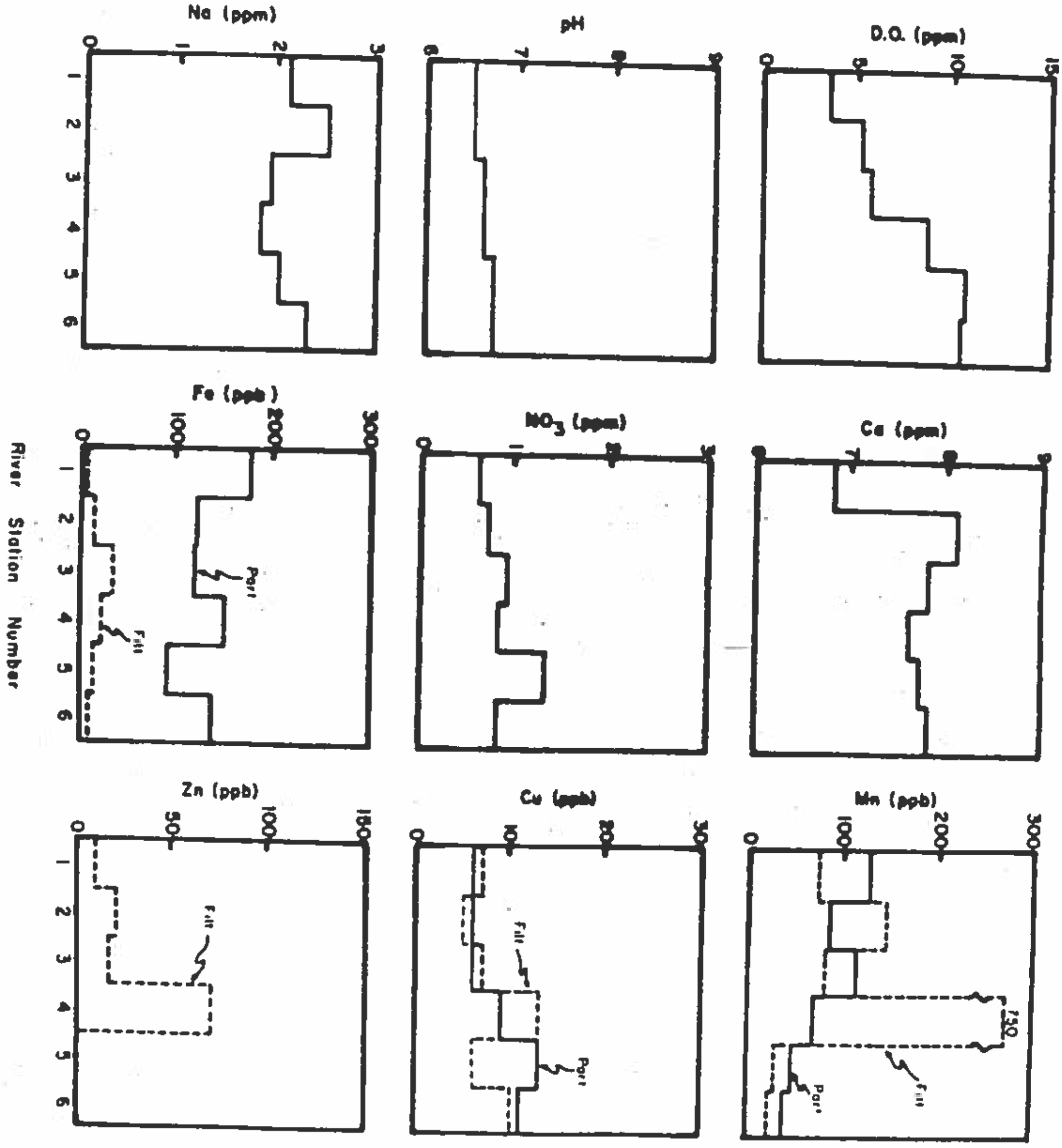

Na (ppm)
pH
D.O. (ppm)
Fe (ppb)
NO3 (ppm)
Ca (ppm)
Zn (ppb)
Cu (ppb)
Mn (ppb)
River Station Number
1
2
3
4
5
6
Part
Filt
730

Figure 63

Temperature distribution in Greers Ferry Reservoir, August 1967 through March 1968

Figure 64

Dissolved oxygen distribution in Greers Ferry Reservoir, August 1967 through March 1968

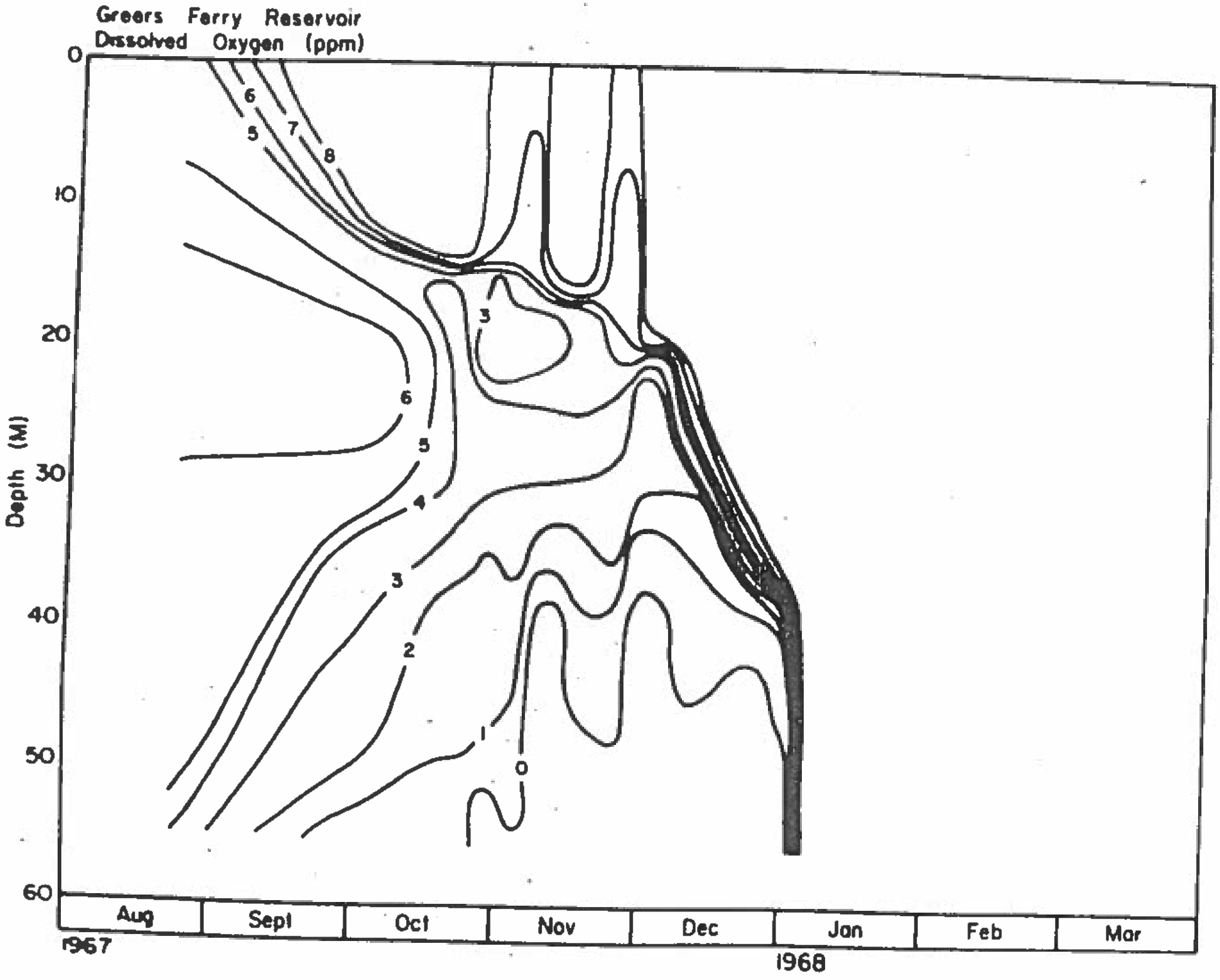

Greers Ferry Reservoir
Dissolved Oxygen (ppm)
Depth (M)
0
10
20
30
40
50
60
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
1967
1968
8
7
6
5
6
5
4
3
3
2
1
0

Figure 65

Temperature distribution in Greers Ferry Reservoir, July 1968 through December 1968

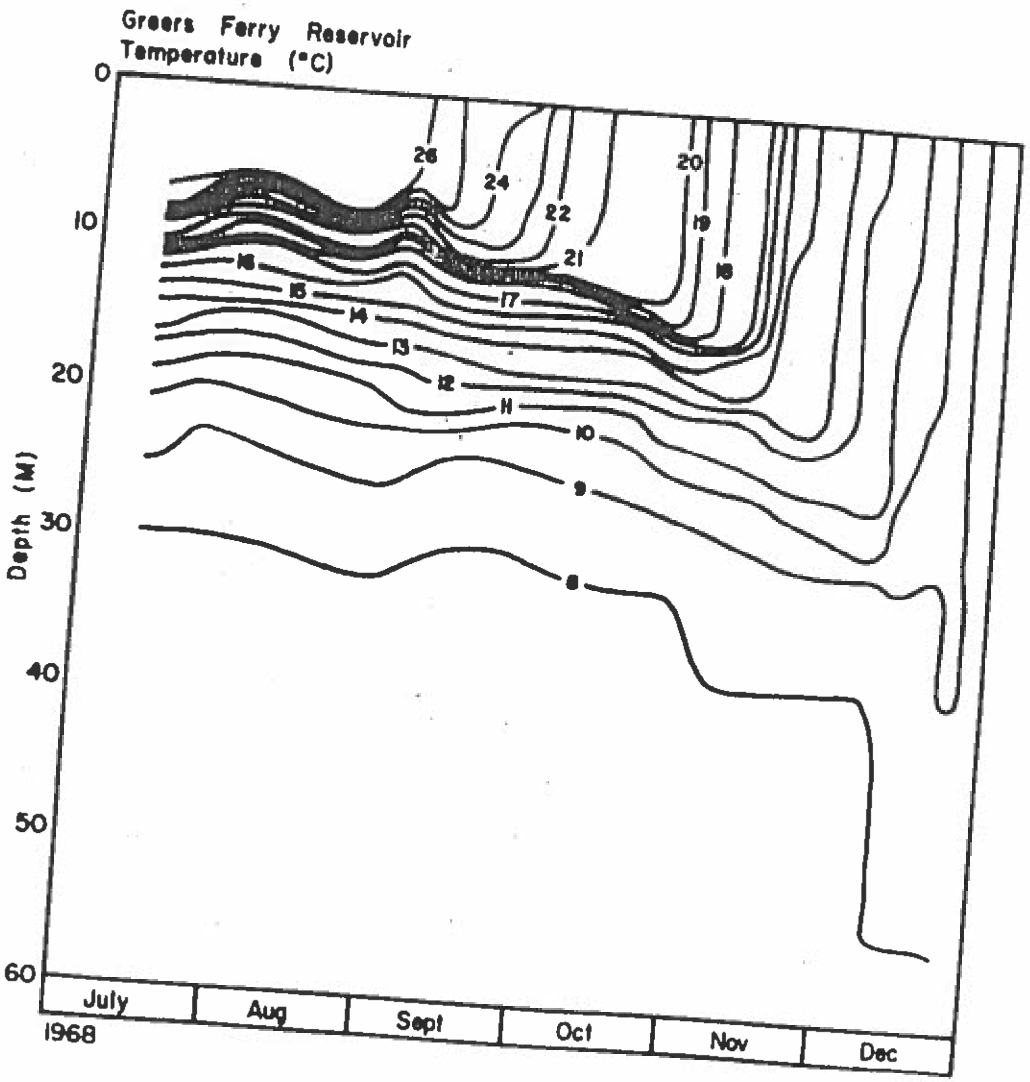

Greers Ferry Reservoir
Temperature (°C)
Depth (M)
0
10
20
30
40
50
60
26
24
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
July
Aug
Sept
Oct
Nov
Dec
1968

Figure 66

Dissolved oxygen distribution in Greers Ferry Reservoir, July 1968 through December 1968

Figure 67

Manganese distribution in Greers Ferry Reservoir, July 1968 through December 1968

Greers Ferry Reservoir
Manganese (ppm)

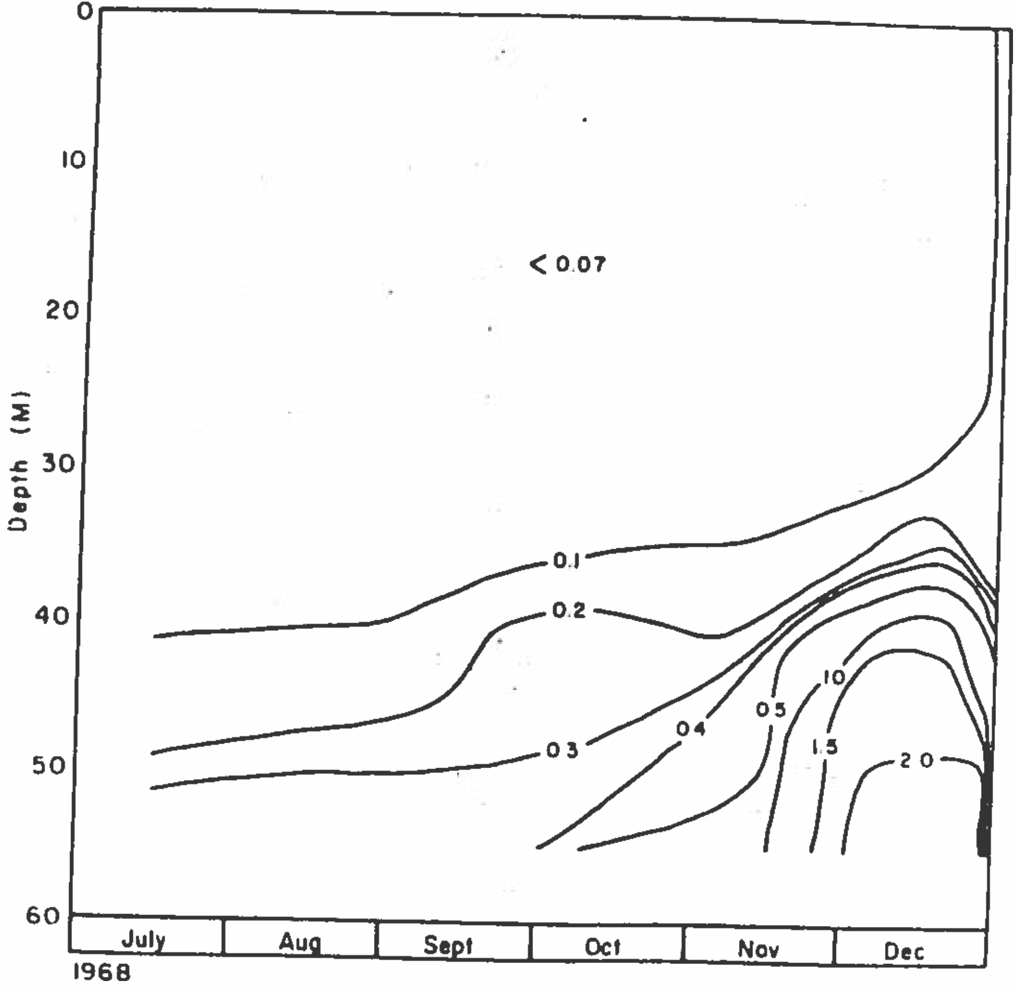


Figure 68

Temperature distribution in Greers Ferry Reservoir, October 1969 through January 1970

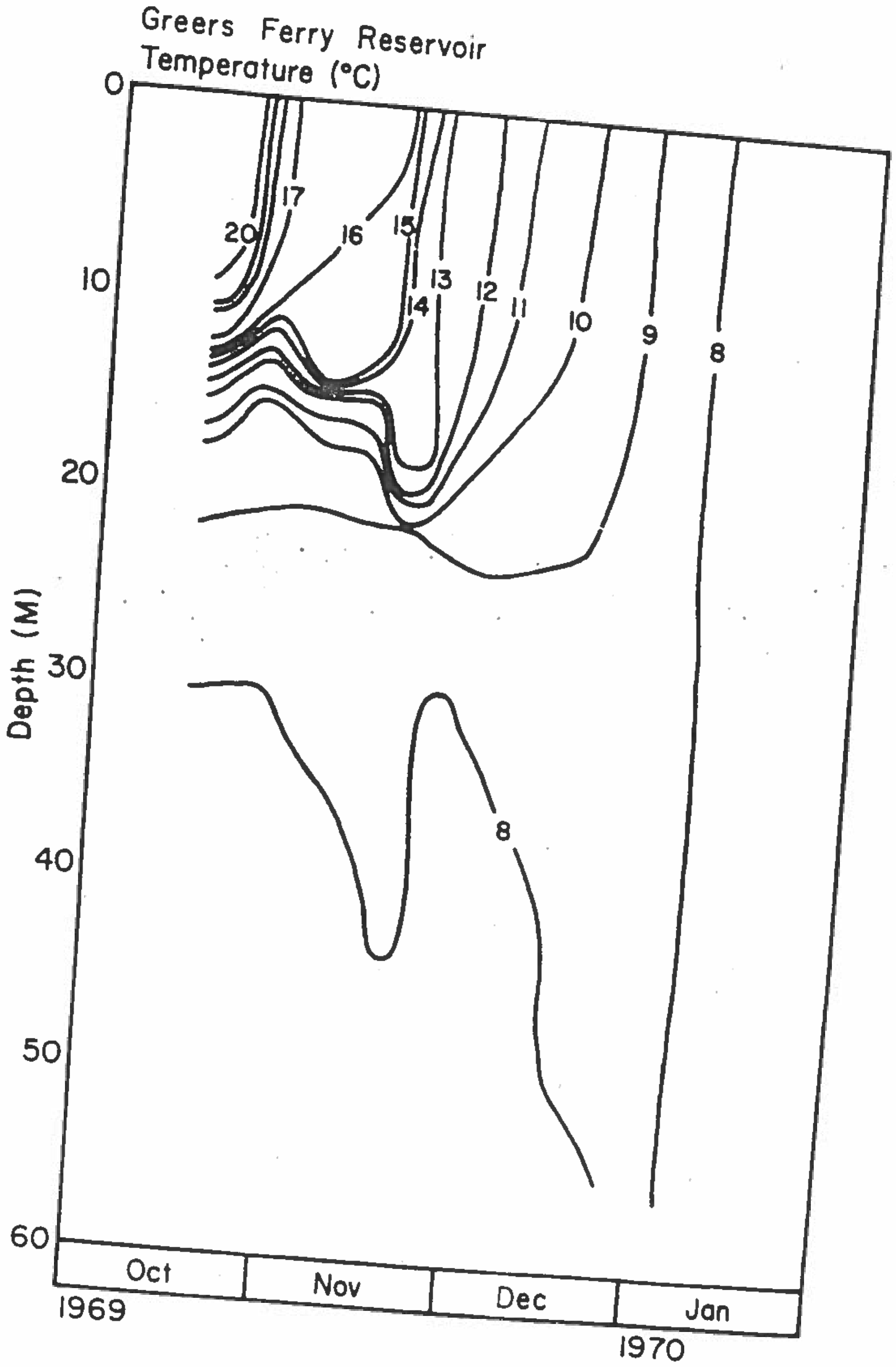

Greers Ferry Reservoir
Temperature (°C)
Depth (M)
0
10
20
30
40
50
60
20
17
16
15
14
13
12
11
10
9
8
8
Oct
Nov
Dec
Jan
1969
1970

Figure 69

Dissolved Oxygen distribution in Greers Ferry Reservoir, October 1969 through January 1970

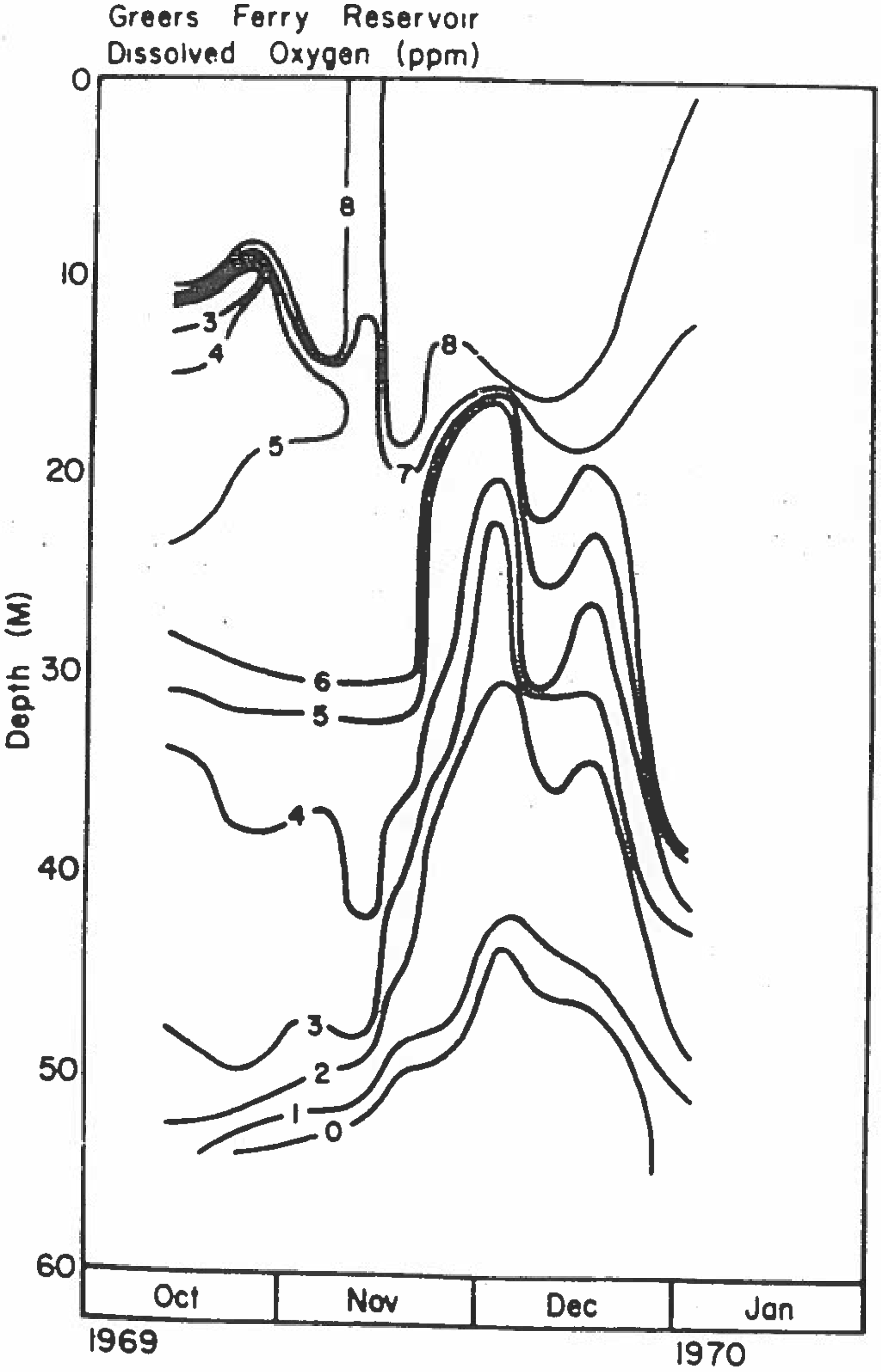

Greers Ferry Reservoir
Dissolved Oxygen (ppm)
Depth (M)
0
10
20
30
40
50
60
8
3
4
5
8
7
6
5
4
3
2
1
0
Oct
Nov
Dec
Jan
1969
1970

Figure 70

Manganese distribution in Greers Ferry Reservoir, October 1969 through January 1970

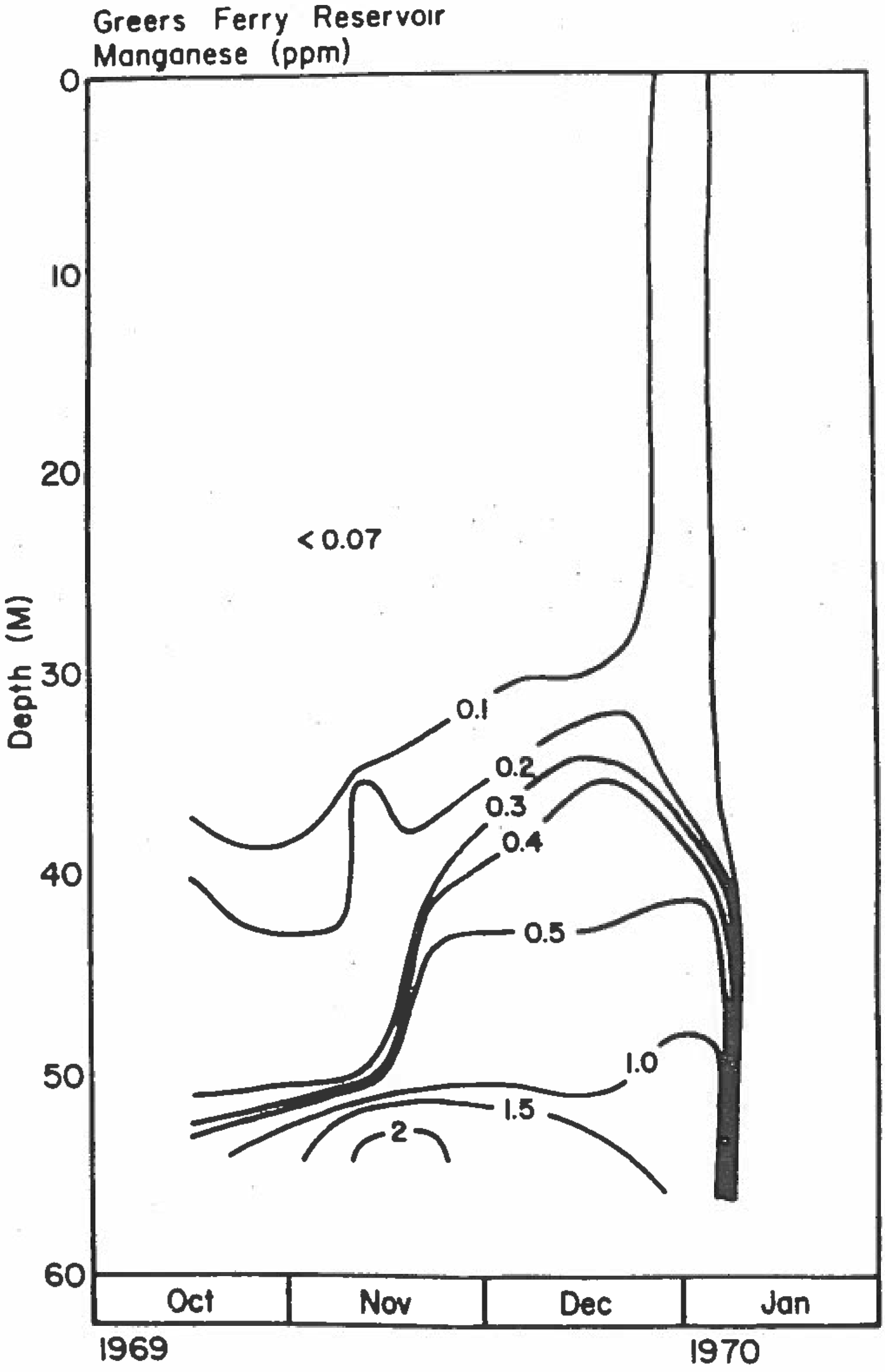
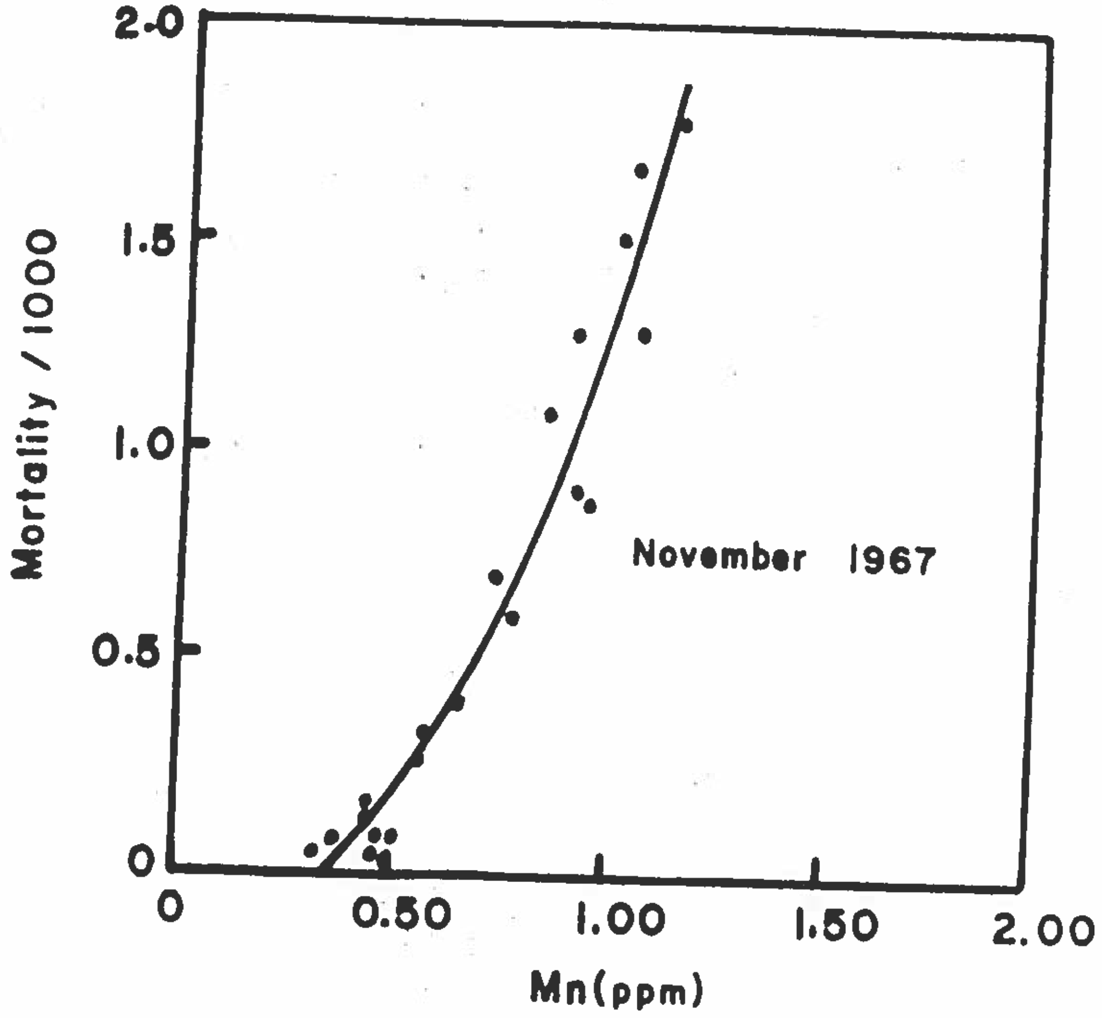

Greers Ferry Reservoir
Manganese (ppm)
0
10
20
30
40
50
60
Depth (M)
< 0.07
0.1
0.2
0.3
0.4
0.5
1.0
1.5
2
Oct
Nov
Dec
Jan
1969
1970

Figure 71

Plot of trout mortalities per 1000 in one tank vs manganese concentration for November 1967


2.0
1.5
1.0
0.5
0
Mortality / 1000
0
0.50
1.00
1.50
2.00
Mn(ppm)
November 1967