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INTRODUCTION

This report presents the results of a physical and chemical study of Lake Michigan water, conducted by the Great Lakes-Illinois River Basins Project during the spring, summer, and autumn months of 1962 (April 1962 to December 1962).

The study was conducted through the collection of appropriate samples during a series of eight cruises made on the Lake by three laboratory-equipped vessels, the Cisco, Fitzgerald and Kaho. Analyses which required immediate attention were carried out aboard ship. Other analyses were performed at the GLIRBP laboratories. These procedures are described later. A detailed description of the vessels and the cruises may be found in the special report LM-2, "Sampling Surveys."

The purpose of this report is to present the physical and chemical findings of this study of Lake Michigan, in order to establish present levels of chemical water quality and to describe those areas of the lake which exhibit significant deviation from the general quality of the entire lake.

PARAMETERS, DEFINITIONS AND SIGNIFICANCE

Parameters

The parameters which were considered and reported in subsequent sections of this report are: Ammonia Nitrogen; Total Phosphate; Silica; Dissolved Oxygen; Phenols; Alkyl Benzene Sulfonate (ABS); Biochemical Oxygen Demand (BOD); Hydrogen Ion Concentration (pH); Dissolved Solids; Nitrate; Sodium; Potassium; Calcium; Specific Conductance; Alkalinity; Magnesium; Sulphate; Chloride; and Toxic Metals (Copper, Cadmium, Nickel, Zinc, Lead and Chromium). Certain of these parameters were found to have practically no variation, either geographically or by depth on all of the lake samples analyzed to date, whereas others exhibited detectable changes in some areas and seasons but not in the others. The parameters showing significant changes were Ammonia Nitrogen; Nitrate; Total Phosphate; Silica; Dissolved Oxygen; Conductance; Phenols; and Biochemical Oxygen Demand (BOD). Of these, the first three cited appeared in appreciable variation in all areas of the lake. Deepwater samples showed fewer variable parameters than did the inshore samples, and the greatest variability was shown in the harbor studies.

Definitions and Significance

Nitrogen; Ammonia and Nitrate-Nitrite

Nitrogen is necessary to the normal life cycle of aquatic life. If it is present with phosphate in moderate concentrations, accelerated growths of algae and plankton can result. Ammonia in high concentrations, above 2 to 2.5 mg/l and under alkaline pH conditions (pH 8-8.5) (1, 2) is a substance toxic to many forms of aquatic life (3). At all levels, it is an increased burden to municipal water treatment because of its high chlorine demand. It is an indicator of sewage pollution because of its presence in human and animal waste discharges, and may be a significant contribution in some industrial wastes. Amines and cyanide have toxicity properties peculiar to specific compounds containing these chemical groupings. Nitrate nitrogen (3) has been implicated as a cause of Methemoglobinemia in infants; a limit of 45 mg/l of nitrate (as nitrate) has been recommended in the U.S. Public Health Service Drinking Water Standards (4).

Total Phosphate

Phosphate, like nitrogen, is a necessary nutrient for biological activity. Its presence in the water will permit the processes of organic decomposition to proceed at an optimum rate. Its presence in water is not considered harmful to human health. Excessive concentrations of phosphate, coupled with other favorable conditions

such as abundant nitrogen supply, optimum temperature and sunlight, can result in dense algal blooms. These excessive growths affect the quality of water, interfere with water treatment operations, increase taste and odor problems, cause unsightly scums and decaying matter, and create problems due to fluctuations of dissolved oxygen. Concentrations of phosphates between 0.03 and 0.3 mg/l are needed to stimulate algal growth according to various authors (5). Sawyer (6) states that "nuisance conditions can be expected when the concentration of inorganic phosphorus equals or exceeds 0.01 mg/l" (0.03 mg/l as phosphate). The biological impact of phosphate is discussed further in Special Reports LM-1, "Trends in Water Quality" and LM-4, "Biological Investigations."

Phosphate enters the water environment in treated sewage because it is not removed by conventional treatment processes. It is normally present in human and animal waste products; synthetic detergent formulations used in modern day washing practices contain high concentrations of phosphates and have further increased the quantities discharged. Phosphate is also present in surface runoff, particularly from fertilized fields, and may be a component of the effluent from certain industrial processes.

Silica

Silica appears in water as finely divided or colloidal suspended matter. Most silica probably occurs in water as a result of contact with deposits of minerals high in silicate such as feldspar, kaolinite, etc. The concentrations of silica normally found in water have no significant physiological effects. However, since diatoms require silica for manufacture of their skeletons, it would follow that the availability of the substance should be one of the factors limiting the production of large crops of this strategic group of plankton.

The presence of diatoms in large numbers interferes with water treatment processes, especially the clogging of filters.

Dissolved Oxygen

Dissolved oxygen is one of the most important constituents of a natural water. The existence of desirable aquatic life is dependent on the presence of adequate levels of oxygen at all times. The solubility of oxygen in water is low and is affected by both physical and biochemical forces. The maintenance of satisfactory levels depends upon the equilibrium established between the forces utilizing oxygen and those contributing it.

Oxygen is utilized by aquatic organisms during the processes of respiration. It is replenished from the atmosphere by physical forces and can also be added through photosynthesis by algae and higher aquatic plants. When organic pollution enters an aquatic environment,the balance between consumption and contribution is upset. The bacteria present in water or introduced with the pollution begin active consumption of the organic matter, multiply rapidly in the process, and consume the oxygen dissolved in the water. If they use oxygen at a great enough rate the resultant oxygen in the water may not be sufficient to support life. In polluted waters, these conditions are particularly in evidence during warm weather when the rate of oxygen consumption is increased and the ability of water to hold oxygen in solution is decreased. Organic pollution discharged into the lake may have an adverse effect for considerable distances. Persistent discharges of this nature from tributaries would degrade large areas, affecting breeding grounds of lake fish, and altering an otherwise favorable environment for desirable aquatic life.

Biochemical Oxygen Demand (BOD)

The introduction of organic waste into water - whether the waste originates from domestic sewage, industrial processes, land runoff, or any other source - initiates a chain of events involving the organic material, microorganisms accompanying it, and the natural biota present in the receiving water. Organic matter is rapidly utilized as food by those organisms capable of converting it; the net result of this action is consumption of dissolved oxygen. Because control of dissolved oxygen is important in water quality management programs, a means of measuring the oxygen depletion potential of wastes is necessary if adequate control measures are to be adopted. The test commonly used for this purpose is the BOD test.

The BOD test is a biochemical reaction rather than a well defined chemical reaction; it involves observation of oxygen usage by microorganisms which convert unstable organic matter into cellular material and respiratory products. The organic waste material supplies the energy to effect this conversion. Toxic substances, if present, adversely influence this test.

In general, high BOD values can be expected to result in low dissolved oxygen levels in the receiving waters; this implies an unsuitable environment to fish and other desirable aquatic life, greater need for chlorine and chemicals for water treatment, and a deterioration of the quality of treated water because waste residues are present.

Phenols

Phenolic material, which includes phenols, cresols and xylenols, when found in water is usually the result of pollution by industrial wastes (7). Phenols are widely used in the synthesis of many organic compounds. Waste products from oil refineries, coke areas, and chemical plants may contain high concentrations.

Lethal concentrations for fish are somewhat related to the species, time of contact, temperature, and other conditions. Experimental data, however, show that 5.0 mg/l would be toxic to most fish (8) and some of the chlorinated phenols exhibit toxicity in concentrations as low as 0.2 mg/l (9).

Very low concentrations of phenols will impart a disagreeable taste to water when chlorinated. The chlorophenols produced by the addition of chlorine will have a more disagreeable taste and odor than the parent substance. Thresholds of taste and odor for chlorophenols range 0.001 to 0.02 mg/l (10). The drinking water standards of the U.S. Public Health Service have set the upper limit for phenol at 0.001 mg/l because of its objectionable taste following chlorination. Fortunately, phenols are decomposed by bacterial action in the presence of dissolved oxygen, and their persistence from point of entry is relatively short-lived.

Alkyl Benzene Sulfonate (ABS) (Apparent)

This test is a measure of the large, anionic-type molecules which are representative of the synthetic organic detergents now contaminating many surface and ground waters. The ABS is that portion of a common household or industrial cleaning compound that imparts foam and reduces surface tension to aid in the removal of dirt particles by the cleaning compound. ABS compounds are new to the water environment. They have been used as substitutes for soap only in recent years. They pass through water and sewage treatment processes with only partial reduction in concentration; moreover, they are not readily attacked by stream purification processes. Consequently, ABS can be found for many miles below sources of waste water discharge. ABS is believed to be non-toxic to man (11, 12) in the concentrations found in contaminated waters; but it produces unsightly, persistent foams in water at points of agitation. The ABS content of drinking water used on interstate carriers is limited to 0.5 mg/l in the U.S. Public Health Service Drinking Water Standards (4).

Hydrogen Ion Concentration (pH)

pH is defined as "the logarithm of the reciprocal of the hydrogen ion concentration or, more precisely, of the hydrogen ion activity - in moles per liter (9). pH 7 is the neutral point, or dividing line

between an "acid" and an "alkali;" pH values below 7 indicate an acid condition, values above 7 indicate an alkaline condition. Each unit change in pH indicates a tenfold change in hydrogen ion concentration; e.g., pH 6 is 10 times stronger than pH 7, and pH 5 is 100 times stronger than pH 7, in terms of hydrogen ion concentration.

The pH value of water is significant for several reasons. Low pH values (acidity) disrupt biological activity, cause corrosion of steel and concrete, intensify the effect of toxic materials such as sulfide and cyanide, interfere with water plant coagulation practices and tend to add undesirable iron and manganese to the water. High pH values (alkalinity) also disrupt biological activity, precipitate calcium and magnesium from water and increase the toxicity of ammonia and other amines.

Dissolved Solids

The dissolved solids test measures the concentration of dissolved material present in the sample. This includes both organic and inorganic matter. Excessive dissolved solids in water can be unpalatable, and increase the cost of water treatment for many water uses. The Drinking Water Standards of the U.S. Public Health Service recommend the rejection of sources providing water containing over 500 mg/l of dissolved solids (if another water source is available) because of a noticeable saline taste, and possible cathartic effect on many individuals.

Sodium

Sodium is an alkaline base metal, the salts of which are very soluble in water and tend to remain in solution. The use of sodium salts is very common in industry, and industrial wastes may contain large quantities of the element.

Sodium is not particularly significant in drinking water, except for those persons having abnormal sodium metabolism. It has been disclosed (13) that sodium in excess of 200 mg/l is is significant to those suffering from high blood pressure.

Potassium

Potassium, an alkaline metal, is abundant in the earth's crust, yet its content in natural waters is usually small. In low concentrations it is essential for plant development (14), but must be maintained in proper balance with phosphorus.

Potassium stimulates plankton growth (15), but is otherwise insignificant unless found in concentrations above 400 mg/l, a level considered to be toxic to fish (16).

Calcium

Calcium, an alkaline earth metal, is one of the constituents which produces hardness in water. However, the amount of calcium usually found in "hard" waters is less than the daily nutritional requirement. Hardness is ordinarily considered undesirable because of scaling and reduced heat transfer in heating and cooling systems and because of increased soap consumption. Research (17) has demonstrated that there may be a relationship between the hardness of drinking water and a reduction in cardiovascular diseases.

Magnesium

Magnesium, like calcium, is a "hardness" producing mineral and contributes to the hardness effects discussed under calcium. It is not known to produce toxic effects, although in high concentrations magnesium salts have a pronounced laxative effect.

Specific Conductance

Specific conductance yields a measure of a water's ability to carry an electric current and is therefore an indication, within rather wide limits, of the ionic concentration of the solution. The amount of dissolved matter in a sample may often be estimated by multiplying the specific conductance by an empirical factor. This factor may vary from 0.55 to 0.9 depending on dissolved substances and temperature of water.

Waters polluted by brines and chemical saline wastes will produce a relatively high level of conductivity. This gives rise to an increase in osmotic pressure which has a harmful effect on living organisms. Wide variations in total salinity or in the concentrations of individual salts can have far-reaching effects upon water fauna, resulting even in the elimination of species (18,19).

Alkalinity

Alkalinity is defined as the capacity of a water to neutralize hydrogen ions and is expressed in terms of an equivalent amount of calcium carbonate. Alkalinity is caused by the presence of carbonates, bicarbonates, hydroxides, and to a lesser extent by borates, silicates, phosphates, and organic substances.

In itself high alkalinity is not considered detrimental to man but it is generally associated with high pH values, hardness and excessive dissolved solids, all of which may have an adverse effect on the quality of the water.

Sulfates

The sulfate radical is of significance only as it is associated with calcium or magnesium. When in combination with these minerals a laxative effect is produced. To control this effect the drinking water standards suggest a maximum of 250 mg/l as acceptable.

Chloride

This is a component of the dissolved ionized solids present in most surface waters. It is closely associated with man's activities since it is a component of human waste and is also used freely in many industrial processes. Chloride can produce a salty taste to drinking water and render it unpalatable. Many waters are unsuitable for domestic use, irrigation and industrial processes because of high chloride content. The Drinking Water Standards of the U.S. Public Health Service recommend the rejection of sources providing water containing over 250 mg/l chloride if other water of better quality is available. It is not treatable by conventional water and waste treatment methods. Increased chloride concentration would imply deterioration in water quality for many beneficial uses.

Toxic Metals

The U.S. Public Health Service Drinking Water Standards limit the concentration of certain metals in drinking water because of potential toxic properties to human beings. These limits are as follows: Arsenic, 0.05 mg/l; Barium, 1.0 mg/l; Cadmium, 0.01 mg/l; Chromium, 0.05 mg/l; Lead, 0.05 mg/l; Selenium, 0.01 mg/l; and Silver, 0.05 mg/l. The presence of any of these elements in excess of the concentration listed shall constitute grounds for the rejection of the water supply. In addition, the standards list tolerance limits for metals that, if exceeded, can constitute grounds for rejection if other suitable supplies can be made available. These are as follows: Arsenic, 0.01 mg/l; Copper, 1.0 mg/l; Iron, 0.3 mg/l; Manganese, 0.05 mg/l; Zinc, 5.0 mg/l. The basis for rejection in this tolerance list is not toxicity in all cases but is also related to consumer acceptance. In addition to human toxicity, some of these metals are toxic to aquatic life and can play an important part in the biological makeup of the aquatic environment. The term toxic metals as used in this report refers to copper, cadmium, nickel, zinc, lead and chromium.

LABORATORY PROCEDURES

Sample Preservation

After samples were collected as described in Special Report LM-2, "Sampling Surveys", each sample was divided (on shipboard) into half-gallon portions according to substances to be analyzed and preservation requirements. Preservatives added to each half-gallon polyethylene bottle of sample were as follows:

1. For phosphate analysis - 10 ml of chloroform.
2. For nitrogen analysis - 1.8 ml of sulfuric acid.
3. For phenol analysis - 20 ml of 10% copper sulfate and 20 ml of phosphoric acid.

On Cruises 5 and 6, BOD analyses were performed on shipboard. On the other cruises, BOD samples were packed in ice at the time of collection and returned to Project headquarters for analysis. The average time in transit for these samples was four hours, and the longest time five hours.

Special preservation measures were not necessary for the sample portions used for mineral analyses.

Analytical Methods

The physical and chemical data included in this report were obtained, unless otherwise indicated, by following the procedures published in "Standard Methods for the Examination of Water and Wastewater," 11th Edition, 1960, referred to throughout this report as "Standard Methods." While many methods may be used in water analysis, those described in the "Standard Methods" have been selected for this study because the procedures are supported by collaborative studies of capable analysts, throughout the nation, who have demonstrated the methods to be accurate and reproducible within specified limits.

Minor modifications have been made on some of the methods used, when they could better accomplish the purpose for which the procedure was applied. Before adopting any change or modification, however, many repetitive analyses were made to determine the precision of the modified method and also its agreement with the "Standard Methods."

To assure continually reliable data, reference standards of known composition and many blanks were analyzed simultaneously with all tests.

A skeleton outline of tests performed is presented below. Where the tests conform strictly to "Standard Methods" only the pages wherein the procedure may be found are cited, but where modifications or changes are made these have been described in detail. Tests marked by asterisks were performed on shipboard.

Nitrogen-Ammonia and Organic

Free ammonia nitrogen was quantitatively determined by the distillation method described on pages 298-299. Organic nitrogen was measured by the Kjeldahl method using mercuric sulfate as a catalyst. This procedure is described on pages 305-307.

Nitrate and Nitrite Nitrogen

Nitrogen in the form of nitrates was determined by the phenol-disulfonic acid method described on pages 302-303. The nitrites, if present, were oxidized to nitrates with hydrogen peroxide in acid medium. This was the procedure used on the first five cruises of Lake Michigan. This method was run in duplicate with the Greis method for the Technicon Auto-Analyzer, described below, for analyses of ninety-six samples from the sixth cruise. The results obtained by the Greis method proved superior and the procedure was adopted for subsequent analyses.

Method for Nitrate Nitrogen by the Auto-Analyzer

Nitrogen in the form of nitrates was determined by the Greis Method following its reduction to nitrite, utilizing the Technicon Auto-Analyzer. The nitrates were reduced by means of a zinc column in an acid medium. The following procedure was followed:

1. Apparatus used:

Technicon Auto Analyzer. (20)

2. Reagents used:

a. Sodium Acetate Solution: 34 g. per liter.

b. Sodium Acetate Hydrochloric Acid Buffer Solution: (100 ml of hydrochloric acid (1 : 99) mixed with 1,000 ml of sodium acetate solution (a).

c. Sulfanilic Acid Solution: 6.0 g. of sulfanilic acid plus 200 ml of concentrated hydrochloric acid per liter.

d. Naphthylamine Hydrochloride Solution 6.0 g. of 1-naphthylamine hydrochloride, 10 ml of concentrated hydrochloric acid and 500 ml of 95% ethyl alcohol per liter. (This reagent eventually becomes slightly discolored and may form a slight precipitate. If discoloration occurred it was removed by mixing with nitrate free activated carbon and filtering.)

e. Color Reagent: Equal volumes of sulfanilic acid reagent(c) and naphthylamine hydrochloride reagent (d) were mixed and stored in the dark for increased stability.

f. Zinc metal 30 mesh, granular, reagent grade. This zinc was washed with chloroform just before use.

g. Stock Nitrate Solution: 7.2138 g. of anhydrous potassium nitrate per liter. This solution contained 1 mg of nitrate nitrogen per ml.

h. A series of working standards from 0.05 to 3.0 mg per liter of nitrate nitrogen was prepared from the stock solution(g).

3. Procedure:

a. The analytical system was set up in accordance with the flow diagram provided by Technicon.

b. The instrument was standardized using standard solutions listed in 2 h. A distilled water wash was interposed between each standard.

c. Samples were arranged on the analyzer with a distilled water wash between each sample. A series of standards was introduced after each 10 samples to detect possible drift in the instrumentation.

d. Standardization curves were prepared which show the relationship of recorder response to concentration of nitrate as nitrogen. Sample results were evaluated by reference to this curve.

The precision of this method was compared with the "Standard Method" by analysing ninety-six separate samples by both methods. The results were found to be in good agreement. This method was therefore adopted as a routine procedure because of its great superiority with respect to speed of analysis as well as improved precision.

Total Phosphate

This test was performed in accordance with procedures described in "Standard Methods," Method C, Total Phosphate and Polyphosphate, pages 204-206, on samples filtered to remove suspended matter.

Silica

The procedure for silica was the Colorimetric Heteropoly Blue Method described on pages 228-229.

Dissolved Oxygen*

This test was performed in accordance with the procedure described as Method A, Alsterberg (Azide) Modification of the Winkler Method, pages 309-311.

Phenols

Phenols were determined as described on pages 404-408, using the Aminoantipyrene Method.

Alkyl-Benzene Sulfonates

The methylene blue procedure for determining alkyl-benzene sulfonate (ABS) as described in "Standard Methods," pages 245-251, was modified by this laboratory. The changes in no way affected the reproducibility of the method, but did speed up the procedure and economize on the use of time and reagents.

The modifications were as follows:

(a) The washing of extracts with wash solution was eliminated because comparative studies showed that values were equally reproducible and accurate without this step.

(b) Twenty-five ml aliquots or aliquots diluted to 25 ml were used for analysis.

(c) Five ml of methylene blue solution was added to each sample. An additional amount, if needed, would be indicated by the water phase becoming clear after extraction with chloroform.

(d) The sample was extracted two times with 10 ml portions of chloroform and filtered through a pledget of cotton in the tip of the separatory funnel. This filtered and removed moisture from the chloroform extract satisfactorily.

(e) The sample was collected, made up to volume and read in the spectrophotometer at a wave-length of 650 millimicrons.

Biochemical Oxygen Demand*

The procedure for biochemical oxygen demand was the same as described on pages 318-23 in "Standard Methods."

Hydrogen Ion Concentration (pH)*

This test was performed by the Glass Electrode Method as described on page 194.

Dissolved Solids

Dissolved solids were measured by the method described on pages 326-330 of Standard Methods titled "Filtrable Residue."

Sodium and Potassium

Sodium and potassium content were measured by the Flame Photometric Method as described on pages 231-232.

Calcium

The method used was the EDTA Titrimetric Method as recommended in "Standard Methods" pages 67-68.

Conductance (Specific)*

This test was performed using a specific conductance meter and cell as described on pages 114-116.

Total Alkalinity

This test was performed using a mixed indicator, consisting of two parts methyl orange and one part methyl purple, as described on pages 45-47.

Magnesium

This test was performed by the Photometric Method as described in "Standard Methods" on pages 153-154.

Sulfate

The Turbidimetric Method was used as described on pages 241-242.

Chloride

Chloride content was measured by the Mercuric Nitrate Method described on pages 326-330.

Metals (Toxic)

A polarographic technique was used to analyze water for toxic metals. The instrument used was the Sargent Model XV. Metals in concentrations as low as 0.01 mg/l can be determined, and with the addition of the range extender and/or greater concentration of sample, lower levels may be detected.

The method has been demonstrated to be as accurate as, and definitely more time-saving than, the usual colorimetric procedures for these metals. The precision was in the range of ± 3%.

A detailed description of procedure has been given previously(21).

RESULTS OF ANALYSES

Samples of Lake Michigan water were subjected to a large number of physical and chemical analyses to establish base line water quality, to identify those parameters likely to provide the best index of water quality, and to determine areas or zones of water quality variability. The parameters studied were those listed on page 2 of this report. In general, the bulk waters of Lake Michigan were found to be of good chemical quality, in that the concentrations of the constituents present would be acceptable to the present water uses and to anticipated future uses of these waters.

The parameters showing appreciable variability and likely to provide the greatest threat to satisfactory water quality management were found to be ammonia nitrogen, total phosphate, silica, phenol and dissolved oxygen. These and other findings will be discussed with respect to the study area in subsequent paragraphs.

Deepwater Studies

Ammonia Nitrogen

The deepwater study in the northern sector of the lake was conducted in the spring. Figure 1 represents the ammonia nitrogen levels found in this area. The range was from less than 0.01 mg/l to 0.12 mg/l for all depths. The averages (shown in Table 1a) for surface, middle and bottom depths were 0.03, 0.05 and 0.05 mg/l respectively. There appears to be no particular pattern in the distribution of these results, since they vary from station to station with respect to maxima and minima in relation to depth. A similar condition exists geographically in that high and low values are at random throughout the sector. The highest value was found 16 miles out from Sheboygan. The second highest value was found in Green Bay.

Figures 2 and 3 show the southern portion of the lake which was also studied during the spring season. The surface concentrations ranged from less than 0.01 mg/l to 0.20 mg/l. The two highest concentrations, 0.20 mg/l found at the surface, and 0.10 mg/l found at bottom, were located along the same longitude in the southern end of the lake about 20 miles apart. The overall averages for all depths for the southern sector are not appreciably different from those observed in the northern sector for the spring period. The recorded averages for the southern sector were 0.05, 0.05 and 0.04 milligrams per liter.

Additional sampling for ammonia nitrogen in the southern sector of the lake was conducted during the summer season. These results are presented in Figures 4 and 5. The levels of concentration range from 0.01 to 0.20 mg/l, with an average of 0.06, 0.07 and 0.08 milligrams per liter for surface, middle and bottom depths respectively. The data show a slight increase in concentration of ammonia nitrogen occurring in the area when compared with the results reported for the spring season (Figures 2 and 3). The highest concentrations in the southern sector were found in the area off Hammond and East Chicago, Indiana.

With the exception of the two high results of 0.18 mg/l and 0.20 mg/l found in the south basin during the summer, and the high results of 0.13 mg/l and 0.12 mg/l found in the north basin, the deepwater ammonia nitrogen results indicate no water quality deterioration with respect to this parameter.

Phosphate

The average phosphate concentrations found in each area of the lake in each season are presented in Table 1. The phosphate results are also presented graphically in Figures 9 through 16. A study of Table 1 shows that phosphate levels in deepwater samples, during the spring, averaged 0.01 mg/l at the surface, middle depths and bottom depths. During the summer the average phosphate levels at the surface increased to 0.04 mg/l, and the average at middle and bottom depths remained constant at 0.01 mg/l.

Figure 9 present the phosphate results in the northern basin of Lake Michigan. All sampling in the upper half of Lake Michigan was in the spring. Only two results above 0.03 mg/l were found in this part of the lake. One was about mid-lake at 44°40' north, 86°30' west and the other was found in Green Bay.

Figures 10 and 11 show the phosphate levels found in deepwater in the lower half of Lake Michigan in the spring season. A study of these figures reveals that two results were above 0.03 mg/l. One of these was at mid-lake between Milwaukee and Muskegon, and the other was 17 miles out from Ludington, Michigan.

Figures 12 and 13 show the phosphate results in the summer in both deepwater and inshore samples. The summer deepwater samples were found to be higher than the spring samples, with seven values above 0.03 mg/l, and two of these as high as 0.73 and 0.20 mg/l.

Although there was found to be a substantial increase in deepwater phosphate between the spring and summer periods, with the exception of the few high results cited above, phosphate levels of the surface, mid-depth and bottom samples were below that considered necessary to produce high concentrations of algae (22).

Silica

The average silica concentrations found in each area of the lake in each season are presented in Table 1. A study of this table shows the silica results in deepwater samples during the spring to average 3.3, 2.6 and 2.8 mg/l in the surface, middle and bottom samples respectively. The average silica results in the deepwater samples during the summer were essentially the same as during the spring in the mid-depth and bottom values (2.7 and 3.2 mg/l), but the average surface value dropped from 3.3 mg/l in the spring to 1.5 mg/l in the summer.

Thirteen samples were found with silica results greater than 4 mg/l. Four of these were surface samples which were all found in the spring. Nine of these were found at the bottom depth and all nine were found during the summer. The geographical distribution of the high results was random in both the spring and summer sampling.

The variations found in silica concentration serve to demonstrate its uptake by biological life during multiplication. Since silica forms the skeletal structure of diatoms, its removal indicates significant biological activity. It could be a limiting factor in population explosions of diatoms where other growth factors are at optimum levels (23) (24).

Dissolved Oxygen (DO)

Table 2 shows the dissolved oxygen and related temperature results of samples collected in Lake Michigan in 1962. This table presents the average, maximum and minimum DO, the associated temperature, and the maximum and minimum per cent saturation values. These results are presented together because temperature is necessary to determine the per cent saturation values presented. The per cent saturation calculation is made assuming a standard sea level barometric pressure of 760 mm of mercury. One hundred and ninety-five deepwater samples were collected in the spring and summer of 1962 for dissolved oxygen analysis. The results are summarized in the first two groups of results in Table 2. With the exception of a few bottom samples collected in the spring, the results were between 91 and 118. The minimum per cent saturation figure for these few

bottom results was 71 per cent. The minimum DO result was 7.1 mg/l. This sample was collected from a station located in Green Bay at 44°45' N 87°50' W. Other than the few values indicated above, the dissolved oxygen levels in deepwater all were near 100 per cent saturation.

Alkyl Benzene Sulfonate (ABS) (Apparent)

As expected, ABS concentrations found in all deepwater samples were below the level of accuracy of the method used. Therefore no water quality significance is attached to the levels (0.01 to 0.05 mg/l) reported.

Nitrate Nitrogen

Nitrate nitrogen results are presented in Table 3. The results in deepwater sampling in the spring ranged from 0.03 to 0.25 mg/l at the surface, 0.06 to 0.26 mg/l at mid-depth and 0.02 to 0.21 mg/l at the bottom depth. The average values were 0.14, 0.14 and 0.11 mg/l at the surface, mid-depth and bottom respectively.

Results of deepwater sampling in the summer had approximately the same ranges of values but slightly lower averages. The average values were 0.09 at the surface and 0.11 at the mid-depth and bottom. The maximum concentration in each sampling period was found in the bottom depth. The difference between spring and summer results is minimal and no appreciable difference is found in geographical distribution.

Toxic Metals

Toxic metals were measured in a number of lake samples from each area of the lake to ascertain if any one of them might be found in sufficient concentration to be significant. The metals were found in detectable amounts but the quantities were quite low and are important only from the standpoint that the laboratory has established that they are not present in sufficient quantity to have any effect on human or aquatic life.

Table 3 shows the frequency of occurrence in any one area and season and the concentrations found.

Zinc was found in measurable amounts, ranging from 0.005 - 0.021 mg/l, over the entire northern half of the lake during the spring sampling. Copper, cadmium and lead were found between Charlevoix and Manistique in the range of 0.005 - 0.008 mg/l.

In the summer sampling, nickel was present in the center of the lake at a level of 0.005 mg/l opposite North Side Chicago and 0.009 mg/l of lead was found twenty miles out from Waukegan. Lead, in a concentration of 0.009 mg/l was found near Muskegon, chromium was found all the way across the lake between Muskegon and Milwaukee, in the range of 0.005-0.008 mg/l. Copper and chromium were present in the center of the lake opposite Manitowoc in the range of 0.007-0.008 mg/l.

Other Parameters

In the deepwater study of the lake, other parameters showed results of some variability but of little water quality significance. The analyses performed and the ranges found are briefly discussed below:

pH; range 8.0 to 8.9. There was no difference between spring and summer.

Alkalinity; range 100 to 125 mg/l. There was no difference between spring and summer.

Dissolved Solids; spring; range 98 to 258 mg/l. No results above 150 were found in the upper third of the lake. In summer samples, the range was 140 to 160 mg/l.

Conductance (specific); spring; range 216 to 298 micromhos per cm. In summer samples, the range was 192 to 272 micromhos per cm. The variation with changes in depth at each station was less than 20 micromhos per cm.

Sodium; range 3.5 to 4.9 mg/l. Results were very low and nearly constant. Analysis for sodium was discontinued in the fall because of uniform results.

Potassium; range 0.9 to 1.3 mg/l. Results were very low and nearly constant. Analysis for potassium was discontinued in the fall because of uniform results.

Calcium; range 30 to 35 mg/l.

Magnesium; range 9 to 11 mg/l.

Sulfate; range 19 to 23 mg/l.

Chloride; range 4.5 to 8 mg/l.

Inshore Studies

Inshore studies of Lake Michigan were made in the summer and fall of 1962. The inshore studies comprised sampling at one mile, four miles, seven miles and ten miles from the shore with samples collected at several depths at each station where indicated. In addition to the parameters which were found significant in the deepwater studies (Ammonia Nitrogen, Total Phosphate, Silica, Dissolved Oxygen and Nitrate), Phenols were found in significant quantities in some of the inshore samples. Greater variations were found in the parameters in the inshore studies than in the deepwater studies.

Ammonia Nitrogen

Ammonia nitrogen determinations on inshore stations of Lake Michigan were conducted during the summer and fall seasons. The results are presented graphically according to areas and seasons in Figures 4, 6, and 7, and are summarized in Table 1.

Figure 4 represents concentrations found during the summer period in the southwest quadrant of the lake. The range of values according to sampling depths are from 0.01 to 0.37 mg/l at the surface; 0.01 to 0.20 mg/l at mid-depth and 0.01 to 0.12 mg/l at the bottom. The higher values tend to distort the average because they are found in only two or three locations for each depth, yet it is observed that the greater number of high concentrations, particularly from surface samples, are found in the southern end of the lake between Chicago and Gary. The other points, with the exception of several stations near Waukegan and Milwaukee, which rise as high as 0.12 and 0.13 mg/l respectively, tend to be fairly uniform throughout. The averages for surface, middle and bottom were 0.05, 0.04, and 0.04 mg/l respectively.

The southwest quadrant comprising approximately the same stations selected in the summer was also studied in the fall season. The overall results are shown in Figure 6. When comparing this chart with Figure 4 it is observed that, although several individual stations show a higher concentration of ammonia nitrogen during the summer (Figure 4), the average values for the fall period are distinctly higher, (Table 1b). The concentrations during this period are 0.06, 0.04 and 0.09 milligrams per liter for top, middle and bottom depths respectively. The figures indicate that the bottom concentration is slightly higher than at the other two measured depths, and is double the value found for the same depth during the summer (Table 1a). The increased overall concentration for the

fall period is probably due to colder temperatures which reduce the rate of oxidation of ammonia to nitrates. Similarly, the bottom level may be higher because of cooler temperatures. Also apparent from the figure is that the higher concentrations tend to occur in the southern tip of the lake as was reported for the summer period of study.

The inshore stations in the southeast quadrant of Lake Michigan were studied during the fall season. The graphical picture is presented in Figure 7. Concentration ranges of ammonia nitrogen are from 0.01 to 0.08 mg/l for surface samples and from 0.01 to 0.10 mg/l for both middle and bottom depths. The averages are 0.04, 0.04, and 0.05 mg/l for surface, middle and bottom respectively (Table 1a). These figures would indicate no significant differences with respect to vertical depths, but do show slightly higher values geographically for the points between Michigan City and Benton Harbor as compared with the results from points immediately north of this area. There is again a slight increase in average concentration at the extreme northern sector of this quadrant around Muskegon where values reach around 0.10 mg/l and are comparable to those in the extreme southern sector. An interesting observation is noted when comparing Figure 6 and Figure 7, the southeast and southwest quadrants respectively. Both studies were conducted during the fall season but concentrations were significantly higher on the west side. This is probably due to the more heavily populated areas adjacent to the west shore.

It is apparent from this study of ammonia nitrogen concentrations that the inshore areas of the lake, particularly in the southwest sector, carry higher levels than the deeper water. These increased levels indicative of deteriorating water quality can be attributed to the heavy population concentration of the adjacent land area. However, with the exception of the several extreme values noted above, the levels found do not represent serious degradation at this time.

Total Phosphate

The average phosphate concentrations found in each inshore study area in each season are presented in Table 1. These results are also presented graphically in Figures 12 to 15. A study of Table 1 shows average phosphate results in inshore samples during the summer to be 0.01, 0.10 and 0.27 mg/l respectively at the surface, middle and bottom. This table reveals further that the average phosphate concentration in inshore samples in the fall was only 0.01 mg/l at the surface and middle, and only 0.02 mg/l in the bottom sampling depth. This was a marked decrease from the concentrations found in the summer samples.

Figure 12 shows the geographical distribution of the inshore results in the summer. All of these samples were collected in the southwest quadrant of the lake. Of a total of one hundred and twenty-nine samples, twenty-two were greater than 0.03 mg/l (including five between 0.10 mg/l and 1 mg/l, and six above 1 mg/l). Fourteen of the twenty-two high results were in the vicinity of Milwaukee, including all six which were above 1 mg/l and four of the five others above 0.10 mg/l. These showed a fairly even distribution between middle and bottom samples. Six high results (greater than 0.03 mg/l) in these inshore samples were distributed between Racine and Waukegan. One of these results was greater than 0.10 mg/l. The remaining two results above 0.03 mg/l were between Waukegan and Chicago.

Figures 14 and 15 illustrate the inshore phosphate results in the fall of 1962. Figure 14 shows the southeast quadrant and Figure 15 shows the southwest quadrant of the lake.

Twelve out of two hundred thirty-seven fall samples had phosphate results greater than 0.03 mg/l. In the southeast quadrant two of these high results were at the surface, six at mid-depth and one at the bottom depth. The remaining three were in the southwest quadrant. A comparison by depth in the southwest quadrant in fall samples is not of any value because all of the samples except nine were collected at the surface.

Georgraphically the high phosphate results occur with greatest frequency in two general areas: inshore between Milwaukee and Kenosha, Wisconsin on the west shore; and inshore between Muskegon and Benton Harbor, Michigan on the east shore.

The extremely high levels found in the Milwaukee area are logically attributed to the discharge of waste effluents from those cities. The low concentrations found at the surface during the summer study may be the result of uptake by planktonic organisms.

Silica

The average silica concentrations found in each inshore area in each season are presented in Table 1. This table shows average silica results in inshore samples during the summer to be 1.5, 2.0 and 2.5 mg/l respectively for the surface, middle and bottom samples. All of these samples were collected in the southwest quadrant of the lake. The average silica results in inshore samples during the fall in the same quadrant of the lake were somewhat less, being 1.4, 1.8 and 1.5 mg/l respectively for the surface, middle and bottom samples. The average silica results during the fall in the southeast

quadrant of the lake were nearly the same as in the southwest quadrant, that is, 1.7, 1.8, and 1.9 mg/l at the surface, middle and bottom respectively. A review of these averages, deepwater and inshore, indicates that the surface results are highest in the spring, the bottom results highest in the summer and a nearly uniform distribution occurs in the fall. The top to bottom variations noted in these observations are paralleled by the findings in the deepwater study, namely that this variation can be attributed to biological uptake. The above averages reflect a range from 0.02 mg/l to 4.0 mg/l in the areas studied.

Dissolved Oxygen (DO)

Table 2 shows the dissolved oxygen levels and related temperatures of samples collected in Lake Michigan. Included are both the maximum and minimum DO values, the corresponding temperatures and the maximum and minimum per cent saturation values.

Five hundred eighty-one inshore samples were collected for dissolved oxygen analysis in the summer and fall of 1962. The concentrations on the southwest side during the summer range from a maximum 99 per cent saturation on the surface to a minimum 77 per cent saturation at the bottom. Samples from this same area in the fall range from 84 to 107 per cent saturation at the surface, 94 to 100 per cent saturation at mid-depth, and from 78 to 105 per cent saturation at the bottom. The minimum DO value was obtained in the summer and was 6.7 mg/l.

No inshore samples were collected from the southeast side of the lake during the summer but the samples collected during the fall range from 96 to 106 per cent saturation at the surface. A minimum of 93 per cent saturation at the middle depths and 75 to 87 per cent saturation at the bottom depths. Little geographical variation was noted.

Dissolved oxygen concentrations in Lake Michigan do not appear to be of serious concern with respect to the water quality of the inshore waters.

Phenols

Since phenolic compounds are not likely to persist at distances far removed from the source of entry, except during low temperature periods, the samples analyzed for these materials were taken from the three principal harbors on the western shore of the lake and at inshore stations near industrial complexes in the southeast and southwest quadrants of the lake.

The inshore study for phenols in the southeast quadrant includes sampling stations extending from Michigan City, Indiana northward to a point above Muskegon, Michigan. The range at Benton Harbor was from less than 1.0 to about 2.0 micrograms per liter. Results from Saugatuck and Grand Haven areas range from 1.0 to 5.0 μg/l, and 0 to 5.0 μg/l respectively. No indication of phenols was found in the Muskegon area. The sampling stations for the southwest quadrant extend from inshore at Gary, Indiana northward to Milwaukee. The range of values reported at Gary is from 1.0 to 9.0 μg/l at Chicago from less than 1.0 to 5.0 μg/l; Racine 2.0 to 3.0 μg/l; at Milwaukee and Kenosha from less than 1.0 to 3.0 μg/l and 1.0 to 2.0 μg/l respectively. In the southwest quadrant it is observed that the maximum values tend to increase from the north to the south, while in the southeast quadrant the reverse is true. This is probably due, in part, to the nature of the industries located around or near the selected sampling points. The observed levels of phenols found in the southwest inshore area may at times affect the quality of municipal water supplies by imparting disagreeable tastes following chlorination.

Nitrate Nitrogen

Nitrate nitrogen sampling was conducted at inshore stations of the lake during summer and fall seasons. The results are summarized in Table 3.

The average values found in the southwest quadrant during the summer were 0.10, 0.14 and 0.16 mg/l for surface, middle and bottom depths respectively. The ranges were 0.02 to 0.18 mg/l at the surface, 0.08 to 0.22 mg/l at mid-depth, and 0.03 to 0.27 mg/l at the bottom. The same geographical area studied during the fall season reveals results that are in comparable ranges: from 0.05 to 0.19 at the surface, 0.08 to 0.16 at mid-depth and 0.07 to 0.19 at the bottom.

The southeast quadrant of the lake was sampled for nitrate nitrogen during the fall. The average concentrations found were 0.10, 0.12 and 0.13 mg/l for surface, mid-depth and bottom samples respectively. The ranges were from 0.08 to 0.13 mg/l at the surface, 0.08 to 0.32 mg/l at mid-depth and 0.05 to 0.36 mg/l at the bottom.

These figures show a slightly higher value at bottom than at surface or mid-depth, but average values are not appreciably different. In fact there is a fairly uniform distribution of nitrate nitrogen in all areas of the lake studied.

Biochemical Oxygen Demand (BOD)

BOD analyses on inshore samples in the summer season ranged from 0.5 to 2.6 mg/l. BOD analyses on inshore samples in the fall ranged from 0.2 to 2.5 mg/l.

Although these results are not high when compared to BOD levels found in flowing streams below sources of pollution, they do indicate some evidence of deteriorated water quality.

Toxic Metals

On inshore samples collected during the summer in the southwest quadrant of the lake, nickel, chromium, lead and zinc were found to be present only in close proximity to major cities in the range of 0.005-0.025 mg/l.

On inshore samples collected during the summer on the south end of the lake, copper, chromium, lead, nickel and zinc were found to be present in the immediate vicinity of the major cities in the range of 0.005-0.032 mg/l.

Other Parameters

Other parameters were considered in the inshore studies of the lake. Some were studied which had values of some variability but of little water quality significance. These results have importance in establishing that these parameters are not present in sufficient quantity to have any apparent effect on human or aquatic life. The parameters examined and the range found are briefly discussed below:

Alkyl Benzene Sulfonate (ABS) concentrations were below the level of accuracy of the method used. Therefore no water quality significance is attached to the levels (0.01 to 0.03 mg/l) reported.

pH values ranged from 8.0 to 9.0 in the summer, and 6.8 to 9.3 in the fall.

Alkalinity ranged from 100 to 115 mg/l in the summer and 87 to 136 mg/l in the fall.

Dissolved solids ranged from 140 to 160 mg/l in the summer; 119 to 172 mg/l in the fall.

Conductance (specific) varied from 256 to 340 μmho/cm in the summer and from 220 to 380 μmho/cm in the fall.

Sodium and Potassium results were very low; sodium ranged from 3.5 to 4.9 mg/l and potassium ranged from 0.9 to 1.3 mg/l.

Calcium results were also low, varying from 25 to 33 mg/l.

Magnesium results ranged from 9 to 11 mg/l.

Sulfate results ranged from 19 to 22 mg/l.

Chloride results ranged from 5 to 7.1 mg/l.

Harbor Studies

Chicago Harbor

The analyses performed and the ranges found were as follows:

Ammonia Nitrogen, average concentration 0.07 mg/l; range. 0.02 to 0.16 mg/l.

Total Phosphate, average concentration 0.01 mg/l; range up to 0.05 mg/l.

Dissolved Oxygen, average concentration 12.0 mg/l; range 11.6 to 12.6 mg/l.

Phenols, range up to 2.0 μg/l.

Nitrate, range 0.05 to 0.1 mg/l.

ABS, less than 0.1 mg/l.

BOD, range 1.0 to 1.5 mg/l.

Other parameters - None of the other parameters measured showed significant differences when compared to analyses of inshore waters taken in the vicinity.

The results of the analyses presented above compare very closely with results obtained in the inshore study, southwest quadrant, fall season. This is to be expected since the movement of water in this vicinity is toward the harbor, rather than away from it. Therefore, it can be concluded that the waters adjacent to the inlet of the Chicago River were representative of the inshore waters of the southwest quadrant with respect to the chemical parameters.

Racine Harbor

The analyses performed and the ranges found were as follows:

Ammonia Nitrogen, average 0.06 mg/l, max. 0.10 mg/l.

Total Phosphate, average 0.02 mg/l, max. 0.10 mg/l.

Dissolved Oxygen, average 11.7 mg/l, range 11.1 to 12.7 mg/l.

Phenol, range up to 5.0 μg/l.

Nitrate, range 0.05 to 0.17 mg/l.

ABS, less than 0.1 mg/l.

BOD, 1.0 to 2.5 mg/l.

Other parameters. Of the parameters measured, only chloride showed a slight increase in concentration when compared to the results obtained in the inshore study, southwest quadrant, fall season.

Racine Harbor receives the flow of the Root River, which is a small tributary draining the immediate area. Any drainage from the Root River would include the overflows of storm sewers and surface runoff but not the effluent from the sewage treatment plant, the outfall of which is located two miles south of the harbor.

With the exception of very minor differences in DO and phenol levels, the chemical quality of these waters compares favorably with the levels found for inshore waters in this area.

Milwaukee Harbor

Because considerable variation in chemical quality was observed in these waters when compared with the inshore waters of the southwest quadrant, this harbor study will be reported in greater detail.

Figure 8 presents the findings with respect to ammonia nitrogen. Inspection of this figure reveals significantly high concentrations, both within and outside the breakwater. The overall average for the study area was 0.6 mg/l. The highest values, (max. 2.73 mg/l) were observed within the breakwater, but several values above 0.5 mg/l were found outside, near the breakwater openings.

The concentrations found outside the breakwater form a pattern indicating a southward movement of the water in that vicinity.

The phosphate levels found in this study of Milwaukee Harbor are presented in Figure 16. Levels as high as 1.4 mg/l were observed, with an overall average of 0.27 mg/l. Concentrations of phosphate outside the breakwater form a pattern similar to the ammonia nitrogen values.

Dissolved oxygen levels in the harbor averaged 10.0 mg/l. The values ranged from 11.4 to 5.3 mg/l with the corresponding saturation values between 98 and 52 per cent. These values are considerably lower than the comparable levels found in the inshore, southwest quadrant, fall survey.

Phenols ranged up to 11.0 μg/l within the harbor area and may be compared in Figure 17.

Nitrates ranged from 0.08 to 0.27 mg/l in the harbor and averaged 0.16 mg/l. This average was higher than the average value for deepwater and inshore samples.

ABS levels (see Figure 18) were as high as 0.3 mg/l and BOD was found to be as high as 4.5 mg/l.

Other parameters of interest were; pH, which was lower than adjacent waters, and chloride, as high as 37.9 mg/l.

In contrast to the other harbor areas studied, the Milwaukee Harbor and adjacent areas showed significant evidence of degradation of chemical water quality. Low DO and high BOD values indicated severe water quality deterioration. The high ammonia nitrogen and phosphate levels which are typical of polluted streams may be expected to stimulate algal growth. Phenols and ABS levels were further evidence of this degradation. Because all the wastes of the Milwaukee area, including treated domestic sewage, surface runoff and stormwater overflow are discharged through the harbor into the Lake, it is not difficult to understand why the beaches of Milwaukee are frequently closed to bathers.

It may also be presumed, subject to further confirmation by current measurement studies, that most of the subtle differences observed in chemical quality of the western inshore area are the result of the waste discharges from the Milwaukee area.

CONCLUSIONS

Studies of chemical water quality were undertaken in specific areas of Lake Michigan. Of the chemical parameters considered, Ammonia Nitrogen, Phosphate, Silica, Phenol and Dissolved Oxygen were found to be significant with respect to the differences encountered.

The deepwater studies provided little or no evidence of water quality deterioration, in the areas studied. Considerable uniformity was displayed between surface and depth samples for most parameters measured. The low silica levels observed on surface samples during the summer study are believed to be due to uptake by plankton.

The inshore studies provide information which points to some water quality deterioration in areas adjacent to populated sectors of the lake. Ammonia nitrogen levels were highest in the southwest sector; phosphate was also highest at depths other than the surface. The low concentrations found at the surface may be due to uptake by planktonic organisms. Phenol, in sufficient concentrations to affect municipal water supplies, was detected.

Of all areas studied, Milwaukee Harbor was found to be most degraded with respect to chemical quality of the water. Significant degradation was evidenced by the high concentrations of ammonia nitrogen, phosphate, ABS, phenol and BOD, and the low concentrations of DO observed. Some of the tests also revealed evidence of southward movement of waters from this harbor.

An illustration of the probable effects of returning Chicago's sewage effluents to the lake may be obtained by observing the Milwaukee Harbor results. Although this may be an extreme example of the conditions which might occur, nevertheless the return of any large portion of Chicago's effluents would be expected to have somewhat similar effects on the surrounding waters as those observed in the Milwaukee Harbor area. Among these expected effects would be an accelerated increase in nitrogen and phosphate levels which are already approaching critical levels in the Southwest inshore quadrant of the lake.

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TABLE 1a
Averages of Chemical Results
By Seasons and Areas
Lake Michigan 1962

Area of lake Sampled	Season	Sample Depth	AMMONIA NITROGEN Total No. of Samples	AMMONIA NITROGEN Avg. Results mg/l	TOTAL PHOSPHATE AS PO_4 Total No. of Samples	TOTAL PHOSPHATE AS PO_4 Avg. Results mg/l	SILICA Total No. of Samples	SILICA Avg. Results mg/l	NITRATE NITROGEN Total No. of Samples	NITRATE NITROGEN Avg. Results mg/l
Deep water	Spring	Surface	55	0.04	50	0.01	53	3.3	32	0.14
		Middle	49	0.05	33	0.01	32	2.6	77	0.14
		Bottom	44	0.05	19	0.01	19	2.8	36	0.13
Deep water	Summer	Surface	30	0.06	31	0.04	31	1.5	31	0.09
		Middle	32	0.07	22	0.01	19	2.7	18	0.11
		Bottom	31	0.08	29	0.01	30	3.2	31	0.11
Offshore South-west	Summer	Surface	53	0.05	52	0.01	42	1.5	56	0.10
		Middle	18	0.04	24	0.10	13	2.0	16	0.14
		Bottom	58	0.04	57	0.27	46	2.5	60	0.16
Offshore South-east	Fall	Surface	38	0.04	39	0.01	29	1.7	38	0.10
		Middle	30	0.04	28	0.01	27	1.8	34	0.12
		Bottom	34	0.05	41	0.02	41	1.9	37	0.13

TABLE 1b
Averages of Chemical Results
By Seasons and Areas
Lake Michigan 1962

Area of lake Sampled	Season	Sample Depth	AMMONIA NITROGEN Total No. of Samples	AMMONIA NITROGEN Avg. Results mg/l	TOTAL PHOSPHATE AS PO_4 Total No. of Samples	TOTAL PHOSPHATE AS PO_4 Avg. Results mg/l	SILICA Total No. of Samples	SILICA Avg. Results mg/l	NITRATE NITROGEN Total No. of Samples	NITRATE NITROGEN Avg. Results mg/l
Offshore South-west	Fall	Surface	81	0.06	79	0.01	41	1.4	103	0.11
		Middle	12	0.04	-	-	3	1.8	13	0.12
		Bottom	42	0.09	9	0.01	28	1.5	46	0.12
Milwaukee Harbor	Fall	Mid-Depth	72	0.60	76	0.27	79	1.4	74	0.16
Racine Harbor	Fall	Mid-Depth	36	0.06	32	0.02	37	1.5	36	0.09
Chicago Harbor	Fall	Mid-Depth	12	0.07	13	0.01	-	-	13	0.07

TABLE 2
LAKE MICHIGAN 1962
DISSOLVED OXYGEN AND PER CENT SATURATION
BY SEASONS AND AREAS

Area of Lake Sampled	Season	Sample Depth	Total No. of Samples	Avg. Results	Min. DO	Temp. of Min. DO	Max. DO	Temp. of Max. DO	% Saturation Min.	Max.
Deep Water	Spring	Surface	65	12.7	10.1	17.4	14.3	1.6	104	104
		Middle		12.7	9.8	12.0	13.9	2.0	91	101
		Bottom		12.6	7.1	16.0	14.0	1.0	71	99
Deep Water	Summer	Surface	30	10.0	9.0	20.8	11.0	14.4	100	106
		Middle	31	12.4	8.9	---	15.4	4.0	---	118
		Bottom	31	11.4	9.0	18.5	12.8	4.0	96	98
Inshore S.W.Side	Summer	Surface	68	9.0	6.7	---	11.0	11.3	---	99
		Middle	50	9.4	7.2	---	13.1	---	---	---
		Bottom	67	9.4	7.1	19.8	11.9	4.6	77	93
Inshore S.E.Side	Fall	Surface	59	9.6	9.3	16.9	10.3	16.6	96	106
		Middle	38	9.6	9.3	16.2	10.0	---	93	---
		Bottom	58	9.5	7.9	13.3	11.4	4.1	75	87
Inshore S.W.Side	Fall	Surface	120	10.9	8.9	19.0	13.0	7.0	84	107
		Middle	57	10.7	9.1	17.0	12.2	7.0	94	100
		Bottom	116	11.0	7.6	17.0	12.8	7.0	78	105
Milwaukee Harbor	Fall	Mid-Depth	74	10.0	5.3	10.0	11.4	9.0	52	98
Racine Harbor	Fall	Mid-Depth	36	11.7	11.2	8.0	12.2	9.0	94	105
Chicago Harbor	Fall	Mid-Depth	13	12.0	11.6	8.0	12.6	7.0	98	103

TABLE 3a
LAKE MICHIGAN 1962
TOXIC METALS
By Seasons and Areas

Area of Lake Sampled	Seasons	Total No. of Samples	Copper		Cadmium		Chromium	
			Frequency	Conc. mg/l	Frequency	Conc. mg/l	Frequency	Conc. mg/l
Deep Water North	Spring	29	2	0.005-0.008	1	0.008	0	<0.005
Deep Water South	Summer	31	1	0.007	0	<0.005	5	0.005-0.008
Inshore S.W.	Summer	69	1	0.014	0	<0.005	3	0.005
Inshore S.E.	Fall	63	0	<0.005	0	<0.005	6	0.005-0.008
Inshore S.W.	Fall	26	1	0.009	0	<0.005	0	<0.005

TABLE 3b
LAKE MICHIGAN 1962
TOXIC METALS
By Seasons and Areas

Area of Lake Sampled	Seasons	Total No. of Samples	Lead		Nickel		Zinc	
			Frequency	Conc. mg/l	Frequency	Conc. mg/l	Frequency	Conc. mg/l
Deep Water North	Spring	29	4	0.005	2	0.005	24	0.005-0.021
Deep Water South	Summer	31	2	0.009	1	0.005	1	0.011
Inshore S.W.	Summer	69	3	0.006-0.008	5	0.005-0.006	1	0.025
Inshore S.E.	Fall	63	2	0.005-0.007	1	0.005	5	0.009-0.032
Inshore S.W.	Fall	26	0	<0.005	0	<0.005	0	<0.005