

A PROPOSED WATER QUALITY
MONITORING PROGRAM FOR SELECTED
INLAND LAKES OF MICHIGAN

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ABSTRACT

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By

Richard Kenneth Hodge

The Water Resources Commission of the Department of Natural Resources administers the State Water Quality Monitoring Program which efficiently samples the water quality of numerous rivers and streams throughout the state. Begun in the early 1950s, it is today an extensive program as evidenced by more than 150,000 chemical analyses performed annually. Nevertheless, the program's emphasis has been primarily restricted to rivers and streams, neglecting a valuable surface water resource, the inland lakes. In an attempt to further the knowledge of water quality surveillance, this thesis develops a methodology for inland lake monitoring.

The proposed program applies many of the known river monitoring techniques to the lake environment. For example, sampling techniques, frequency, duration, and stations are adjusted to secure representative background and pollution control data. In addition, a lake classification system is developed based upon a variety of lake uses. These four classifications of lake use include: High Value

Recreational Lakes, Important Sport Fishing Lakes, Wildfowl and Fur-bearing Animal Breeding Areas, and Receiving Waters For Effluent.

For each classification, a set of pertinent parameters is identified along with a list of lakes which satisfy the classification's criteria. However, some lakes listed qualify for more than one classification. In this case, the monitoring program is composed of each set of applicable parameters.

To apply the monitoring programs, three lakes are selected. These lakes consist of Higgins Lake, Roscommon County, Headquarters Lake, Grand Traverse County, and Lake Chemung, Livingston County. For each lake the parameters are discussed and the sampling stations are identified. In addition, each program's cost analysis compares the sampling and analytical costs charged by a state agency to those charged by a private water quality laboratory.

The conclusions emphasize that the two objectives of the monitoring program are entirely compatible. For example, to collect both background data and to identify nutrient sources, many of the same parameters are utilized. On the other hand, the costs of implementing the three monitoring programs are much too high. To reduce these costs various solutions are presented. However, the most beneficial suggestion involves the use of lake residents. It is recommended that members of each lake association become involved in monitoring their own lakes and under the supervision of water quality technicians collect the required number of lake samples. With volunteer assistance, the labor costs can be reduced by one half.

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CHAPTER I

MICHIGAN'S RESOURCES

Glacial Geology

The Wisconsin glacier, the last of four great ice advances of the Pleistocene, moved through Michigan over 10,000 years ago. At its maximum, the ice covered over 15 million square miles of the earth's surface--completely engulfing Michigan. Three of the four main lobes of ice followed the troughs of Lake Michigan, Lake Huron, and Lake Erie, while the last lobe ventured off the Huron ice sheet and moved southwesterly until it again merged with the other three. During this time in glacial history, the Great Lakes formed.

Originally the lake basins were different in appearance than they are today. Scoured by the creeping ice, the early stream valleys were shaped and reshaped by the massive glacial ice. The tremendous weight of the continental ice sheets continued to depress the valleys until the ice melted, retreating to the north. As a result, the basins acquired their present shape.

Geologists have divided this period of the Great Lakes formation into six stages, beginning with the formation of old Lake Chicago. This lake emerged between the northern retreating glacier and the high land to the south. Across the land surface to the east,

Lake Whittlesay developed out of the smaller Lake Maumee. Completing this first stage were the beginnings of Lake Huron and Lake Saginaw (Fig. 1 A).

Unlike the present drainage system of the St. Lawrence Seaway, this region drained to the west, from Lake Whittlesey, through Lake Saginaw, down the Grand River Basin, and into Lake Chicago where it emptied into the Mississippi River.

As the years passed and the ice withdrew further northward, Lake Saginaw and Lake Whittlesey merged and became known as Lake Warren (Fig. 1 B). Next, as Lake Duluth was forming in the northwest corner of the upper peninsula, a large lake named Lake Lundy developed (Fig. 1 C). This point marks the beginning of the eastward drainage system because Lake Lundy drained down the Mohawk and Hudson Rivers.

In this next to last stage, Lake Chicago enlarged, Lake Algonquin formed, covering the present basins of Lakes Huron, Michigan and Superior, Lake Erie and Ontario increased to the present size, and the St. Lawrence Valley developed--filled by the entering sea waters. Now the final stage, the Nipissing Great Lakes Stage, began. During a period of many years, the Great Lakes decreased in size. Concurrently, a connection developed between Lake Erie and Lake Ontario. With the St. Lawrence Seaway draining toward the Atlantic, this largest system of fresh water lakes in the world was complete.

The Pleistocene Ice Age deposited ponderous glacial boulders as well as a myriad of stones, sand, and clay throughout Michigan as it moved southwestward from the Canadian highland areas. In some

places in the southern peninsula, this glacial drift measures 1,000 feet thick. Moraines, eskers, kames, drumlins, and other geomorphological features remain today as evidence of the Great Ice Age. In particular, morainic areas fostered numerous inland lakes as the ice retreated north making these areas especially valuable recreation areas today.

Land and Water Resources

With the melting of the massive Wisconsin Glacier, the present land and water resources emerged. Today, land acreage amounts to nearly 62 million acres. The Great Lakes surface area covers 24.8 million acres, by far the largest portion of the total water surface acreage. On the other hand, inland lakes and ponds are numerous covering nearly 850,000 acres. Add to these figures 3,000 miles of Great Lakes shoreline and over 36,000 miles of inland streams, and an impressive statistical outline is drawn which reveals the state's potential for an enormous recreational enterprise.

Recreational land use is the largest land use in Michigan. There are in excess of 19 million acres of forest land located within the state. On a percentage basis all recreational lands, which includes wildlife refuge areas, amount to 58 per cent of the total land area in Michigan. Despite this fact, public ownership varies considerably throughout the state (Fig. 2). Situated at the two extremes are Van Buren County, located in southwestern Michigan, devoting 0.01 per cent of its public lands to recreation and Schoolcraft County, located in the upper peninsula with 60.8 per cent of its land denoted as forest and recreational. Nevertheless, the state

average is 18.7 per cent--this figure comprises national and state forests, parks, and recreation areas.

Climatic Conditions

The water resource base of Michigan, consisting of its lakes, ponds, streams, and ground water resources is replenished by the annual precipitation. Averaging 31 inches per year, precipitation varies from 26 to 36 inches throughout the state. Those areas receiving the greatest amount of precipitation are located in southern Michigan along the western shores of Lake Michigan and in the upper peninsula along the southern shores of Lake Superior. Air masses moving easterly across these lakes distribute the moisture in this manner. Nevertheless, precipitation is quite uniform throughout the year, but rainfall is somewhat heavier during the growing season.

Snowfall within the state varies greatly. Some areas in the northwestern portion of the upper peninsula receive 160 inches of snow annually, while others located in the southeastern lower peninsula receive only 30 inches. This wide discrepancy is caused by three factors: (1) variations in latitude, (2) differences in elevation, and (3) moving air masses. Moving from south to north, winter temperatures decrease and latitudinal lines increase. Similarly, as elevations increase, moist air moves upward where it cools and produces snow. However, these two causes are merely secondary causes of snowfall variation. The primary cause is air mass movement. Heavier snowfalls occur along the eastern and southern shores of the Great Lakes because air masses traveling eastward accumulate moisture from these surface bodies. For example, counties along the southern

shore of Lake Superior, such as Houghton County, receive between 90 to 120 inches of snow annually as compared to those counties bordering the northwestern shores of Lake Huron, like Alpena County, which receive between 50 to 90 inches.

It should be understood that such comparisons made between differing snow depths may lead to false conclusions. This is highly probable because snow contains varying amounts of moisture. For example, the Water Resources Commission has found snow in the southern counties of Michigan that contains as much as 7 inches of water per foot of snow--two inches per foot is more characteristic of late winter snow. Therefore, comparisons should be made between moisture content, not snow depth, when assessing winter precipitation levels.

Soils

Michigan is divided into two zonal soil regions, the Podzol or Spodosols and the Grey-Brown Podzolic or Alfisols. The Spodosols are found north of a line connecting Allegan County on the west to St. Clair County on the east. Included in this region is the northern half of the lower peninsula and the entire upper peninsula. South of this east-west line the Alfisols are found.

Despite developing from different parent materials, all Spodosols display certain similarities. For example, they are all poor in chemical and physical qualities and are not very good agricultural soils. The soils of the northern half of the lower peninsula typically consist of a layer of acid organic matter on the surface, followed by a dull gray A₁ horizon. In this horizon, leaching processes have removed carbonates, sulfates, and other

soluble salts. Also removed from these horizons are the characteristic iron and aluminum oxides, which now accumulate in the B horizon.

The Alfisols are also leached soils. They too contain organic matter in the upper horizons, but unlike the Spodosols, the organic matter does not accumulate on the soil surface. Instead, it is incorporated into the mineral soil of the A_p horizon. In addition, the Alfisols exhibit a yellow-brown A_2 horizon instead of the gray siliceous layer characteristic of the Spodosols. This horizon is also a zone of eluviation, but contains exchangeable calcium and is not particularly acidic. Although some iron and aluminum oxides accumulate in the B horizon, it typically contains silicate clays. Because of these clay materials, Alfisols are often poorly drained soils.

Concluding Comments

The preceeding discussion provides an introduction to the land and water resources of Michigan. From this discussion, it is impossible to justify a water quality monitoring program on a natural resource basis alone. However, the fact that Michigan has over 35,000 inland lakes, ponds, and reservoirs represents a sizeable recreational resource. In addition to these recreational water resources, hundreds of thousands of acres are devoted to recreation--many of which depend upon water resources. Others depend upon the availability of water related recreational land. What must be determined is that common water quality problems exist among many of Michigan's inland lakes. This is the thrust of Chapter II, which examines lake eutrophication.

It must be determined that a need exists for a inland lake monitoring program. A discussion of the natural processes that

continually occur within the lake ecosystem and the role that man's activities play will reveal a basis for need determination. Chapter II explores these processes as it examines lake eutrophication.

CHAPTER II

THE LAKE ENVIRONMENT

Problem Statement

The basic problem confronting the inland lakes of Michigan is one of excessive nutrient inputs. Derived from agricultural and forest land drainage, urban runoff, industrial discharges, and sewage effluent, nutrients enter the lake basins and accelerate the natural aging process or eutrophication of our lakes. Before long the nutrient overloading of the lakes produces excessive weed growth and algae bloom. In this manner, numerous lakes are degraded before the water quality problem is identified.

In general, these eutrophication problems are not detected until the lake residents complain about aesthetic or recreational damage. Then, a limnological study is initiated by the state to explore the water quality problem. Water quality data is collected, assessed, and a control program may develop as a result of the study.

These events occur in this order because adequate background water quality data has not been gathered for many of Michigan's 25,000 inland lakes. Granted, this number of lakes is too large to monitor. However, a selected group of inland lakes could be monitored to yield background and nutrient source data. With this

purpose in mind, my thesis develops an inland lake monitoring program that can be adapted to a number of selected lakes throughout Michigan.

To guide its development and to delineate the lake problems, an ecological basis for monitoring is presented in the next sections. This discussion centers around the lake environment and the seasonal changes which distribute mineral and organic constituents throughout the water volume. In addition, the sources of nutrient inputs are examined and their importance is assessed. With this ecological background explanation, the selection of water quality parameters and the development of the entire monitoring becomes more meaningful.

Lake vs. Stream Environment

The lake environment has been characterized as a closed ecosystem in comparison to the stream environment or open ecosystem. In general, this distinction refers to a lake's stable nature and its slowness to change. As measured by most water quality parameters, this characterization is accurate. Similarly, the water body mixes only di-annually, not continuously like a river. In addition, stable bottom conditions in a lake maintain present fish species and resist rapid successional changes. Yet, the lake environment does not represent a static ecosystem because it does change with time.

Temperature Relationships

The temperature of a lake affects the aquatic conditions and the life which the lake supports. For example, as the temperature rises, carbon dioxide, oxygen, and other soluble gases decrease in quantity. This occurrence triggers a chain of events beginning with

a reduction in the metabolism of the aquatic life and ending with a lowering of organic decomposition. In its most severe state, temperature changes cause specie succession. However, this succession is normally a slow process caused by natural aging conditions.

Temperature variations also produce the characteristic layering of lake water. This condition known as thermal stratification occurs annually and may be conveniently separated into four seasonal segments.

Beginning in the winter, ice covers the surface of the lakes in Michigan. Water densities vary throughout each particular surface body, however, the maximum density is reached near the surface at four degrees centigrade. Since ice freezes at zero degrees centigrade, it is less dense than the underlying water at this temperature and consequently it floats.

As snow covers the lake, shading out the sun's rays, photosynthesis is inhibited. In addition, a lower incidence of sunlight occurs during the winter, which combines to reduce plant growth. Working together these factors cause a reduction in oxygen content which is normally replenished through atmospheric contact and photosynthetic activity. Further oxygen depletion results as aquatic organisms respire. By March, the oxygen near the bottom of the lake is severely depleted--in some cases "winter kill" of fish occurs.

With the approach of spring, the process of oxygen depletion reverses and becomes a process of replenishment. As the surface ice melts, stratification develops throughout the lake. The denser surface water, which warmed to four degrees centigrade as the ice melted, moves downward toward the lake's bottom. This movement

creates convection currents, which circulate throughout the lake mixing the lake's water. Encouraged by spring winds, oxygen is captured from the atmosphere and travels downward along with the denser waters. In this manner, oxygen is replenished to depleted depths throughout the lake.

The advent of summer produces a thermal stratification of lake waters. As the weather warms and the brisk spring winds subside, the surface waters warm, expand, and decrease in density. This condition provides a resistance to mixing. Thus, the typical lake becomes stratified into three distinct thermal layers: the epilimnion, thermocline, and hypolimnion.

As fall begins, an erosion of the thermocline commences. The epilimnion cools as the days shorten and the light incidence decreases. Similar to spring overturn, this fall overturn circulates the cooler oxygenated waters downward. With the increase in wind intensity, the circulation reaches deeply into the lake disrupting the summer aquatic conditions that produced the characteristic thermal stratification. As ice again forms in the northern hemisphere, the lake returns to its winter state.

Characteristics of the Thermal Layers

The three layers or temperature zones listed in order by increasing depth consist of the epilimnion, thermocline or metalimnion, and the hypolimnion (Fig. 3). Though many lakes exhibit all three layers others do not. Nevertheless, the epilimnion is characteristically a warm layer which varies only slightly in temperature throughout its volume. In larger sized lakes, this layer is generally thicker

than in smaller ones. In addition, it is oxygen rich, absorbing oxygen from the contacting atmosphere.

On the other hand, the thermocline is a layer of rapid temperature decline. Averaging a one degree centigrade drop per meter depth, this layer is usually thinner than the associated epilimnion, particularly in large lakes.

The last layer, the hypolimnion, is characterized by a lack of oxygen. Typically uniform in temperature, it reveals less than a one degree centigrade change per meter depth.

Oxygen Distribution

In the lake environment, the oxygen distribution between thermal layers is represented by two basic profiles, even though many intermediates exist. The first profile, the clinograde profile, is characteristic of highly productive lakes or eutrophic lakes. This profile shows a sharp decline in the dissolved oxygen concentration in the thermocline (Fig. 4). The decline continues into the hypolimnion--often oxygen is entirely lacking in this layer. In contrast, the second profile, the orthograde profile does not show a similar oxygen decrease in these two layers. Surprisingly, the concentration may even increase. Typically, the orthograde profile is characteristic of lakes of low productivity, oligotrophic lakes.

Between these two extremes, numerous intermediate conditions exist which exhibit varying degrees of oxygen concentration and diverse levels of lake productivity. For example, a shallow stratified lake located at a high altitude, may remain relatively oligotrophic, but exhibit the clinograde oxygen profile. On the other hand,

the opposite situation may occur. "A deep lake may be very productive, but if the hypolimnion is large enough, it may show until late summer a fairly orthograde oxygen curve. . . ."¹ Green Lake, located in Wisconsin, is an example of this type of lake. Therefore, it is quite evident that clinograde and orthograde profiles represent extreme conditions in nature and do not preclude the existence of intermediate conditions.

Natural Eutrophication

Every lake experiences an aging process beginning with its formation and ending with its death. In Michigan, the lakes have been aging or eutrophying since the time of the Pleistocene. Though most of these lakes are still considered immature, some have become extinct, as evidenced by our present muck farms. Nevertheless, all existing lakes may be generally classified as either oligotrophic or eutrophic.

An oligotrophic lake is characteristically clear and low in nutrient content. It is usually very deep and possesses a rock or sand bottom. In contrast, a eutrophic lake is turbid, high in nutrient content, and usually shallow. Its bottom consists of mud or marl and is quite unstable. "A eutrophic system . . . [has been characterized as] one in which the total potential concentration of nutrients is high. . . ."² Therefore, a lake containing a low

¹National Academy of Sciences, Eutrophication: Causes, Consequences, Correctives (Washington, D.C.: National Academy of Sciences, 1969), p. 20.

²Ibid., p. 19.

concentration of dissolved nutrients is still considered eutrophic if a high concentration of nutrients are trapped in its sediments.

Some Physical Factors
Affecting Eutrophication

The two important physical factors which affect the lake eutrophication process are lake depth and shoreline shape. The depth of surface water bodies varies from a shallow pond to a very deep lake. In contrast, a shallow pond permits light energy to penetrate entirely to its bottom. With abundant nutrients present, the pond soon becomes clogged with weeds. But, a deep lake is not as easily overrun by weeds because sunlight cannot penetrate to its bottom. Nutrients which are not utilized by plants accumulate on the lake's substratum. These nutrients remain unavailable until spring when seasonal overturn occurs.

The shape of a lake's shoreline also affects its productivity. A lake with a long irregular shoreline and many coves possesses numerous shallow areas which fill with aquatic weeds. Each year's growth of weeds dies and provides additional nutrients for the next year's growth. Lobdell Lake, located near Fenton, Michigan exemplifies these conditions. At the other extreme, is a deep lake exhibiting a regular shoreline. Because it lacks numerous shallow areas, few weeds develop. Consequently, corrective measures employed to reduce nutrient inputs are usually more successful when applied to deep infertile lakes as compared to shallow fertile lakes.

Bacteria and Eutrophication

The entire life and death of a lake is really dependent upon the bacteria found in its waters. They are the primary agents of decomposition and transformation. Through the assimilation of soluble organic nutrients, bacteria begin the food chain. Ideally, this bacterial activity should not release more nutrients from plant and animal decomposition than can be assimilated by existing aquatic life. However, this situation rarely occurs.

The place which bacteria occupy within the lake ecosystem is inferred by E. A. Birge's concept which states " . . . bacteria stands at the base of the fertility of lakes."³ To delineate this statement, the balance between nutrients and organisms in the lake environment is diagrammed as a unilateral triangle (Fig. 5). As a lake changes from oligotrophic into eutrophic and finally becomes a dead lake, the balance shifts to a greater proportion of plants and animals as opposed to bacteria.

With an oligotrophic lake, the nutrients and the aquatic life are restricted--still they remain in balance. In contrast, a dead lake exhibits an imbalance of nutrients and aquatic organisms. The nutrients actually accumulate to the extent that bacteria can no longer entirely decompose them. Between these two extremes stands the triangle representing the conditions characteristic of a eutrophic lake. Like the oligotrophic situation, it displays a balanced triangle, however, this triangle comprises a higher level of nutrients.

³Ibid., p. 332.

Water Quality and Variation Factors

The water quality of a lake is influenced by three spacial variation factors. These factors include: the physical shape of the lake, the nature of its submerged land surface, and the sources, distribution, and quality of the water supply. In relation to the shape of a lake, its surface area and surface area-depth ratio affect the water quality the most. Concerning the surface area, a large unbroken area enables the wind and wave action to distribute the chemical constituents throughout the water body--both laterally and vertically. In a similar manner, the area-depth ratio influences the transfer of oxygen and energy into the aquatic environment. As this ratio increases, a better opportunity exists for complete mixing and a thorough dissolution of oxygen and energy throughout the entire lake.

Submerged lands control the quality of the lake water at the point of contact or interface. In particular, the substratum removes chemical constituents from the water. Nitrogen and phosphorus represent typical examples. In addition, organic plant and animal debris fall to bottom adding to the nutrient accumulation. This build up begins in the fall and continues throughout winter. Then, during spring overturn, the constituents are redistributed throughout the water volume.

Surface water sources supplying water to a lake have a greater affect upon lake water quality than do subsurface sources. Though ground water furnishes many lakes with their primary source of supply, it marginally influences lake water quality because of its low nutrient content. Soil leaching processes and cation exchange reactions strip

nitrogen, phosphorus and other chemical constituents from soil percolates producing this low concentration of nutrients in ground water. On the other hand, surface runoff carries vast quantities of nutrients into rivers and streams. Consequently, inflowing streams transport these nutrients which are held in solution and suspension into the lake basin.

There are also two temporal variation factors that tend to influence water quality. They are retention time and solar energy supply. The first factor, retention time, expresses the relationship between water inflows and outflows. The longer inflow sources are detained in the lake basin, the greater the impact will be upon the lake's water quality. Thus, lakes which exhibit a mean flushing time of several years are substantially influenced by surface water inflows carrying abundant nutrients.

Diurnal and seasonal supplies of solar energy significantly influence lake water quality by stabilizing soluble organic constituents. At the beginning of summer, energy is absorbed by the surface water layer and stratification develops in the lake. Consequently, nutrient constituents are distributed unevenly throughout the water body. For example, dissolved organic constituents reach their maximum concentration in the epilimnion and lower hypolimnion.

How does solar energy directly affect this concentration of chemical constituents? The heat from solar energy warms the epilimnion causing molecular movement. Various cation and anion exchange reactions occur which tends to hold the constituents in solution. As a result, the nutrients are available for assimilation by phytoplankton and zooplankton species.

In an indirect manner, energy concentrates nutrients in the hypolimnion. Light energy which penetrates the upper two thermal layers reaches the hypolimnion and supplies the energy requirements for photosynthesis. Aquatic plants continue to thrive until light incidence decreases in the fall and disappears entirely in the winter as snow covers the ice. As a result, the plants die, fall to the lake bottom, and decompose. Thus, solar energy has indirectly produced this concentration of nutrients in the hypolimnion.

Artificial Eutrophication

Eutrophication, the natural aging process of a lake, is accelerated by man's activities. To separate this induced eutrophication from the natural eutrophication, the term artificial is selected. Therefore, any human activity which introduces nutrients into the aquatic environment represents a cause of artificial eutrophication. Five categories identify the major cause of artificial eutrophication. They consist of agricultural drainage, forest runoff, urban runoff, industrial discharges, and municipal effluent.

Agricultural Drainage

Drainage from agricultural land carries nitrogen and phosphorus into lakes and streams. Supplied by agricultural fertilizers, nitrates and phosphates enhance the growth of aquatic plants. In shallow coves or near the mouth of an inflowing stream, aquatic plants thrive. Similarly, various algal species have developed the capacity to assimilate great quantities of nutrients. In fact one researcher has proven that algae will consume all nitrates and

phosphates right down to the last ion. In addition, another researcher concluded from experimental evidence, "a physiologically equilibrated growth [algae] requires the uptake of about twenty times more nitrate ions than phosphate ions."⁴ Therefore, nitrates and phosphates entering a lake or stream are bound to increase the productivity of the water resource.

In the soil, nitrogen occurs primarily in an organic form--approximately 95 per cent originating from organic matter. However, it must be converted into soluble forms before aquatic organisms can utilize it. This is accomplished by bacteria through microbial decomposition. In the presence of adequate oxygen and favorable temperatures, microorganisms oxidize ammonium (NH_4) producing nitrite (NO_2^-) and then nitrate (NO_3^-). Nitrogen is soluble in this last form and moves with soil-water. However, if poor oxygen conditions exist, ammonium is reduced to gaseous nitrogen and lost to the atmosphere--approximately 15 ppm/day of nitrates are lost in this manner. This reduction process, denitrification, is also a major means by which nitrogen escapes from waterlogged soil (Fig. 6).

Phosphorus also occurs in both organic and inorganic forms in the soil, but unlike nitrogen it is not particularly soluble in either form. It varies from .01 to .13 per cent in the soil. In acid soils, phosphorus appears in the form of iron and aluminum phosphates, while in alkaline soils calcium phosphates predominate. All three of these

⁴ Earnest F. Goyna and Wesley W. Eckenfelder, "Advances in Water Quality Improvement," in Objectives, Technology, and Results of Nitrogen and Phosphorus Removal Processes, ed. by Karl Wuhrmann (Zurich, Switzerland: Swiss Federal Institute of Technology), p. 22.

forms are extremely insoluble. In addition, phosphorus derived from fertilizer or resulting from organic matter decomposition is quickly converted to insoluble forms. Therefore, the amount of phosphorus present in agricultural drainage waters is very small.

Surface Runoff and Soil Percolates

Only minor amounts of soluble inorganic nitrogen are transported by surface runoff. This phenomenon occurs because ammonium and nitrate forms are dissolved in the first rains of a storm and infiltrate into the soil. With respect to rain water, it usually contains a higher average concentration of nitrates than does surface runoff. However, once nitrates are dissolved in the soil percolates, they are completely soluble and move readily. If they are not absorbed by plant roots, they enter drainage waters which flow into nearby lakes and streams. Conversely, soil percolates are very low in phosphorus since phosphorus precipitates out in the subsoil. Therefore, phosphorus reaches its highest concentration in surface runoff, not in soil percolates.

Suspended Particle Matter

Individual soil particles are dislodged from aggregates by falling raindrops, surface runoff, and stream bank erosion. Once in solution, the suspended particles travel varying distances, from a few feet to many miles. For example, raindrops create soil erosion on morainic topography moving suspended particles downslope with the surface runoff. Many of these particles eventually settle out of suspension along the banks of a stream while other particles remain in suspension until the stream empties into a larger river or lake.

However, all chemical constituents held in suspension must be converted to soluble forms before they can be assimilated by aquatic organisms.

Nitrogen absorbed by suspended particles usually exists in an organic form. In this state, it does not significantly contribute to the soluble nitrogen supply. However, when the particles settle out of suspension, microorganisms convert the organic nitrogen to soluble inorganic forms. Consequently, this nitrification process occurs on the lake bottom wherever soil particles and organic matter accumulates--fresh organic materials decompose readily, but humified organic matter does not.

Where phosphorus is contained in suspended particles, it is present in both organic and inorganic forms. As with organic nitrogen, decomposition converts organic phosphorus to soluble inorganic forms, however, the process is more complex. Essentially, the inorganic phosphorus bonded with iron, aluminum, or calcium in mineral particles seeks a state of equilibrium with the phosphorus in solution. If the higher concentration of phosphorus is present in the suspended particles, then the movement will be toward a higher concentration in solution. In the opposite situation, phosphorus moves out of solution. This knowledge led two soil scientists, J. W. Biggar and R. B. Corey of the University of Wisconsin, to state,

The contribution of eroded particulate matter to the nutrition of the algae may be associated more with its effects on the concentration of soluble nitrogen and phosphorus in the incoming waters than with the total or "extractable" nitrogen and phosphorus in the particles themselves.⁵

⁵ National Academy of Sciences, Eutrophication, p. 409.

Therefore, it is expedient to analyze data which represents soluble nitrogen and phosphorus concentrations when predicating the ecological effects of nutrient inputs upon a lake.

Presently, there is little concrete data available concerning nutrient loss from agricultural lands. However, one study performed by the Agricultural Experiment Station of Michigan State University provides some reference data. By sampling water from drain tile, drainage ditches, and several small streams, the study sought to determine the quantities of nitrogen and phosphorus lost through drainage water from agricultural lands. Conducted in five southern lower Michigan counties, the study collected data from four farmland areas during 1968 and 1969. The results established maximum and minimum values of 11.1 ppm and 0.1 ppm, respectively, for nitrogen and 0.3 ppm to 0.01 ppm for phosphorus (Tables 1-3). Since these figures refer to soluble nitrogen and phosphorus, they represent amounts which could be readily assimilated by aquatic organisms.

What effect would these levels of soluble nitrates have upon a lake? One researcher, F. A. Ferguson, reports that nuisance algal growth might occur under the following conditions:

If the average concentration of inorganic nitrogen exceeds 0.3 ppm and the inorganic (soluble) phosphorus content exceeds 0.01 ppm. . . . However, some waters containing as much as 0.5 ppm soluble phosphorus do not support excess algal growths.⁶

The last sentence is explained by "Liebig's Law of the Minimum." In general, it states that growth is limited by any factor or factors

⁶F. A. Ferguson, Environmental Science and Technology, Vol. II, N. 188, in David W. Ehrenfeld, Biological Conservation (New York: Holt, Rinehart, and Winston, Inc., 1970), p. 52.

present in minimum amounts. Therefore, the existence of an algal bloom depends upon many interrelated parameters, any one of which may prevent the predicted bloom from developing.

Forest Land Drainage

Forest land is not often considered a major source of nutrients because concentrations of nutrients in runoff are usually low. Though man's influence in the forest is considered intense today, as compared to a century ago, his management of forest resources does not produce appreciable runoff. Nevertheless, the aggregate amount of forest subsurface flow is sufficient to transport large quantities of organic material into lakes and streams every year. Consequently, subsurface flow is considered the main transportation channel for nutrients from forest drainage.

Compared to the atmosphere, living and dead organic matter, and rock materials, the forest soil contributes the largest proportion of nutrients to subsurface flow. This is accomplished by precipitation falling on the forest floor and infiltrating into the soil. As it moves downward under the force of gravity, soil-water accumulates nutrients leached from the soil horizons. Under the pulling force of a hydraulic gradient, the subsurface flow eventually reaches a lake or stream. Here, the soluble nutrients become inputs into the lake or stream environment.

Forest ecosystems contribute only small quantities of phosphorus to subterranean flow. This is because phosphorus forms precipitates in the soil and is removed from soil-water. Many studies have documented this statement. One particular study conducted by

J. P. Miller in 1961 failed to detect any phosphorus in 23 samples of stream water, which drained the forests of the Sangre de Cristo Range of New Mexico. Other scientists have been more successful, however, nearly all research has characterized phosphorus as a very "immobile nutrient."

The available data supports the claim that nitrogen content is also low in forest drainage (Table 4). It is so low that some researchers feel that nitrogen input and output are actually in balance. Therefore, the impact upon a surface water resource is not great when forest runoff enters a lake or stream.

Urban Runoff

Only within the past few years has storm water been recognized as a major source of pollution. Street litter debris, salt and ice control chemicals, vehicle oil and grease, herbicides, insecticides, and pesticides as well as, animal and bird droppings are sources of pollutants which enter storm sewers. Various combinations of these materials resulted in an extremely high coliform bacterial count as reported by a study of Detroit storm-water. Conducted in 1949 by C. L. Palmer, bacterial counts varied from 25,000 to 930,000 per 100 ml samples, which were collected in street catch basins. In 1960 these results were confirmed by another storm-water study conducted in Detroit by the same researcher. In addition, other American and foreign research studies have gathered data concerning storm-water pollution (Table 5).

A Chicago study conducted in 1959 established an index for the solids causing surface pollution of an urban area of ten acres in size.⁷ The results of this study are as follows:

<u>SOURCES</u>	<u>PERCENTAGE</u>
Air Pollution Dustfall	2.9
Domestic Sanitary Wastes	16.1
Garbage	15.4
Rubbish	56.0
Street Sweeping	5.7
Catch Basins	2.9

These percentages in effect represent the influent end of polluting solids in the urban environment. If converted to tonage, catch basins amount to over five tons. Depending upon the capacity and efficiency of city removal efforts, the quantity of these solid pollutants entering storm-waters will vary. However, even the most efficient removal operations cannot prevent a portion of this serious source of pollution from reaching surface water resources.

Industrial Discharges

One could compile an extensive list of industrial pollutants which are discharged regularly into the aquatic environment. In all probability, many of these wastes are high in nitrogen, phosphorus, sulfur, calcium and magnesium. Consequently, these pollutants affect water resources in the same manner as the nutrients supplied by agricultural, urban, or forest sources. In general, the eutrophication

⁷ U.S. Department of Interior, Federal Water Pollution Control Administration, Water Pollution Aspects of Urban Runoff (Washington, D.C.: Government Printing Office, 1969), p. 31.

process accelerates with the additional input of nutrients. Thus, algal blooms, the depletion of dissolved oxygen, the development of anaerobic zones, and the reduction of aesthetic and recreational values, often results where industrial discharges enter a natural lake.

Many lakes in Michigan have received effluent from industry. For example, it is well known that the steel mills and other heavy industry of Detroit have seriously degraded Lake Erie to the extent that swimming is no longer considered safe on many public beaches. In the same geographical area, mercury discharges from both American and Canadian industries have threatened the sport fishing in Lake St. Clair.

Along with these large lakes, many small inland lakes have also experienced accelerated eutrophication from industrial discharges. Besides inducing weed growth and algal blooms, industrial discharges will completely kill all bottom dwelling organisms where the effluent enters a lake. This particular situation is adequately documented by a Water Resource Commission's survey of Barton Lake.

Located in Kalamazoo County, the lake receives waste discharges from a sewage plant and a paper company. Both facilities, which are located on Gourdneck Creek, an inlet to the lake, severely pollute the creek and Barton Lake. The survey conducted by the Water Resource Commission on August 12, 1953, reported that the effluent from the paper mill extended from the inlet to a distance of 200 feet out into the lake. All bottom dwelling organisms were killed in this area.

By order from the Water Resource Commission, settling ponds were installed by Lee Paper Company. Another survey conducted on July 22, 1954 reported that dissolved oxygen levels in the lake had

improved, however, seasonal algal blooms and excessive weed growth still prevailed. Thus, this particular case documenting industrial pollution effectively reveals the degradation experienced by one inland lake.

Sewage Effluent

The first recorded water-born epidemic occurred in London, England in 1854. In August of that year, an outbreak of cholera developed at Bradstreet Parish. Before the cause of the epidemic was traced to sewage line seepage, 90 persons had died within a two-month period. Apparently the casing around an old Bradstreet well had deteriorated to the point where sewage wastes could enter the water supply. Once contaminated, all the individuals who drank water from the well contacted cholera and died.

Fortunately, today our technology of waste treatment has advanced to the point where sewage effluent no longer threatens to contaminate public water supplies. However, surface water resources have not escaped the degradational effects of sewage effluent. Though remaining substantially free from disease-causing organisms, inland lakes have experienced nuisance algal blooms, excessive weed growth and increased turbidity. These conditions have directly resulted from sewage effluent inflows and septic tank seepage.

One of the earliest observations of a nuisance algal bloom occurred in 1896 at Lake Zurich, Switzerland. In that year, Oscillatoria rubescens a specie of blue-green algae, first appeared. Forty years later, the situation had substantially worsened as algae covered most of the lake releasing an offensive fish oil odor.

What biologically occurred to produce these results? Nutrients accumulated as municipal sewage effluent was regularly discharged into the lake. Anaerobic bacterial action continued to release carbon dioxide from decaying plant material which along with soluble nitrates and phosphates provided the nutritional requirements for a healthy algal bloom. A self-perpetuating nutrient cycle developed--greater nutrient inflows produced a more extensive algal bloom, which died releasing additional nutrients to support the next year's bloom.

This degradational pattern was not just restricted to European lakes. It was occurring in American lakes as well. For example, observations of Lake Erie water analyzed in 1920 showed an increase in the lake's phytoplankton. As time passed, other changes occurred. One change in particular replaced the cisco fishery with a less desirable, but more tolerant fish specie. Though many nutrient sources besides municipal effluent were responsible for the accelerated eutrophication of Lake Erie, municipal discharges did play a very significant role.

Lake Lansing Eutrophication-- A Case Study

Lake Lansing, which covers 452 acres, is located seven miles northeast of Lansing in Ingham County. It is the county's largest lake and exhibits a maximum depth of 37 feet--the average depth is closer to 10 feet. Since the lake is entirely spring-fed, it is not surprising to discover that it has virtually no stream inlets and outlets. However, three drainage inlets and one outlet, which is controlled by a dam, do service the lake.

During the years prior to 1964, septic tank drainage provided the primary nutrient source which produced the lake's abundant weed

population. Though few pipes drained directly into the lake, many tile fields apparently contacted the ground water which transported the nutrients into the lake basin. This greater availability of growth-inducing nitrates and phosphates enabled the weed population to increase rapidly. As a control measure, sodium arsenite was applied to the lake, but only marginal control was accomplished. Though numerous weeds died, they settled to the bottom of the lake and contributed additional nutrients which further accelerated the process of eutrophication.

The conversion to a municipal sewage system in 1964 effectively curtailed the effluent source. Unfortunately, the many years of sewage infiltration into the lake's basin has caused permanent damage. Now, each year excessive weed growth develops which threatens many recreational uses, such as swimming, boating, and water skiing. Thus, it became clearly evident to county commissioners and lake residents alike that a technique must be found to reverse the present eutrophication trend which is leading to the inevitable death of Lake Lansing.

With this purpose in mind, a reconnaissance report was initiated by Richard Sode, the Ingham County Drain Commissioner. The report entitled "Eutrophication Problem" identified four feasible alternatives for lake renovation. They include: building a new lake, breeching the dam and removing the lake spoil by land based equipment, dredging the lake to a uniform depth of ten feet, and dredging the lake to either a ten foot depth or to hard bottom.

From the standpoint of a benefit-to-cost ratio, the first alternative, which suggests constructing a new lake, registers the highest ratio, a 4.5 (Table 6). Nevertheless, this alternative does

not really tackle the problem; it actually avoids the problem of declining riparian property values. What will happen to the present lake? In addition, a new artificial lake might also require renovation in the future. Therefore, this alternative is not an acceptable technique for renovating Lake Lansing.

The report does not specifically recommend that one of the three remaining alternatives should be selected as the renovation technique. But, it suggests that further research of these techniques is needed before any particular method can be selected. Accordingly, a means of funding the renovation project must be discovered. To this end, it is recommended that the Army Corp of Engineers prepare a detailed study of Lake Lansing. Then, it is recommended that if the project is selected for federal funding, the techniques of dredging should receive primary consideration. Whether it is decided to dredge the lake to a ten foot depth or to a hard bottom, the water must be accurately monitored before and after dredging to obtain representative data concerning the changing aquatic conditions.

The problems of dredging Lake Lansing are adequately outlined in a publication of the Institute of Water Research entitled, Evaluation of Dredging as a Lake Restoration Technique. Divided into six categories, the report discusses the effects of dredging upon turbidity, nutrient release, increased nutrient inputs, species composition, eutrophication, and the release of toxic substances. For example, as a dredge removes sediments from the lake bottom, the turbidity may increase in the surrounding water. Similarly, more nutrients will probably become available for plant growth as the bottom of the lake

is disrupted. Conversely, the additional turbidity may provide a barrier to this photosynthetic activity by screening out light incidence.

The report also suggests that eutrophication may actually increase because of dredging. Other problems involve probable changes in the aquatic life and a release of sodium arsenite from bottom sediments. Thus, the report develops an ecological picture of Lake Lansing after dredging is conducted--a technique which may or may not prove to enhance its recreational quality.

Economics of Lake Eutrophication

Depending upon the technique selected the projected costs vary for renovating Lake Lansing. For example, the least expensive method, which proposes that a new lake be constructed, amounts to an initial cost of \$334,000 (Table 6). In comparison to this renovating method, the most expensive technique involves dredging the lake to a uniform ten foot depth. This is estimated to initially cost \$4,320,000. In all cases cited, the operation and maintenance costs amount to \$8,000 annually, while research and development figures amount to \$10,000.

The annual benefits derived from each of the alternative renovation techniques are estimated at \$161,000. This value is derived on the basis of an income of \$1.25 per recreation man-day. Since tri-county boat registrations amounted to 17,942 in 1965, an average of three persons per boat grosses approximately \$67,500. Consequently, if one quarter of the tri-county population of 299,000

visited the lake once more each year, the annual income would be \$93,500. Thus, these figures total \$161,000.

The annual benefits obtained from a greater use of the lake offset the annual charges in every case except where dredging is recommended to a uniform ten foot depth. In this case, a deficit of \$89,000 is experienced annually. For obvious economic reasons, this technique is an unlikely choice. Concerning the other possibilities, the criteria for selection will probably be influenced by the availability of funding, the funding source, the ecological impact of the technique upon the aquatic environment, and the efficiency of each technique.

An Ecological Basis for Monitoring

The interaction of physical, chemical, and biological parameters makes the lake environment a complex ecosystem. For example, solar energy establishes a vital link between photosynthesis and nutrient production. Anaerobic bacteria function to decompose dead organic matter, releasing nutrients back into the environment for reuse. Temperature variations distribute dissolved oxygen and nutrients by thermal layers and initiate spring and fall overturn. As these ecological processes serve to maintain the lake environment, eutrophication continues at a normal rate.

As man's influence is noticed in the aquatic environment, the natural slow process of eutrophication accelerates. In their general order of increasing toxicity, forest runoff, agricultural drainage, urban runoff, municipal effluent, and industrial discharges, all operate to degrade the aesthetic and recreational values of an inland

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lake. When an aquatic weed or an algae problem reaches serious proportions, a renovation technique is required to restore a lake's natural values.

Selecting a renovation technique is a difficult problem because most techniques have not progressed beyond the experimental stage and are usually expensive. The Lake Lansing problem represents a case-in-point. To restore the lake, it will cost a minimum of \$1,092,000. This figure which includes first costs, annual charges, interest on investment, amortization, operation and maintenance, and research and development costs is based upon 1969 cost figures.

An analysis of the costs of renovation seems to generate support for the concept of lake water quality monitoring. Today, when many local, state, and federal agencies are endeavoring to prevent river and stream pollution through monitoring, it seems only logical that similar surveillance efforts should be directed toward preventing lake degradation as well. However, because the lake environment combines a unique interaction of bacterial, chemical, and biological processes a monitoring program must be specifically designed to record pertinent data. Thus, Chapter III directs its attention to monitoring techniques as they apply to the lake environment.

CHAPTER III

WATER QUALITY MONITORING

Lake Water Quality Monitoring

In the fall of 1969, Jerome K. Fulton, a member of the Huron River Watershed Council, organized an information seeking interview team. During the months of October and November, one day interviews were conducted with state officials of the Great Lakes States and New England⁸ in an attempt to analyze the extent of inland lake and shoreline management. He concluded that a specific monitoring effort directed toward inland lakes was absent in all of the states surveyed. Specifically, his survey reported the following:

. . . none of the states surveyed had an adequate program of water quality monitoring for inland lakes. Having the standards and classifications is one thing, enforcing them adequately is quite another.⁹

A search for background information for this thesis also provided a measure of the various states' efforts concerning inland lake monitoring. In July of this past year I sent a letter to forty-five state pollution control agencies seeking information related to

⁸These states include Minnesota, Wisconsin, Michigan, New York, Maine, New Hampshire, Vermont, Massachusetts, and Connecticut.

⁹Jerome K. Fulton, "A Summary of Inland Lakes and Shoreline Management in the Great Lakes States and New England" (survey performed for the Huron River Watershed Council, Ann Arbor, Michigan, 1970), p. A-2.

water quality monitoring--particularly lake monitoring techniques which they employed. The results which I received substantiate Mr. Fulton's earlier survey. At the very most, a small number of lakes were monitored by states as part of their river monitoring program. However, not one state had a distinct inland lake monitoring program.

The amount of available literature concerning inland lake monitoring may be accurately described as minimal. As my survey revealed, there are no states explicitly monitoring their inland lakes. Furthermore, only a few states include inland lakes in their river monitoring program. Consequently, a conventional literature review of related research is not useful nor significant to the purpose of my thesis. On the other hand, a review of monitoring techniques and their adaption to the lake environment is important. Therefore, the following pages discuss these techniques.

Objectives

An objective is a goal which strives to accomplish a generally prescribed condition. On occasion, it implies an ideal condition, however, it normally establishes a logical goal or set of goals to accomplish. Therefore, one can express the water quality monitoring objectives of a state water resource agency as to gather and analyze water data as measured by physical, chemical, and biological parameters.

The objectives of the Department of Water Resources for the State of California represents a typical example of the goals of a state water resource agency. These objectives may be stated as follows: "To provide timely and adequate surface water quality data

through systematic examination and surveillance for determining conditions and detecting changes. . . ."10 Thus, the changes that occur to water resources either naturally or as a result of human activity are traced through monitoring procedures in order to identify degradational sources.

Standards and Criteria

A water quality standard is a definitive measure that is established by a water resource authority. Though standards are established by a water resource agency, this does not mean that they carry any guarantee of fairness or equitability. They are also not necessarily based upon sound scientific knowledge. In many cases, they reflect a lack of cognizance through their expression of generality. This is observed in Michigan's Intrastate Water Quality Standards where it establishes the recreational standard for toxic and deleterious substances. In reference to these substances, the standard states that "[they are] limited to concentrations less than those which are or may become injurious to the designated use."11

This appears to be the general response applied to all parameters where inadequate background knowledge is available. On the other hand, the states' recreational standard for bacterial organisms is very specific. It recognizes a limited number of colonies and samples

¹⁰ California Department of Water Resources, The Resources Agency, "Surface Water Quality Data," Sacramento, n.d. (Mimeographed.)

¹¹ Michigan State Department of Natural Resources, Water Resource Commission, Use Designation Areas for Michigan's Intrastate Water Quality Standards (Lansing, Mich.: Water Resource Commission, 1969), p. 6.

of coliform group organisms which are considered permissible for surface water resources. Thus, as these examples suggest, standards may fluctuate between a mere generality and a specific quantitative measure.

A criterion "designates a means by which anything is tried in forming a correct judgment respecting it."¹² In comparison to a standard, it does not possess any authority except that it is fair and equitable. However, a criterion is only useful if it can be quantitatively evaluated by approved analytical procedures. For example, the criterion of dissolved oxygen for intolerant fish, cold-water species, (trout and salmon) is established at "not less than 6 mg/l at any time."¹³ Because dissolved oxygen can be quantitatively measured, it is a useful criterion. Therefore, criteria establish the acceptable limits of various substances affecting water uses and provide the quantitative material for which standards are written.

Basically there are two types of standards, including their associated criteria. The first type, the limnological standard, is established to protect the aquatic organisms living in the lake or stream environment. Dissolved oxygen criteria are particularly useful measures for limnological standards. Others include nutrients such as nitrates, phosphates and chlorides, and such physical and chemical parameters as temperature, pH, and turbidity. The second type, the

¹²Richard D. Pomeroy and Gerald T. Orlob, Problems of Setting Standards and of Surveillance for Water Quality Control, prepared for California State Water Quality Control Board (1967), p. 4.

¹³Michigan State Department of Natural Resources, Use Designation Areas, p. 6.

health standards, are responsible for protecting human life. Bacteriological parameters are measures utilized in this category. Some examples consist of the coliform, fecal coliform, and fecal streptococci bacteria. These parameters are more closely monitored than any of the physical, chemical, or biological parameters comprising the first type. Because of their importance both of these types of standards and criteria are utilized in this monitoring program whenever they apply to a specific water use.

Water Quality Legislation

The Federal Water Quality Act of 1965 (P.L. 89-234) is part of the Federal Water Pollution Control Act, as amended (33U.S.C. 446 et seq.). The Act which was unanimously passed by Congress, required each state to submit to the Federal Water Quality Administration¹⁴ interstate water quality criteria along with a plan of implementation and enforcement.

All states complied with the mandate and met the June 30, 1967 deadline. Nevertheless, some of the state's criteria was not accepted by the Department of the Interior and required revision. Michigan was one of the eight states whose interstate water quality standards met with incomplete approval. However, the problem which involved Lake Michigan's water temperature criteria has since been corrected and the changes have been accepted by the Environmental Protection Agency.

¹⁴Since December 2, 1970, the Division of Water Quality Standards, Office of Water Programs of the Environmental Protection Agency has administered the program.

Every state with the exception of Georgia and Wyoming has established intrastate water quality standards which means that nearly all surface waters now have water quality criteria protecting their uses. In Michigan, intrastate standards were adopted by the Water Resource Commission at a public hearing on January 4, 1968. These standards which apply to rivers and streams throughout the state provide protection for specific water reaches. Similarly, inland lakes were also designated for protection.

The authority to set intrastate standards is granted to the Water Resource Commission by Act 245, Public Acts of 1929, which has been amended to read:

An Act to create a water resources commission to protect and conserve the water resources of the state, to have control over the pollution of any waters of the state and the Great Lakes, with power to make rules and regulations governing the same. . . .¹⁵

Section 5 and 6(a) of the act convey the powers to the Commission to adopt pollution control regulations. Section 5 reads as follows:

The Commission shall establish such pollution standards for lakes, rivers, streams and other waters of the state in relation to the public use to which they are or may be put, as it shall deem necessary.¹⁶

Michigan's Intrastate Standards

To avoid misinterpretation and to maintain uniformity with water quality terminology, the Water Resource Commission patterned the Intrastate Water Quality Standards after its interstate standards. For example, identical water use categories appear in both sets of

¹⁵Michigan State Department of Natural Resources, Use Designation Areas, p. 2.

¹⁶Ibid.

standards. These categories are water supply (domestic and industrial), recreation (total and partial body contact), fish, wildlife and other aquatic life, agricultural use, and commercial and other uses.

In the water supply category, waters designated as domestic possess very strict criteria. For example, with reference to coliform bacteria, "the monthly geometric average shall not exceed 5,000 nor shall 20 per cent of the samples examined exceed 5,000, nor exceed 20,000 in more than 50 per cent of the samples."¹⁷ In comparison, industrial water criteria are more lenient since they raise the 5,000 colony count to 10,000 and also allow small amounts of fecal coliform to be present.

The recreation category places more stringent requirements upon waters designated for total body contact than it does for partial body contact water. Again the relative septic condition of the water is the primary concern. Basically the difference is that samples cannot exceed 1,000 counts in the total body contact category, while 5,000 counts are allowed when the lake use involves partial body contact sports. Therefore, swimming, water skiing, and skin-diving are protected by a more particular set of bacterial criteria than are fishing and boating.

The third category, fish, wildlife and other aquatic life is separated into four water use sub-categories¹⁸ on the basis of

¹⁷ Ibid., p. 6.

¹⁸ The categories include: intolerant fish, cold-water species (trout, salmon); intolerant fish, warm-water species (bass, pike, panfish); tolerant fish (carp, bullheads); and principal anadromous fish migrations in warm-water rivers.

dissolved oxygen and temperature requirements. The first sub-category, consisting of the most intolerant fish species, such as, trout and salmon requires 6 mg/l of dissolved oxygen and maximum water temperatures of 70° F. On the other hand, carp will withstand a maximum of 87° F, and considerably less oxygen.

In the last two categories, agricultural and commercial and other uses, the principal distinguishing criteria are toxic and deleterious substances. Agricultural requirements demand adherence to the State Department of Public Health Drinking Water Standards as related to toxicants, while commercial uses are much more flexible.

These and other intrastate standards apply to all surface water resources throughout Michigan. The values presented for the five categories of uses are standards for the receiving body and not effluent standards. Therefore, the standards apply to waste effluents which have mixed with the receiving water body. However, the mixing area is not allowed to act as a barrier to fish migration or other designated water uses. In addition, where more than one use applies to a specific reach of stream or body of water, the most restricted standards shall govern the water quality.

Procedural Steps in Water Quality Monitoring

Selection of Pertinent Parameters

To ascertain the water quality of a surface water resource, parameters or indicators are utilized. They are defined as, " . . .

constituents or characteristics which serve to measure water quality."¹⁹ For example, dissolved oxygen, biochemical oxygen demand, pH, nitrates and phosphates, and coliform bacteria all qualify as parameters because they accurately measure a condition and detect any changes in the condition over time. Therefore, parameters require precise analytical procedures to provide meaningful water quality data.

Each constituent must possess certain qualifications to become classified as a parameter. First, a parameter must be capable of measuring a water quality characteristic which significantly affects a particular water use. For instance, fecal coliform bacteria satisfy this requirement when they are employed to measure the septic condition of a lake for total body contact recreation--swimming and water skiing. Secondly, a parameter must yield to measurement by acceptable scientific techniques. These techniques are listed in Standard Methods for the Examination of Water and Wastewater, the thirteenth edition. Thirdly, the parameter's measurement must be pragmatic, reproducible, and accurate. Lastly, a parameter should be able to measure both short and long term variability.

This monitoring program utilizes three categories to separate the numerous water quality parameters. These categories are designated as bacterial, chemical, and physical. To facilitate the discussion these three categories are further sub-divided into ten sub-categories. Because this thesis is directed toward water quality monitoring and

¹⁹Richard D. Pomeroy and Gerald T. Orlob, "Problems of Setting Standards and of Surveillance for Water Quality Control" (prepared for California State Water Quality Control Board, 1967), p. 5.

emphasizes bacterial, chemical, and physical constituents many important parameters, such as aquatic organisms and algae species, are not discussed since they do not fall within the realm of this monitoring program. However, the parameters which follow are discussed in detail.

I. Bacterial Parameters

- a. total coliform
- b. fecal coliform
- c. fecal streptococcus

II. Chemical Parameters

- a. Gaseous
 - 1. dissolved oxygen
 - 2. carbon dioxide
 - 3. biochemical oxygen demand
 - 4. chemical oxygen demand
- b. Nutrients
 - 1. nitrogen
 - a. ammonia
 - b. nitrate
 - c. nitrite
 - 2. phosphorus (orthophosphates)
 - 3. sulfur
 - a. sulfate
 - b. sulfide
 - 4. chloride

c. Metals

1. chromate
2. iron
3. mercury

d. Solids

1. total dissolved solids
2. settleable
3. suspended
4. volatile suspended

e. Trace elements

1. calcium
2. potassium
3. sodium
4. manganese
5. magnesium

f. Toxic substances

1. cyanide
2. herbicides, pesticides
3. phenols

g. Composite parameters

1. alkalinity
2. hardness
3. pH
4. oil and grease

h. Radioactive materials

1. alpha, beta, gamma radiation

2. radium-226
3. strontium-90

III. Physical Parameters

a. Water related

1. color
2. turbidity
3. temperature, air and water
4. discharge rate
5. specific conductivity
6. drainage area

b. Weather related

1. cloud cover
2. evaporation
3. humidity
4. climate
5. rainfall, snowfall
6. wind-direction

Bacterial Parameters

Coliform bacteria are found in the intestinal tract of man and other warm-blooded animals. Two important species, Escherichia coli and Enterobacter aerogenes, originate from fecal and soil material, respectively. When the Escherichia coli are detected in a water sample, this indicates the presence of sewage pollution. On the other hand, the second specie identifies a soil bacterial source. Though these coliform bacteria are not pathogenic, their discovery suggests that

pathogenic organisms may be present. Therefore, the coliform group is used as an indicator of pathogenic bacteria.

Besides fecal coliform and total coliform parameters which separate fecal from non-fecal sources, fecal streptococcus is also used to indicate the existence of pathogenic bacteria. Because they are less persistent than fecal coliform organisms, the presence of fecal streptococcus organisms in a water sample, suggests that the sewage pollution is fresh. Therefore, fecal streptococcus, fecal coliform, and total coliform bacteria represent three bacterial indicators which a water quality laboratory employs to analyze the septic condition of a water body.

Chemical Parameters

Gaseous.--Dissolved oxygen is an important water quality parameter because it regulates the life functions of aquatic organisms and facilitates organic decomposition. Fish species and other aquatic organisms require specific concentrations of dissolved oxygen in order to survive in their environment. For instance, the most intolerant fresh water species, trout and salmon, require 6 mg/l of dissolved oxygen. However, as a lake eutrophies, a greater demand is placed upon the dissolved oxygen supply by plants and bacteria. Consequently, if the dissolved oxygen levels are forced below 6 mg/l, the trout and salmon fishery may be succeeded by more tolerant species. Thus, monitoring dissolved oxygen levels provides an indication of the state of aquatic life and the degree of organic decomposition.

Carbon dioxide is another commonly used parameter because it also indicates the presence of organic decomposition. As nutrients

accumulate on a lake or pond bottom, anaerobic bacteria reduce these materials to useable forms. One of the by-products, carbon dioxide, is released in the process. It diffuses throughout the water volume as it rises upward. Algae consume the carbon dioxide and produce oxygen through photosynthesis. Thus, carbon dioxide levels reflect the magnitude of organic decomposition.

Two other parameters also measure oxygen utilization in the aquatic environment. The first parameter, biochemical oxygen demand (BOD), measures the oxygen requirements of organic decomposition. Consisting of carbonaceous and nitrogenous stages, BOD may require an incubation period of 30 days, however, the standard test is concluded in five days. Since some organic matter cannot be decomposed by bacteria, this parameter fails to measure the entire oxygen demand. Realizing this limitation, biochemical oxygen demand is still a useful parameter for water quality interpretation.

The chemical oxygen demand (COD), supplements this first demand parameter. It measures the chemical oxidation of waste material. For a water resource containing a large quantity of industrial-wastes, this parameter is particularly useful. Because a large proportion of industrial wastes are non-biodegradable, they resist microbial decomposition. Therefore, the chemical oxygen demand is often greater than the biochemical oxygen demand. To obtain an accurate measure of the oxygen demand, these two parameters should both be monitored.

Nutrients.--Nitrogen primarily exists in nitrate and ammonium forms in the aquatic environment. When present as ammonium, nitrogen is not soluble, however, it is soluble in the nitrate form. Aquatic

plants and animals readily assimilate nitrates, particularly during spring overturn when the nutrient's concentration reaches its highest level. As phytoplankton increase, the process of eutrophication may accelerate producing algal blooms and putrid odors. Yet, "the presence of nitrates does not necessarily mean that plankton will thrive."²⁰ Phosphates, carbon dioxide, and other parameters combine to exert a controlling influence upon algae growth. Therefore, nitrate concentrations must be evaluated in the presence of these other nutrients in order to determine the causes of accelerated eutrophication.

Ammonium nitrogen is produced as organic matter decomposes and is an intermediate stage of the decomposition process. This parameter is particularly important because it exhibits a high oxygen demand. In addition ammonium nitrate is toxic to fish. When present in high concentrations it also indicates the existance of organic pollution--normally it is present in low concentrations in surface waters. However, it is insoluble as ammonium, therefore, it must undergo oxidation passing through nitrite and into soluble nitrate forms.

In the nitrite form, nitrogen possesses a fairly low oxygen demand. However, its presence in a water resource also indicates that decomposition is occurring. Because it is unstable in this form, it rapidly converts to soluble nitrate nitrogen. As nitrate nitrogen, it represents the end product of aerobic decomposition and is available to plants.

Equally responsible for algal blooms is phosphorus, which is also derived from sewage effluent, particularly household and

²⁰Ibid., p. 4.

commercial detergents. Though unlike nitrates, low concentrations of phosphates may support a large phytoplankton population. For example, a phosphate concentration of 0.1 mg/l is a sufficient amount to induce excessive plant growth. However, only orthophosphate is soluble and available for plant growth. Because nitrates and phosphates both induce plant growth, monitoring the water for both nutrients provides an estimate of the productive potential of a water body.

Sulfates which originate from rock material, such as, gypsum and shale are dissolved in water solution. Sodium sulfate (Na SO_4) and potassium sulfate (K_2SO_4) are particularly soluble forms, while calcium sulfate (CaSO_4) is not. Some sulfides, such as hydrogen sulfide (H_2S) are corrosive, odorous, and toxic to fish. In addition, the sulfate ion has an important effect upon the biological activity in lake waters. Under anaerobic bacterial conditions, sulfates supply oxygen for oxidation reactions. Therefore, sulfates are important indicators of potential toxicity and represent an oxygen source for anaerobic decomposition.

Chlorides are also found frequently in natural waters. In the ionic form, they exist as important anions of inorganic salts. When discovered in high concentrations, they suggest sewage or fecal contamination. Like sulfates, chlorides corrode metals and are also toxic to plants. Monitored along with sulfates, they provide a more comprehensive evaluation of the septic condition of a lake.

Metals.--Iron is derived from the soil through leaching and from dissolution of rock materials high in iron. In the soil, it exists as insoluble ferric compounds--combining with chloride, oxide,

sulfate, and carbonate anions. However, ferric ions are reduced to ferrous ions when oxygen is absent and carbon dioxide and water are available. Because this reduction process occurs anaerobically, the presence of ferrous iron suggests the existence of organic wastes. Consequently, iron is used as an indicator of pollution, particularly industrial pollution.

Mercury emerged as a major water pollutant only within the past decade though it was initially introduced into the environment at the beginning of the industrial revolution. Today, many industrial plants discharge wastes containing mercury. Some of these consist of pulp and paper, chloralalkali, and paint industries. In addition, drugs, antibacterials, and dental amalgams represent other commercial sources of the element. Because fish absorb dissolved mercury through their gills and concentrate it in their tissues, this element is potentially hazardous to man. Consequently, mercury represents an important parameter which deserves to be monitored along with other toxic substances.

Another important industrial pollutant is chromate. It exhibits a characteristic yellow color when present in water, but this hexavalent chromate is rarely found in nature. Nevertheless, it is toxic to fish when present at a concentration of 5 mg/l. Therefore, the rarity and toxicity of chromate characterize it as a sufficient indicator of industrial pollution. Consequently, water containing any concentration of chromate should be considered a potential health hazard to humans and fish species alike.

Solids.--The solid substances present in natural waters are designated as dissolved, settleable, or suspended. A dissolved solid is one which imparts single molecules or ions to an aqueous solution which has undergone filtration. Consisting of trace metals, chlorides, and other substances, dissolved solids may affect the taste of water supplies. On the other hand, settleable solids do not remain in solution when filtered. The last designation, suspended solids, are those solids held in solution which do not dissolve. Actually, when dissolved solids are ignited, the volatile solids burn off leaving the fixed suspended solids behind.

Various prefixes are added to the word solids to identify collective or individually distinct parameters. For example, total is added to dissolved solids to refer to the sum of all molecules or ions present in solution. However, this particular designation of total dissolved solids suffers from a lack of precision and a lack of correlation between the weight of solids measured and the water quality. For instance, a magnesium ion weights three-fifths as much as a calcium ion. Under one set of conditions the magnesium ion is more objectionable to a particular water use, while the calcium ion is more of a problem under a different set of conditions. However, these results are not reflected in the category of total dissolved solids.

A better expression of mineralization is to identify the total equivalent ion concentration. Utilizing this distinction, the different minerals are represented in proper perspective to their effect upon the water quality of a surface water resource.

Data collected for these various distinct categories of solids ~~is~~ useful when determining the necessity for water treatment and the

type of treatment needed. For example, consider the hypothetical situation of a municipal sewage facility discharging effluent into a nearby stream. Suppose that the stream deposits excessive quantities of organic solids at its mouth at a lake inlet. Monitoring the total suspended solids may identify the source of pollution and suggest the necessity for more advanced waste water treatment at the sewage facility.

Trace elements.--Five trace elements impart objectionable tastes and hardness to water. These include: calcium, potassium, sodium, magnesium, and manganese. The first element, calcium, is found in natural waters in ionic form. Water high in calcium requires excessive amounts of soap for laundering clothes. On the other hand, calcium is beneficial to plant growth. Therefore, it may be utilized as an indicator of potential aquatic growth.

Because potassium freely reacts with air and water, it is naturally observed in ionic and combined forms. Potassium salts which are highly soluble in water resist natural settling and filtration. Consequently, they persist in surface waters for a long time. Though present in low concentrations, potassium is an essential nutrient for plant growth.

Sodium salts occur naturally in all waters. High concentrations are observed in wash waters which have been softened by ionic exchange with calcium and magnesium. Because sodium is also found in industrial and domestic wastes, high concentrations may indicate sources of pollution. In addition, persons suffering from circulatory diseases are affected by high concentrations of this element.

Therefore, sodium is monitored for health reasons and because it may indicate the presence of industrial effluent.

Contributing to the state of hardness is another element, magnesium. Like potassium, it is also an essential element for plant life and occurs in ionic form. Because high concentrations impart an objectionable taste to water, a health hazard rarely exists--a taste threshold is reached at 100 mg/l. However, magnesium is often monitored since it does represent a part of the total hardness attributed to water.

The last trace element, manganese is similar to iron since it is also an industrial by-product. Like iron, it exists in the soil as manganic and manganous compounds. Along with iron, it is leached into surface and ground waters. Anaerobic conditions enable the leaching process to function because they reduce the manganic ion to soluble nitrate, sulfate, and chloride salts of manganese. Because of its presence in domestic and industrial wastes, manganese is used as an indicator of industrial pollution.

Toxic substances.--Three important toxic substances are cyanide, various pesticides, and phenols. Cyanide is a naturally occurring toxicant formed in small amounts by many plants. However, it is also produced in higher concentrations by industry, principally by electroplating works. At concentrations of 0.05 mg/l it is lethal to intolerant fish species. Because it is easily destroyed by chlorination, secondary sewage effluent is generally free of cyanide. Therefore, lethal concentrations may be traced to industrial sources since they represent the primary suppliers of cyanide.

Phenolic compounds are also prevalent in plants, as well as, animal bodies and animal excrement. A phenol consists of a hydroxy group attached to a benzene ring. Though it often imparts a taste to fish, low concentrations are non-toxic. However, an occasional industrial mishap will release a highly toxic discharge into a river or lake. Still, monitoring phenolic compounds only proves fruitful when known discharges are sampled.

Undoubtably, the greatest concern within the past decade has been focused upon pesticides, particularly chlorinated hydrocarbons. For example, DDT has been blamed for the death of many song birds when it was extensively used to control the spread of Dutch Elm Disease. Similarly, dieldrin has killed many fish species. Because chlorinated hydrocarbons accumulate in animal fatty tissue, they are transmitted throughout the food chain by natural feeding.

Pesticides enter and pollute natural waters through two major channels. First, they are carried into lakes and streams by drainage waters from agricultural and forest lands. These sources are difficult to monitor because of the great number of both distinct sources and pesticides. On the other hand, the most serious sources of pesticides, manufacturing plants, are conducive to monitoring. Therefore, monitoring is most effective when applied to wastewater discharges and accidental spills.

Composite parameters.--Total alkalinity is a measure of the capacity of a solution to neutralize the effects of acid on pH. In natural waters, the salts of bases and weak acids are responsible for alkaline conditions. These salts consist of carbonates, bicarbonates,

and hydroxides. Consequently, high alkalinity measured in an inland lake denotes the presence of hardness and dissolved solids.

Bicarbonate alkalinity is the most prevalent type of natural alkalinity and results from carbon dioxide action with basic soil materials. In contrast, carbonates occur under conditions of high pH. Carbonate alkalinity is produced by industrial boiler wastes or in nature by removal of carbon dioxide from bicarbonates. This type of alkalinity is particularly important to monitor because it is responsible for algal formation.

The pH of a water body expresses the acid or alkaline character of that water resource. It is defined as "the negative logarithm of the hydrogen ion concentration."²¹ This parameter is particularly important because industrial wastewaters are often either strongly acidic or strongly basic. Thus, a close surveillance of pH attempts to detect sharp changes or extremes due to industrial pollution. It is utilized most effectively when monitored in conjunction with alkalinity.

Another composite parameter is hardness which measures the divalent cations in solution. Calcium and magnesium represent two cations which are the primary cause of hardness in natural waters. These two metals are released into solution by ground and surface waters which contact limestone deposits. Though not considered a health hazard, hardness nullifies the cleansing power of laundry soap.

²¹New York State Department of Environmental Conservation, Periodic Report of Water Quality Surveillance Network (New York: Department of Environmental Conservation, 1967), p. 370.

Therefore, hardness primarily causes an economic and industrial problem for cleaning firms and homemakers.

Tastes and odor producing substances may be detected by true taste sensations or by the odor they expel. For example, dissolved inorganic iron, sodium, or potassium salts can be detected by taste. Similarly, some inorganic compounds, such as, hydrogen sulfide and chlorine are noticed by their inherent odor. In water quality monitoring, taste and odor tests are useful in tracing the sources of contamination. An odor test often yields the first indication of municipal or industrial pollution of surface water resources.

Oil and grease may exist in water as an emulsion discharged by industry or from other sources. Oils also result from the decomposition of plankton and higher aquatic life. Nevertheless, heavy oils and grease are insoluble in water, however, they will emulsify if detergents, alkalis, or other chemicals are added. Furthermore, their greatest hazard is to wildlife and wildfowl. Fortunately, large spills do not occur often near inland lakes.

Radioactive materials.--The development of nuclear science and its industrial applications has generated large amounts of radioactive wastes. Because radioactive materials present in water supplies pose a serious health hazard, standards have been established for drinking water supplies. The Federal Radiation Council has provided the criteria for these standards. For instance, the limits placed upon radium-226 restrict it to 3 pc (picocuries) per liter and strontium-90 to 10 pc per liter. Gross beta activity is set at an upper limit

of 1,000 pc per liter. Should this limit be exceeded, further radionuclide analysis becomes necessary.

Various elements naturally emit alpha or beta and gamma radiation until a stable end-element is produced. Some of these elements include: uranium, thorium, and radium. In addition, through the development of nuclear science, atom smashers and nuclear reactors have produced large quantities of radioactive elements to the point where, today, nearly all elements are capable of emitting radiation. For this reason, all public water supplies must be monitored for nuclear radiation. Therefore, it seems very logical to monitor public water uses including recreational uses--total body contact sports.

Physical Parameters

Water related.--Water acquires its color naturally from organic decaying material and from industrial waste discharges. In addition, metallic ions, such as iron and manganese, may impart a distinct color to the waters in which they are dissolved. Aesthetically, color produced by any of these sources may be detrimental to recreational uses and unsuitable for consumption and industrial application.

Water color is extremely dependent upon the pH of the water resource. As water becomes more basic, its color increases in intensity. Consequently, it is important to specify the pH value when reporting water colors. Still, "apparent" and "true" water color vary because the former determination is made in the field, while the latter determination is made in the laboratory after the turbidity has been removed. Nevertheless, pH values must always accompany color designations.

The turbidity observed in a lake is caused by suspended and colloidal matter, plankton and other microorganisms. As a measure of the optical quality of water, it scatters and absorbs light instead of transmitting it directly through water in a straight line. Therefore, for some food processing industries, such as, the beverage producers, turbidity is an undesirable attribute. Similarly, turbidity may reach excessive proportions in the aquatic environment and damage recreational uses--skin diving is hampered by turbid waters.

In highly turbid water, suspended organic material acts as a substrate for microorganisms. Thus, a thorough chemical and bacterial analysis of turbid water is necessary for public health reasons.

The water temperature affects the aquatic life of the lake environment in three ways. First, rising water temperatures are detrimental to many aquatic organisms because they decrease dissolved oxygen concentrations. Secondly, a greater demand is placed upon available dissolved oxygen as metabolic activity increases. Lastly, temperature extremes are partially responsible for unsightly algal blooms and obnoxious anaerobic conditions--primary causes are industrial and municipal effluent. For these reasons, monitoring water temperatures is a necessary part of an inland lake program.

Temperature measurements are important too because they identify thermal stratification layers. By taking readings every few feet, the water sampler is able to correlate temperature, water-depth, and dissolved oxygen concentrations within a station and between sampling stations. Thus, water quality monitoring cannot adequately explain chemical, physical, and biological conditions of a lake without measuring the water temperatures.

The specific conductance of water refers to the electrical conductivity of the resource. Because conductivity is closely related to temperature and ionic composition, it is a measure of the ion concentration in the water. Both natural and artificial or human sources yield ions to water resources. Consequently, specific conductance indicates the presence of dissolved material and the possible pollution of a water resource.

Expressed in micromhos per centimeter, the conductivity of distilled water varies between .5 to 2 micromhos per centimeter. In contrast, raw and finished waters exhibit a specific conductance of 50 to 500 micromhos/cm., while highly mineralized water varies from 500 to 1,000 micromhos/cm. and higher. Some industrial wastes may even register in excess of 10,000 micromhos/cm.

There are many practical applications of specific conductance measurements. For example, variations in the concentration of dissolved minerals in wastewater can be measured by specific conductance. Conductivity measurements also provide an idea of the aliquots which may be useful for common chemical determination. Thus, specific conductance provides an indication of the contamination of an inland lake as it measures the ionic concentration of the water body.

There are two other important physical parameters which relate to the water volume and mineral and organic content of a lake. These are the discharge rate and drainage area. Data concerning the discharge rate of a lake or reservoir is usually available through the United States Geological Survey and indicates the complete turnover Period for a water resource. It also reflects the impact that

nutrient inflows may have upon the receiving water. For example, a short retention period affects a lake's water quality less than a longer period of retention. Thus, both discharge and recharge rates are valuable parameters for water quality monitoring.

The size and land use characteristics of a drainage area aid in the selection of pertinent water quality parameters. For instance, a drainage area which is heavily industrialized suggests the selection of parameters which include metallic indicators, such as, iron, chromate, and copper if the industries are metal plating and steel-works. On the other hand, a lake which drains agricultural land should be monitored for nitrates, phosphates, and bacterial parameters. Thus, the knowledge of a drainage area and its land use characteristics enables the water quality technician to select the most applicable parameters.

Weather related.--There are a group of parameters which measure the meteorological characteristics around a lake and which facilitate the water quality analysis. These include such parameters as humidity, rainfall, snowfall, wind-direction, evaporation rate, and cloud cover. Reporting data for these parameters will help to explain diurnal and seasonal fluctuations of other water quality parameters. For example, the amount of rainfall and snowfall minus the evaporation provides a general basis for evaluating fluctuations in lake water discharges. Thus, these parameters provide useful supportive data for water quality monitoring by delineating meteorological conditions.

Water Quality Sampling

Objective

"The purpose of every sample is to obtain an aliquot that to all intents and purposes will be analytically identical to the sampled body."²² This degree of precision is difficult to reach because there are many variables associated with water quality sampling. First, the degree to which a sample represents the actual water quality conditions of a lake depends upon the technician's command of the sampling techniques. With adequate training, experience and a sense of good judgment, the sampler can collect samples which are representative of existing conditions. However, the type of sample collected, whether it is a grab or composite sample, represents a second obstacle to water quality sampling.

The grab sample captures the quality of the water at the moment it is taken from the aquatic environment. In contrast, a composite sample consisting of combined aliquots represents an average of the conditions existing during sampling. Consequently, maximum and minimum values are lost when composite samples are collected in this manner. In addition, the sampling period is longer with composite sampling which allows for greater degradation of the water sample. Nevertheless, with adequate preservation procedures, composite samples provide very useful water quality data.

²²Florida Department of Pollution Control, Ambient Water Sampling Procedures (Florida: Department of Pollution Control, 1971), p. 2.

Last of all, proper preservation techniques prevent chemical changes from occurring during shipment from the field to the laboratory. How much time may elapse during collection and analysis periods? This depends upon the parameter sampled (Appendix B). Generally speaking, a shorter time period will produce more reliable results.

To prevent the growth of additional bacterial organisms, a bacterial sample should be stored in a cool, dark place. For a chemical sample, a preservative may be added to prevent ionic exchange between the walls of the sample bottle and the water sample itself. Ionic exchange often occurs with cations of aluminium, chromium, and lead. Other changes which may occur with dissolved oxygen, temperature, and pH are eliminated when these parameters are analyzed in the field. Therefore, with good judgment and experience the sampler can minimize changes occurring in water samples during transit.

Technique

Water quality sampling of an inland lake employs nearly the same methods used for river monitoring, except certain adaptations are made to accommodate the differences intrinsic to a lake. One of the procedures common to both river and lake sampling is water sample collection. For most parameters, a 300 ml aliquot will provide a sufficient quantity of sample for analysis (Appendix B). However, certain parameters such as, chemical oxygen demand and total nitrates require a separate thoroughly cleansed bottle which is free of all soap film. Consequently, an acid rinse and a rinse from the sampling source insures better results.

To collect a water sample a glass or plastic bottle of adequate volume is plunged into the lake at the sampling point. Tilting the bottle slightly upward, it is passed away from the boat, as it is held firmly in one hand. Since a lake does not exhibit a current like a river, there is little likelihood that bacteria will wash off the sampler's hand and into the bottle. When the bottle is entirely filled, it is drawn out of the water and one-quarter of the sample is poured off. Then, the bottle is marked and stored for shipment to the laboratory--it is often placed in an ice chest if the travel time exceeds four hours.

In general, a lake should be sampled at mid-depth to obtain a representative sample of average water quality conditions. To facilitate deep water sampling, a specially designed bottle, such as a Juday bottle is utilized. This bottle has a one to three liter capacity and is equipped with a tube extending to the bottom of a 250-300 ml dissolved oxygen bottle. This apparatus allows water to enter the dissolved oxygen bottle as it is bled from the connection tube.

Sampling stations are strategically placed to gather explicit water quality data. For instance, an effluent outfall area poses a unique problem. Where are the separation points between the concentrated effluent, the mixing zone, and the unaffected lake? The first of these points, where the effluent enters the receiving water, is easily identified. However, the last two points are more difficult

to isolate. To ascertain the impact of the effluent upon the receiving water, these three points should be sampled.²³

Sample Identification

In all probability, the second most important step in the sampling procedure is to correctly identify the sample when it is collected. Legal proceedings especially require verification of the sampling point. Therefore, correct identification of a sample should include six items of information listed on a field record. First, the time and the date that the sample was collected should be listed. This information becomes particularly valuable when evaluating diurnal and seasonal changes in dissolved oxygen and other parameters which consistently fluctuate. Second, a complete source description is needed so that a chemist, a water quality engineer, an administrative officer or anyone else besides the sampler can completely identify the sampling source. To further delineate the source, the sampling depth should also be described. With this information, samples will not be associated with incorrect sources. A fourth item to list in the field record is the specific handling procedures required for protecting the sample while it is enroute to the laboratory. Needless to say, these procedures are only listed if they are different from the prescribed methods. Lastly, two concluding identifications are made. The first one is to identify the sampler, while the other is to list the sampling organization. Thus, a complete record which lists these six items clearly identifies each water sample.

²³ A more detailed explanation of sampling is discussed in a later section.

Sample Numbers, Frequency,
Time, Duration

In theory, the number of samples collected depends upon the precision of the analytical laboratory methods. However, in practice the amount of time for the study, the size of the budget, and the personnel and facilities available for monitoring determine the number of samples to be collected. For example, experience has shown that for coliform bacterial analysis a minimum of twenty-five samples should be collected from the water body, otherwise the statistical results are not as accurate. In this particular case under a restricted budget, the adjustment might be made by reducing the number of samples of another parameter.

Where automatic equipment monitors the water quality of a lake, sampling frequency is continuous. Yet, many parameters cannot be monitored in this manner. For instance, neither the biological oxygen demand nor the coliform bacterial count are adaptable to automatic monitoring. Consequently, these samples must be collected by personnel.

In general, water samples are collected once a day for each work day of the week. This provides a basic understanding of the daily changes. Occasionally, the bacterial parameters are monitored twice or three times a day for a specified length of time to detect changes caused by effluent mixing. However, daily sampling is the more common of the two procedures.

Water quality sampling is normally performed at any convenient time during the day. However, water conditions do vary so accommodations are made by adjusting the collection time. For example, dissolved oxygen levels are affected by light incidence, temperatures,

and relative plant growth. To obtain maximum dissolved oxygen concentrations, both the water and weather conditions must be analyzed. Then, time adjustments can establish the best conditions for sampling.

The inherent characteristics of a lake suggest that the most significant times for sampling are during the spring and fall. Because overturn periods occur during these seasons, the maximum and minimum nutrients are available, respectively. In addition, sampling in late winter through the ice is becoming a common practice of many water resource agencies. Sampling at this particular time of the year, discloses the relative available concentration of dissolved nutrients present in the lake water, at a time when vegetative interception is at a minimum.

The duration of the sampling period depends upon the purpose of the study. In general, lake monitoring is performed to decipher either the background water quality of a water resource or the sources of nutrient inputs. The former purpose does not require continuous monitoring. Here, adequate water quality data is accumulated for evaluation by one or two week studies.

In contrast, to identify the sources and the concentration of nutrient inflows into a lake basin a period of one or more months is required. A longer study period is needed to measure the nutrient load that a stream carries because it varies considerably from day to day. Weather conditions and industrial discharges change periodically, which influences the relative concentration of nutrients entering a lake. Consequently, monitoring must continue through these diverse periods in order to collect representative data. Thus, the purpose

for monitoring a lake should be kept clearly in mind when determining the duration of a sampling period.

Sampling Stations

The selection of sampling stations is influenced by the following four factors: the objective of the lake study, the personnel and facilities available for the study, the amount of money allocated for the study, and the characteristic uses of the lake.

Reiterating a previous statement, lake monitoring is performed to either identify pollution sources or to establish background water quality. Following the first objective, one should locate sampling stations at the inlets of streams and rivers and where pipes and conduits enter a lake. Sampling open pipes should be performed continuously for a period of twenty-four hours. Thus, fluctuations in effluent quality are detected and accounted for when figuring the mean nutrient inflows.

In contrast, monitoring a lake for background water quality data necessitates a uniform data gathering process. Sampling stations are distributed along transects which radiate outward from the deepest point in the lake and intersect the shoreline (Fig. 7). Placed at uniform intervals, the sampling stations generally collect water samples once daily throughout the duration of the study period. Utilizing this procedure the entire water resource is monitored.²⁴

²⁴In some lake studies, these two basic objectives are fulfilled by a single lake study with sampling stations distributed accordingly.

The human, physical, and financial resources available for a lake study directly affect its magnitude. For instance, a study which is well manned, adequately equipped, and financially sound can afford to sample from a maximum number of distinct locations. Conversely, deficiencies occurring with any one of these resources necessitates a reduction in the number of sampling stations, as well as, the number of samples.

Lastly, the characteristic water uses of a lake influences the location and number of sampling stations. For example, the presence of one or more public swimming beaches on a lake requires that the location of bacterial sampling stations be situated along these beaches. Similarly, a lake receiving municipal effluent requires the placement of bacterial stations in effluent mixing zones. Therefore, the objectives of the lake study, the available resources for the study, and the water uses of the lake all influence the relative number of sampling stations and their location.²⁵

Water Quality Data

It is imperative to select the method of data interpretation before the sampling process begins, otherwise, "the data obtained may fail to meet the objectives of the study . . ."²⁶ For example, if a computer analysis is planned, a greater degree of precision and accuracy is afforded to the data collection processes. Because of the

²⁵The number of stations required for each parameter will be discussed in Chapter IV.

²⁶U.S. Department of Interior, Federal Water Pollution Control Administration, A Practical Guide to Water Quality Studies of Streams (Washington, D.C.: Government Printing Office, 1969), p. 77.

increased efficiency and speed of this type of data analysis, means, standard deviations, and variances are easily computed for all parameters which are monitored. Consequently, it is advisable to establish "confidence limits" for each parameter when random sampling is employed --often these limits are set at two standard deviations from the sample mean. Thus, interpretive methods selected at the outset of a surveillance program assist the data gathering process and the entire monitoring program.

The difficulty of obtaining precise and accurate results from water quality analyses is an inherent problem of all statistical methods. Therefore, some errors are unavoidable. For instance, the method of drawing a water sample from a lake fails to recover 100 per cent of the chemical constituents. Similarly, when the same coliform bacterial sample is repeatedly analyzed, different values are produced by the Most Probable Number Method--the Milipore Filter Method yields between two and five times greater precision. Conversely, the lack of precision and accuracy of data collection is usually the fault of inadequate personnel training or inefficient sampling and analytical methods. Skill and common sense are definitely required of the field sampler. Therefore, an adequate training program for field personnel should increase the precision and accuracy of data collection and analysis.

Conclusion

The preceding chapter has reviewed the techniques of water quality monitoring which apply to inland lakes. Admittedly, the discussion is general as it focused only upon the important parameters

pertaining to the lake environment. However, its purpose was to provide only guidelines for inland lake monitoring and to allow for adaptability to local variations in aquatic environments. Thus, Chapter III established the standard techniques and procedures for water quality monitoring, which are applied to selected inland lakes in Chapter IV.

CHAPTER IV

THE MONITORING PROGRAMS

Purpose

This proposed water quality monitoring program for inland lakes utilizes the knowledge of river and stream surveillance techniques. Though specific parameters are cited as the most important ones to monitor, the program is designed to allow for local variations in land and water resources. It is realized that land uses around different lakes vary considerably throughout the state. While one inland lake receives agricultural drainage, another may receive industrial discharges, sewage effluent, or forest land and urban runoff. Consequently, the water quality parameters should reflect these land use characteristics.

Objectives

There are two basic objectives which guide the development and application of this monitoring program. The primary objective is to provide background water quality data for the three lakes, each representing one or more lake classifications. A second goal, which is closely related to the previous one, is to identify sources of lake pollution. Though, this thesis concerns only the developmental stage

of monitoring these two objectives still influence the selection of monitoring procedures, water quality parameters, and sampling stations.

The monitoring program which follows was developed without the benefit of a reconnaissance survey. It was decided that because of time constraints such a survey would not be conducted. Instead, lake maps and secondary information sources were utilized and proved adequate for selecting monitoring procedures, parameters of water quality, and sampling station locations. Nevertheless, it is recommended that a reconnaissance survey be conducted should the program be implemented.

Classification of Lakes

In Michigan the inland lakes are used for a variety of purposes. Some support recreational pursuits, such as swimming, boating, and fishing, while other lakes are breeding areas for wild-fowl and fur-bearing animals. Furthermore, a growing number of lakes are receiving discharges of municipal and industrial effluent. Thus, one standard monitoring program cannot be expected to produce representative water quality data for all these various uses. On the other hand, designing a completely distinct monitoring program for each lake becomes an impossible task.

The approach used in this thesis attempts to solve this dilemma. First, an inland lake classification system is proposed which is based upon a lake's uses. Because any one lake has many different uses, a single lake may belong to more than one class. Secondly, a list of parameters important to each classification is developed. Thus, to design a surveillance program for a particular

lake the parameters are selected according to the uses which they are intended to monitor.

The following four classifications are used to distinguish the inland lakes of Michigan which are presented in later sections of this thesis.

- I. High Value Recreational Lakes
- II. Important Sport Fishing Lakes
- III. Wildfowl and Fur-bearing Animal Breeding Areas
- IV. Receiving Waters for Effluent

To reiterate a previous statement, a lake may be placed in more than one category. For example, Higgins Lake, which is located in Roscommon County, is classified as both a High Value Recreational Lake and an Important Sport Fishing Lake. Consequently, to insure proper monitoring, the parameters applying to each classification are combined into one set of parameters. Thus, it is recommended that to adequately monitor the water quality of Higgins Lake samples should be collected and analyzed for a combination of parameters derived from these two lists.

Sub-Classifications

The four main classifications are distinguished by discrete criteria which were formulated entirely by this researcher. However, the names of certain descriptive sub-classes which are relevant to kinds of contact sports and fish species are taken from the Water

Resource Commission's Intrastate Water Quality Standards.²⁷ These sub-classes include the following:

I. High Value Recreational Lakes

- a. total body contact sports
- b. partial body contact sports excluding fishing²⁸

II. Important Sport Fishing Lakes

- a. intolerant fish, cold-water species
- b. intolerant fish, warm-water species
- c. tolerant fish, warm-water species

The first descriptive sub-class, total body contact sports, refers to recreational activities which involve a complete immersion of the body in a water resource. Included in the sub-class are such sports as swimming, water skiing, and skin-diving. In contrast, the second sub-class, partial body contact sports, consists of those sports which do not normally expose the entire body to immersion. Hunting and boating are recreational activities of this sub-class.

The three descriptive sub-classes of Important Sport Fishing Lakes reflect increasing tolerance to natural eutrophication as one moves from the first through the third sub-class. The first sub-class, intolerant fish, cold-water species, is represented by trout and

²⁷ These sub-classes are used because of their applicability to the monitoring program. Moreover, they maintain the terminology found in Michigan's Intrastate Water Quality Standards.

²⁸ Michigan's Intrastate Water Quality Standards considers fishing as a partial body contact sport. I have separated it from other partial body contact sports and placed it in its own classification.

salmon, while the remaining two sub-classes consist of bass, pike, panfish and carp and bullheads, respectively.

To be placed into one of the four main classifications, a lake or reservoir must satisfy specific criteria. The criteria that this researcher has developed are based substantially upon the water resource's different uses. These are enumerated by classification as follows:

I. High Value Recreational Lakes

- a. A surface water resource that is either a lake or a reservoir.
 1. [A lake is] "a body of water (fresh or salt) of considerable size, surrounded by land."²⁴
 2. [A reservoir is] "a natural or artificial place where water is collected and stored for use . . ."³⁰
- b. Protected for total body contact recreation under Michigan's Intrastate Water Quality Standards, as adopted on January 8, 1968.
- c. Ownership of the lake is public as verified by the presence of one or more public access sites or some equivalent access point.
- d. The primary recreational use includes one or more of the following: swimming, water skiing, or skin-diving.

²⁹The American College Dictionary (New York: Random House, Inc., 1964), p. 683.

³⁰Ibid., p. 1031.

II. Important Sport Fishing Lakes

- a. A surface water resource which is either a public lake or reservoir (same definitions as listed in Classification I).
- b. A lake or reservoir which supports one or more of the following:
 1. intolerant fish, cold-water species (i.e., trout, salmon, whitefish, cisco)
 2. intolerant fish, warm-water species (i.e., bass, pike, panfish)
 3. tolerant fish, warm-water species (i.e., carp, bullheads)

III. Wildfowl and Fur-bearing Animal Breeding Areas

- a. A public surface water resource which is a lake, pond, reservoir, or permanently flooded area.
 1. A pond is "a body of water smaller than a lake, often one artificially formed, as by a dam."³¹
 2. A permanently flooded area is a low land area situated in proximity to a creek, stream, or river which has been dammed to flood the land.
 3. See classification I for definition of lake and reservoir. These same definitions apply here as well.
- b. Area supports a permanent or migratory population of wildfowl and wildlife. Some of the following species inhabit these areas: ducks, geese, field birds, beaver, muskrat, otter, raccoon, and other wildlife.

³¹Ibid., p. 941.

IV. Receiving Waters for Effluent

- a. A public surface water resource which is either a pond, lake, or a reservoir.
- b. Having received in the present or past industrial effluent, municipal sewage effluent, or septic tank effluent by way of a pipe, conduit, drainage ditch, canal, river, tile filed seepage, or by some other mechanism.
- c. Though the industry, municipality, or cottage owner may be a riparian, it is not a prerequisite to this classification.

Selection of Class I and II Lakes

The importance of an inland lake monitoring program is reflected in its sensitivity to designated water uses. Because the acceptable water uses were first classified and their criteria developed, it then became a matter of selecting those lakes which adequately met the specified criteria. Consequently, a non-random selection of lakes was employed.

The lakes appearing in the first two classifications, High Value Recreational Lakes and Important Sport Fishing Lakes, were selected by analyzing the inland lakes of each county in Michigan. In each county, a large public lake was chosen which possessed one or more points of public access. These lakes were then separated according to their primary use.

In some respects, many of these lakes could appear on both lists. For example, Higgins Lake of Roscommon County is classified as a recreational lake because of its swimming, boating, and water

skiing activities which are enjoyed each summer by cottage owners and state park campers alike. On the other hand, it could be classified as an Important Sport Fishing Lake because it supports good pike, panfish, and trout fisheries.

Why were these two classifications separated, when many of the lakes qualify for both classifications? The basic premise for making this separation was to emphasize the important parameters of each classification. For example, the bacterial parameters are possibly the most important indicators of water quality for a recreational lake. Because Michigan's Intrastate Water Quality Standards explicitly limit the number of coliform and fecal coliform colonies which can be present in a lake sample, monitoring the septic condition of a lake depends upon these bacterial parameters. In contrast, temperature and dissolved oxygen are very important parameters for monitoring the aquatic habitat's suitability for a particular fish species. Thus, the two separate classifications emphasize the important parameters in each case.

Classification I Lakes

The following list of lakes³² fulfills the criteria requirements of the first classification, High Value Recreational Lakes.

³² Located on all of these lakes is a state or county park, which indicates that each lake is public.

<u>Lake</u>	<u>County</u>
1. Budd Lake	Clare
2. Lake Charlevoix	Charlevoix
3. Lake Gogebic	Gogebic
4. Gun Lake	Barry
5. Higgins Lake	Roscommon
6. Indian Lake	Schoolcraft
7. Kent Lake	Oakland-Livingston
8. Long Lake	Alpena
9. Lake Mitchell	Wexford
10. Otsego Lake	Otsego

Classification II Lakes

The lakes listed below fulfill the criteria requirements of the second classification, Important Sport Fishing Lakes.

<u>Lake</u>	<u>County</u>
1. Chicagon Lake	Iron
2. Crystal	Benzie
3. Glen Lakes	Leelanau
4. Grand Sable Lake	Alger
5. Houghton Lake	Roscommon
6. Hubbard Lake	Alcona
7. Long Lake	Grand Traverse
8. Lake Mishigamme	Marquette
9. Mullett Lake	Cheboygan
10. Torch Lake	Antrim

Selection of Class III and IV Lakes

The third classification, Wildfowl and Fur-bearing Animal Breeding Areas seeks to protect a special nature use of surface water resources. Because numerous Federal and State tax revenues have been spent on the development and preservation of wildlife flooding areas, it seems that these lakes, ponds, and artificial empoundments need a monitoring program designed to preserve these areas. For this reason, this classification is proposed.

The lakes selected for Classification III, were chosen from a list of sixty major wildlife flooding projects obtained from Michigan's

Fisheries Division of the Department of Natural Resources. These ten lakes and ponds were selected because they met the requirements set forth by Classification III criteria. They also vary considerably by size as evidenced by Chilson Pond which covers 70 acres and Martiny Lake which covers 1,400 acres. Dating back to as early as 1949, these flooded areas provide breeding grounds for many wildlife species.

The last classification, Receiving Waters for Effluent, consists of lakes which are evidencing excessive eutrophication problems as a result of having received presently or in the past municipal, industrial, or septic tank effluent. Selected with the assistance of a new publication recently released by the University of Wisconsin entitled, "Problem Lakes in the United States," the lakes chosen have experienced algal blooms and excessive weed production.

Classification III Lakes

Based upon the criteria set forth earlier, the following list of lakes and ponds belongs to the classification, Wildfowl and Fur-bearing Animal Breeding Areas.

<u>Lake</u>	<u>County</u>
1. Chilson Pond	Livingston
2. Cranberry Lake	Chippewa
3. Crooked Lake	Allegan
4. Devils Lake	Alpena
5. Dog Lake	Cheboygan
6. Grass Lake	Benzie
7. Headquarters Lake	Grand Traverse
8. Martiny Lake	Mecosta
9. Mud Lake	Marquette
10. O'Neal Lake	Emett

Classification IV Lakes

Listed below are the lakes designated as Receiving Waters for Effluent.

<u>Lake</u>	<u>County</u>
1. Barton Lake	Kalamazoo
2. Chemung Lake	Livingston
3. Fremont Lake	Genesee
4. Ford Lake	Washtenaw
5. Lake Lansing	Ingham
6. Lobdell Lake	Genesee
7. Macatawa Lake	Ottawa
8. Manistee Lake	Manistee
9. White Lake	Ottawa

Designation of Parameters

The pertinent parameters for each classification are listed in the next sections. Their purpose in each case is to monitor the water resources for the use expressed by each classification. Selected by this researcher from the many possible biological, chemical, and physical parameters, they represent in my estimation the most important water quality parameters. However, a word of explanation is necessary concerning this last statement.

The parameters selected were strictly limited to those classified as biological, chemical, or physical. Nevertheless, many important biological parameters were eliminated because this researcher was not familiar enough with them to endorse their application. Some examples include: aquatic plants, algae, phytoplankton, zooplankton, and benthic organisms. Though many of these parameters do serve as useful indicator organisms for water quality monitoring and limnological studies, they do not fall within the limited scope of this thesis.

Water Quality Parameters

In this section, each classification is presented with its selected parameters. It is observed by comparing the parameters that many are listed in more than one classification. This is understandable considering different water uses are protected by similar water quality standards. For example, coliform bacteria are important parameters for all classifications. Michigan's Intrastate Water Quality Standards support this statement by delineating their specific acceptable limits (Appendix A). Thus, the classifications are next presented with their selected parameters.³²

High Value Recreational Lakes

I. Biological Parameters (Bacterial)

- a total and fecal coliform
- b. fecal streptococcus

II. Chemical Parameters

- a. biochemical oxygen demand
- b. nitrite, nitrate, and total Kjeldahl nitrogen
- c. orthophosphates
- d. chlorides
- e. sulfates
- f. dissolved and suspended solids
- g. pH

³³The reason for their selection is discussed in a later section when the parameters are applied to a specific lake.

III. Physical Parameters

- a. color
- b. turbidity
- c. temperature
- d. specific conductivity

Important Sport Fishing Lakes

I. Biological Parameters (Bacterial)

- a. total and fecal coliform

II. Chemical Parameters

- a. dissolved oxygen
- b. biochemical oxygen demand
- c. nitrate nitrogen
- d. orthophosphates
- e. dissolved solids
- f. pH

III. Physical Parameters

- a. color
- b. turbidity
- c. temperature
- d. specific conductivity

Wildfowl and Fur-bearing Animal Breeding Areas

I. Biological Parameters (Bacterial)

- a. fecal coliform

II. Chemical Parameters

- a. dissolved oxygen
- b. biochemical oxygen demand
- c. nitrate and ammonia nitrogen
- d. orthophosphates
- e. pH
- f. mercury
- g. chlorinated hydrocarbons (DDT, dieldrin)

III. Physical Parameters

- a. color
- b. temperature

Receiving Waters for Effluent

I. Biological Parameters (Bacterial)

- a. total and fecal coliform
- b. fecal streptococcus

II. Chemical Parameters

- a. dissolved oxygen
- b. biochemical oxygen demand
- c. nitrite, nitrate, and total Kjeldahl nitrogen
- d. orthophosphates
- e. chlorides
- f. sulfates
- g. dissolved and suspended solids
- h. pH
- i. total and bicarbonate alkalinity
- j. hardness

III. Physical Parameters

- a. turbidity
- b. temperature
- c. specific conductivity

Sampling Stations

The basic pattern for locating sampling stations involves the use of transects. A transect is a perpendicular line which either emanates from the deepest points in a lake or passes through these points as it intersects the opposite lake shores (lake maps). Along a transect, sampling stations are evenly spaced. Through the use of transects, the water quality parameters are sampled from stations distributed over the surface of a lake.

The number of sampling stations depends upon many factors. Some of these are economic and relate to financial and budgetary restrictions associated with a water quality monitoring program. However, because this thesis assumes unlimited time and resources, the primary factors are directly related to the lake under study. The size of the lake, its shape, and the land use characteristics bordering the lake all influence the spacing and number of sampling stations.

Accordingly, a very large lake, such as, Higgins Lake, which covers 9,900 acres requires approximately 150 sampling stations to provide a representative picture of the existing water quality.³⁴

³⁴Because this researcher could not obtain a formula for determining the number of sampling stations, the numbers listed are my best estimates.

Conversely, Headquarters Lake of Roscommon County covers only 185 acres and requires about 35 stations.

Closely related to the size of a lake is its shape. In general, fewer sampling stations are required when monitoring a long narrow lake as opposed to an irregular shaped lake possessing coves and islands. In the first case, fewer stations are needed because parallel transects are utilized, while in the second case the transects emanate from the deep points of the lake like the spokes of a wheel--this amounts to more sampling stations.

The land use characteristics also influence the number of sampling stations, as well as, their location. For instance, shoreline areas crowded with cottages suggest that septic tank effluent might be reaching the lake basin. Consequently, more sampling stations are located along sandy beaches to collect additional bacterial samples. Furthermore, the lake inlets which carry land runoff also require additional sampling stations to gather water quality data for entering water sources. Therefore, the size and shape of the lake and the surrounding land use characteristics provide valuable information for locating sampling sites.

Sampling, Time, Duration and Frequency

The water quality monitoring is to be performed during four periods of the year, mid-winter, early spring, late summer, and late fall. In the mid-winter, during the month of February, sampling through the ice will reveal high concentrations of dissolved nutrients, such as nitrogen (Fig. 8). Yet, as early spring arrives, the soluble

nitrogen drops off momentarily, then rises again with spring overturn, the second designated sampling period.

As summer arrives many parameters have noticeably declined in concentration. Accordingly, by late summer some dissolved nutrients are very low. A late summer sampling will detect these low concentrations. Finally, in the late fall as overturn again occurs, the nutrient levels rise with the decomposition of plant and animal matter. By sampling the lake waters at these four times, a description of the concentrations of dissolved gases and nutrients is obtained.

The duration of the sampling period depends upon the weather conditions, the number and skill of the water quality samplers, the efficiency of the sampling techniques, and the size of the surveillance budget. Assuming ideal conditions including adequate funding, the larger lakes with approximately 150 stations will require about four days to sample. The smaller lakes with less than fifty stations will require one or two days. In all cases, the time is not restricted. Thus, each sampling program which involves sample collection, preservation, and shipment to the laboratory shall conclude when the required number of samples has been collected at each station for analysis.

Lake Examples

There was not a specific selection procedure used to choose a lake to serve as an example of each monitoring program. However, the availability of lake maps somewhat limited the selection. Nevertheless, three lakes were selected. These included: Higgins Lake of

Roscommon County, Headquarters Lake of Grand Traverse County, and Lake Chemung of Livingston County.

Higgins Lake represents the first two classifications because it is both a valuable recreation lake and a fine sport fishing lake. Consequently, the first two sets of parameters are combined and applied to Higgins Lake. The other two lakes, Headquarters Lake and Lake Chemung represent wildfowl propagation areas and effluent receiving waters, respectively. Each appropriate list of parameters applies to these lakes.

Higgins Lake

Lake Description

Higgins Lake, which is located in the northern lower peninsula in Roscommon County, covers an area of 9,900 acres. It is a typical oligotrophic lake exhibiting deep cold spring fed waters which support trout, pike, and various panfish species. Besides fishing, its waters are used extensively for swimming, boating, water skiing and other water oriented recreation. Because the lake has many public access points located throughout Higgins State Park, it represents a valuable water resource for the general public and cottage owners alike. In addition to its large acreage and recreational qualifications, Higgins Lake was selected because it illustrates the use of transects which emanate from deep points throughout the lake. Many of these points exceed 100 feet in depth--the maximum depth is 141 feet.

Sampling Stations

To supply sufficient water quality data, a total of 143 sampling sites are identified for Higgins Lake. Seven transects are also utilized with their centers located at the deepest points on the lake (Map No. 1). These transects contain 100 of the total sampling sites. Furthermore, another 40 sampling points are located on the sandy beaches in front of heavily concentrated cottage areas and along the beaches of the state park. The three remaining stations are situated at points where inlets and outlets enter and leave the lake--they are located just upstream or downstream, respectively.

The sampling points located along the transects are spaced every one thousand feet. In contrast, the near-shore and inlet and outlet stations are not placed an equal distance apart because the dwellings and drainage points do not adhere to a rigid pattern. It must be emphasized that these sampling points refer to general areas and not fixed points in nature. However, the sampling procedure will make every effort to adhere to the established distance requirements between stations, as well as, to gather representative samples.

Selected Parameters

At each sampling point the required volume of water is collected, stored, and shipped to the laboratory where it is analyzed for all parameters, except three, temperature, color, and specific conductivity. These parameters are read in the field at each sampling station using a centigrade thermometer, color discs, and a conductivity meter. Because the remaining parameters require more extensive analysis, the sample cannot be analyzed in the field.

A specialized sampling bottle is needed for collecting dissolved oxygen and BOD samples. A 300 ml Juday or Kemmerer type bottle is utilized for both parameters. In addition, water samples for these two parameters are collected at three depths, one for each thermal layer at the center points of transects I through VII (Map No. 1). Furthermore, a single sample is collected at inlets, outlets and at each near-shore sampling station--all other stations are excluded.

Since Higgins Lake is representative of the first two classifications, the two sets of parameters are combined into one composite group. What is the significance of each parameter? To answer this question, the parameters are discussed by groups. The five groups include: (1) BOD and dissolved oxygen, (2) bacterial parameters and chlorides, (3) nitrogen, phosphorus, sulfates, and specific conductivity, (4) solids and turbidity, and (5) pH and color.

The biochemical oxygen demand measured by a five day laboratory test results in an estimation of the septic condition of the water resource sampled. Because aerobic organisms present in the water assimilate dissolved oxygen to decompose organic materials, a significant BOD value indicates that active decomposition is occurring. Consequently, the oxygen demand of these aerobic organisms, such as bacteria, reduces the concentration of dissolved oxygen. This may place a strain upon the other aquatic organisms, particularly fish species, if dissolved oxygen levels fall below minimum concentrations. Therefore, these two parameters were selected because of their close relationship to one another. With established dissolved oxygen levels, the BOD measurements help to explain abnormal fluctuations in dissolved oxygen that are not the result of seasonal changes.

The second group of parameters, which includes the bacterial parameters, are important indicators of sewage effluent and associated pathogenic bacteria. Fecal and non-fecal coliform bacteria identify the source of contamination as originating from human and animal excrement or from the soil, respectively. Furthermore, fecal streptococcus is selected because it also lives in human and animal intestines. Though these bacterial organisms are not harmful themselves, they are associated with pathogenic bacteria. Thus, they are used as indicators of possible, pathogenic bacterial contamination.

Chlorides are also placed in this second group to indicate their relationship to the bacterial parameters. Though normally present in low concentrations in natural waters, sodium chloride passes through the human digestive tract unchanged and reaches high concentrations in sewage effluent. Thus, abnormal concentrations found in natural waters, like Higgins Lake, may indicate sewage effluent and septic tank seepage.

The third group of parameters is composed of two important aquatic nutrients, nitrogen and phosphorus, a supplier of oxygen for anaerobic decomposition, sulfates, and specific conductivity, an indicator of the ionic concentrations present in a water resource. First of all, nitrates and phosphates supply aquatic plants and algae with soluble nutrients vital to their existence.³⁵ Because sewage effluent, agricultural drainage and forest land runoff are potential sources of these nutrients, it is very likely that some or all of

³⁵ See Chapter III for a more detailed explanation of nitrates and phosphates.

these sources are supplying nitrates and phosphates to Higgins Lake. To assess this situation, these nutrients are sampled. The sulfates found in natural lakes of Michigan are derived primarily from rock material. Unlike nitrates and phosphates, they are not suppliers of nutrients, but rather suppliers of dissolved oxygen. Furnishing the oxygen for anaerobic decomposition, they assist in the breakdown of organic materials that collect on the lake bottom. Therefore, the presence of sulfates indicates that organic decomposition is actively occurring.

The last parameter of this group, specific conductivity, measures the ion concentration of a water resource. Because water contaminants and nutrients are present in lakes as disassociated ions, anions and cations, a specific conductivity reading measures their relative abundance. High readings may help to identify points of sewage contamination from septic tanks or from entering stream inlets.

In group four, turbidity was selected because it consists of suspended matter, plankton, and microorganisms. Often attached to the suspended particles, organic matter acts as a food source for microorganisms and may shield bacteria. Consequently, as turbidity increases, so does the chance that bacterial organisms including pathogenic bacteria may be present. To further explain turbidity readings, the solid constituents are monitored also. Though not harmful to man, dissolved and suspended solids affect photosynthesis and hamper some recreational water uses, such as skin-diving.

The last two parameters, pH, and color, are interdependent. As the pH rises, the color increases in intensity. These two parameters were selected to merely serve as background data which compiled

over many years can be utilized to trace sudden changes in lake water quality. In addition, all of the parameters selected to monitor the water quality of Higgins Lake were also chosen with this purpose in mind.

Headquarters Lake

Lake Description

Headquarters Lake, which covers 185 acres, is located in Grand Traverse County. Described as a major wildlife flooding area by the Wildlife Division of the Department of Natural Resources, the lake qualifies as a wildlife breeding area. Surrounded on three sides by forest lands and showing a marsh area on its northeastern end, the lake is thoroughly protected from human development. Only one inlet enters the lake at its northern end and exists through the northeastern end of the marsh.

Sampling Stations

Since Headquarters Lake is long and narrow, transects are placed at right angles to the opposite shores (Map No. 2). This pattern is used throughout the lake except at the southwestern end where the transects begin at a 24 foot depth and run to each shore. Thirty sampling stations are situated along the transects while two more sample the inlet and the outlet--one at each entrance or exit point. Furthermore, approximately 300 feet separates each transect. Again, the sampling stations are not fixed points, however, they are to be sampled as accurately as possible given conventional sampling procedures.

Selected Parameters

To facilitate the discussion, the parameters of the third classification are grouped as follows: (1) fecal coliform, BOD, and dissolved oxygen; (2) nitrate and ammonia nitrogen and orthophosphates; (3) mercury and chlorinated hydrocarbons; and (4) temperature, pH, and color.

What do these parameters indicate? Both fecal coliform and BOD are utilized to identify the presence of sewage wastes. To be more specific a species of fecal coliform called Escherichia coli which lives in the intestinal tract of man and animals is passed with excrement. In testing for fecal coliform it is believed that probable wildlife sources may be confirmed. In addition, the BOD test expresses the oxygen demand of sewage bacteria. Comparing these results with measured dissolved oxygen concentrations, reveals the relationship between oxygen demands and oxygen availability.

Ammonium and nitrate nitrogen were selected because they also indicate the presence of organic decomposition. Ammonia nitrogen exhibits a high oxygen demand which helps to explain any low oxygen levels. Unlike ammonium, nitrate nitrogen is soluble and represents a form available to aquatic organisms. Along with orthophosphates, the measurement of nitrogen forms establishes the nutrient concentrations.

Mercury and chlorinated hydrocarbons have been discovered in large concentrations in the fat tissues of terrestrial animals and aquatic organisms, such as birds and fish. Due to the toxic nature of these substances, they are harmful to wildlife which populate

breeding areas. For these reasons, it was decided to monitor the concentrations of mercury and two chlorinated hydrocarbons, DDT and dieldrin.

The last three parameters consist of temperature, color, and pH. All three are routine parameters with measurements primarily sought for background water quality data.

Lake Chemung

Lake Description

Lake Chemung is located in Livingston County and covers 321 acres. It possesses a drainage area of 4.34 square miles. Closely hugging its four shores are numerous cottages clustered tightly together. Only an occasional cultivated field or woodlot separates the dwellings. Situated on the north shore is a public fishing site. Two lake inlets also enter along the north shore, however, one flows only intermittantly.

The lake was selected because of its historical problems with septic tank seepage inducing algae bloom and excessive eutrophication. Utilized by sport fisherman and water recreationers alike, the lake contains pike and panfish species. Though the Water Resources Commission monitored Lake Chemung in September 1965, appreciable concentrations of nitrates and orthophosphates were not discovered in surface waters. However, the concentration of these nutrients is known to be low in the fall. Accordingly, I believe a more thorough test is to sample during the four periods of a year, as suggested by my sampling procedure.

Sampling Stations

A total of 80 sampling stations are located throughout the lake. Ten transects running approximately north and south and perpendicular to the shores contain 45 stations, while the remaining 35 are located in near-shore areas and in the lake's inlets. The transect sampling stations are each separated by approximately 300 feet of water, however, the transects are placed 900 feet apart (Map No. 3).

Selected Parameters

All stations will monitor the entire list of parameters, however, dissolved oxygen will be collected once again in each thermal layer at central stations on all ten transects. At near-shore and inlet stations only one water quality sample will be collected for dissolved oxygen.

The parameters which are arranged in groups include: (1) bacterial parameters, temperature, dissolved oxygen, BOD, sulfates, and chlorides; (2) nitrogen and phosphorus forms; (3) pH, specific conductivity, alkalinity, and hardness; and (4) solids and turbidity.

The selection of these parameters was made for a variety of reasons though all relate to the objectives, which are to collect background water quality data and to isolate pollution sources. First, of all, dissolved oxygen and temperature measurements establish the limits for all aquatic life. Thus, these measurements provide meaningful data when compared to intrastate standards. Related to dissolved oxygen losses, is BOD. By monitoring this parameter, the organic waste demand is obtained.

The bacterial parameters utilize dissolved oxygen to decompose organic matter. Some of this dissolved oxygen is supplied by sulfates. However, the primary importance of fecal coliform and fecal streptococcus bacteria is to indicate the presence of other pathogenic bacteria. For this reason, fecal coliform and fecal streptococcus bacteria were selected. In addition, total bacterial measurements enable the determination of non-fecal concentrations of bacteria. Again, chlorides are used to indicate sewage pollution.

The second group of parameters composed of nitrogen and phosphorus forms supply nutrient material for lake eutrophication. Nitrites, nitrates, and total Kjeldahl nitrogen represent three nitrogen forms. Nitrates are soluble and available to aquatic organisms. Its associate, orthophosphate is the soluble form of phosphorus. In addition to the possible identification of nutrient sources, the data collected on nitrate and orthophosphate concentrations may indicate the potential for future algal blooms.

The fourth group of parameters consisting of pH, specific conductivity, alkalinity, and hardness are all interrelated. For example, the specific conductivity and hardness measure the ionic concentration of the lake which is primarily caused by divalent metals, such as calcium and magnesium. Similarly, pH and alkalinity are related since the later measures the capacity of the lake to buffer the effects of acids upon the pH of the water. A high alkalinity value reveals the presence of hardness which is also measured. Thus, these parameters provide background water quality data.

The last two parameters, solids and turbidity measure the amount of suspended and dissolved material floating in the water. Solids present in a lake reduce the light incidence which decreases photosynthesis. As mentioned before, turbidity is harmful to certain recreational activities, such as skin-diving.

It is recognized that other parameters could provide additional background and pollution source data. For example, a lake receiving industrial effluent should be sampled for trace elements, such as calcium, magnesium, potassium, and sodium. Still, other parameters could be applied to the monitoring programs presented. However, I believe that the parameters selected for Higgins Lake, Headquarters Lake, and Lake Chemung will furnish adequate water quality information. With the emphasis now turned to Chapter V, a cost estimate is determined for the three monitoring programs.

CHAPTER V

THE COSTS OF MONITORING

Cost Determination

The monitoring program's primary purpose is to produce representative water quality data for each lake studied. Costs were not considered an influential factor. Furthermore, each monitoring program was constructed to thoroughly and accurately sample and analyze the water quality of each lake. Consequently, the cost figures presented for each program appear to be high.

This analysis examines two types of costs, sampling and analysis costs. The costs attributed to sampling include: transportation, food, lodging, and wages paid.³⁶ In contrast, the expenses attributed to sample analysis are based upon the test performed. By tabulating these figures, a cost estimation is derived for each monitoring program.

The following cost figures are applied to each monitoring program.

³⁶Though equipment costs including depreciation are involved, these charges are eliminated from the analysis. The assumption is made that all equipment is available in each case.

Food	\$ 8.00 per man per day
Lodging	10.00 per man per night
Transportation	.10 per mile travelled by car
Wages	\$9,800.00 annual salary of sampler (\$4.71 per hour)

These cost figures were chosen after considering various alternative expenses. The first three values approximate the expense accounts of state officials, while the last figure represents the starting salary of a water quality trainee employed by the State of Michigan.

For each of the three monitoring programs examined, the following cost figures are presented.

Higgins Lake--(Four days sampling)

Food	\$ 128.00
Lodging	60.00
Transportation	25.60
Man Hours (128 at \$4.71/hr.)	<u>602.88</u>
	816.48
Sampling Periods	<u>4</u>
Total	\$3,265.92

Headquarters Lake--(Two days sampling)

Food	\$ 64.00
Lodging	20.00
Transportation	34.20
Man Hours (64 at \$4.71/hr.)	<u>301.44</u>
	419.64
Sampling Periods	<u>4</u>
Total	\$1,678.56

Lake Chemung--(Two days sampling)

Food	\$ 64.00
Lodging	20.00
Transportation	8.00
Man Hours (64 at \$4.71/hr.)	<u>301.44</u>
	393.44
Sampling Periods	<u>4</u>
Total	\$1,573.76

The analytical costs vary considerably between the type of analysis and the laboratory performing the analysis. For example, the state laboratories, such as the Water Resource Commission's laboratory, are much less expensive than the private laboratories because they are non-profit oriented and are heavily subsidized by tax revenue. Also they deal only with other state departments. Consequently, their cost figures are low and do not realistically reflect the actual costs of analytical testing. Conversely, the private laboratories must charge more for analytical testing because they are not subsidized. The profit motive also adds to their costs of analyses. Therefore, both public and private laboratory costs would be similar if subsidies and profits are excluded.

For the purpose of estimating the total cost of sample analyses, the average analytical cost of \$1.00 per sample is utilized.³⁷ This figure is charged by the Water Resource Commission against its own account for water quality analysis performed on lake and stream

³⁷ Though this cost may seem low, it was obtained from Mr. Russ Krueger, Chief Chemist, of the Water Resource Commission.

samples. As a comparison between a state laboratory and a private laboratory, the following cost analysis is presented.³⁸

Analytical Costs-State Laboratory

Higgins Lake

Total analyses	\$ 1,887.00
Cost per analysis	<u>1.00</u>
Total analytical cost	1,887.00
Total sampling cost	<u>3,265.92</u>
Total program cost	\$ 5,152.92

Headquarters Lake

Total analyses	\$ 320.00
Cost per analysis	<u>1.00</u>
Total analytical cost	320.00
Total sampling cost	<u>1,678.56</u>
Total program cost	\$ 1,998.56

Lake Chemung

Total analyses	\$ 1,425.00
Cost per analysis	<u>1.00</u>
Total analytical cost	\$ 1,425.00
Total sampling cost	<u>1,573.76</u>
Total program cost	\$ 2,998.76

Total cost for the three monitoring programs \$10,150.24

Analytical Costs-private Laboratory

Higgins Lake

Total analytical cost	\$18,379.35
Total sampling cost	<u>3,265.92</u>
Total program cost	\$21,645.27

³⁸The private cost figures were obtained from Du Bois Analytical and Microbiological Testing Laboratory of Cincinnati, Ohio. These figures are found in Appendix C.

Headquarters Lake

Total analytical cost	\$ 4,838.40
Total sampling cost	<u>1,678.56</u>
Total program cost	\$ 6,516.96

Lake Chemung

Total analytical cost	\$10,878.75
Total sampling cost	<u>1,573.76</u>
Total program cost	\$12,452.51

Total cost for the three monitoring programs \$40,061.74

As the previous cost analysis clearly indicates, the costs of water quality monitoring are very expensive. However, the state laboratory's analytical work seems reasonable when compared to the private laboratory's cost figures. This comparison reveals that private costs are four times larger than the public costs. Thus, it seems unlikely that any organization, such as a lake association would employ the analytical services of a private laboratory.

An examination of the total program costs computed with state laboratory figures, reveals that the three programs total \$10,150.24. Since the average figure amounts to approximately \$3,300, a monitoring program sampling 50 lakes would amount to a cost of \$165,000. Because it is not probable that the state legislature will allocate nearly this much revenue for an inland lake monitoring program, some adjustments must be made to the three monitoring programs to reduce their total costs.

Recommendations

The three variables, the sampling stations, the parameters and the personnel involved in the monitoring programs represent areas where

adjustments can be made. With this in mind, the following five recommendations are offered.

1. Reduce the number of sampling stations located along the transects (i.e., approximately 30 to 35 transect stations could be eliminated from the Higgins Lake Monitoring Program without destroying its purpose).
2. Eliminate those parameters which are not essential to each lake's water quality analysis (i.e., color).
3. Reduce the number of personnel involved in each study from four to three. This must be done only in conjunction with one or more of the previous recommendations to lower the costs.
4. Replace some state personnel with lake association members who have been instructed in sampling techniques.
5. Lower the number of two or more of the variables in combination.

A number of non-essential parameters can be eliminated, however, the objective to collect background data may be sacrificed in the process. Up to an arbitrary point, the number of sampling stations can be reduced without forsaking this objective. Nevertheless, drastic reductions are not recommended in this particular area. Therefore, sampling stations should not be eliminated if their absence substantially destroys the value of the collected background data.

This same general reasoning prevails for the remainder of the recommendations as well. For example, the elimination of non-essential

parameters must be backed by sound scientific judgment. Some parameters, such as color can be safely eliminated, but others like nitrates, phosphates, and dissolved oxygen are essential parameters. Again the changes must be made in view of the two program objectives.

The fourth recommendation offers the greatest challenge. It also appears to attack the largest single program expense, the cost of labor. If the average lake association membership is examined, it will be observed that many professional people are members of the association. Doctors, nurses, lawyers, and business men and women are year-around or seasonal residents and many are members of lake associations. Conceivably, a selected group of association members could be trained in the techniques of water quality sampling.

Assuming that these association members were unpaid volunteers, two agency personnel and two lake residents could collect the required number of water samples for each program. This change will cut the labor costs in half. Instead of \$6,518.24 they amount to \$3,259.12. This figure in turn produces a total program cost for the three monitoring programs of \$6,891.12 and an approximate average cost of \$2,300.

In addition to the monetary benefits, the public relations between agency personnel and lake association residents stands a good chance of improving when association members are utilized in the monitoring of their own lakes. Needless to say, the Department of Natural Resources and its employees are not well liked by all lake residents. Possibly their mutual interest and endeavors in inland lake monitoring may improve their relations. For these reasons, it

is recommended that water resource personnel seriously consider the role that lake association members could play in an inland lake monitoring program.

Conclusions

The combination of the two program objectives and the classification system of lakes appear to be beneficial to the monitoring programs. The two objectives, to provide background data and to identify sources of nutrient inputs, are compatible. Granted, the first objective does demand a more thorough monitoring effort, however, the lists of parameters selected to accomplish each objective are inclusive. For instance, coliform bacteria, nitrates, phosphates, and chlorides are pertinent parameters for both objectives. Therefore, it is advantageous to combine these two objectives into one monitoring program.

The lake classification system is merely a means of identifying common uses among lakes for the purpose of selecting appropriate water quality parameters. From my preliminary investigation, it appears that the classifications do serve to identify the pertinent parameters. This is understandable because similar lake uses generate many of the same water quality problems. Nevertheless, land uses create other water quality problems that are not often related to water use. Therefore, the limitations of the classification system must be realized and accommodated for when selecting the parameters for lake monitoring.

It seems that water quality monitoring has reached a point in Michigan where the reordering of its priorities is needed. In the

past eight years since the passage of the Federal Water Quality Act, a great deal has been accomplished in river and stream pollution control. Monitoring throughout the state has provided substantial water quality data.

It is now time to begin monitoring our inland lakes. By shifting some of the emphasis from river monitoring to inland lake monitoring, the Intrastate Water Quality Standards will become more meaningful. Thus, as background and pollution control data becomes readily available, the inland lakes will receive greater protection.

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APPENDICES

APPENDIX A

**SELECTED PARAMETERS FROM MICHIGAN'S
INTRASTATE WATER QUALITY STANDARDS**

APPENDIX A

SELECTED PARAMETERS FROM MICHIGAN'S INFRASTRATE WATER QUALITY STANDARDS

Parameter Water Use	Coliform Group (Organisms/100 ml. or MPN)	Dissolved Oxygen (mg/l)	Nutrients Phosphorus, ammonia, nitrate, and sugars	Temperature (°F)	Hydrogen Ion (pH)
RECREATION (1) Total Body Contact Such as swimming, water-skiing and skin-diving.	The geometric average of any series of 10 consecutive samples shall not exceed 1000 nor shall 20% of the samples examined exceed 5000. The fecal coliform geometric average for the same 10 consecutive samples shall not exceed 100.	Present at all times in sufficient quantities to prevent nuisance.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and alimes which are or may become injurious to the designated use.	90°F maximum	Maintained within the range 6.5-8.8 with a maximum induced variation of 0.5 unit within this range.
(2) Partial Body Contact Such as fishing, hunting, trapping, and boating.	The geometric average of any series of 10 consecutive samples shall not exceed 5000 nor shall 20% of the samples examined exceed 10,000. The fecal coliform geometric average for the same 10 consecutive samples shall not exceed 1000.	Present at all times in sufficient quantities to prevent nuisance.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and alimes which are or may become injurious to the designated use.	90°F maximum	Maintained within the range 6.5-8.8 with a maximum induced variation of 0.5 unit within this range.
FISH, WILDLIFE AND OTHER AQUATIC LIFE Such as growth and propagation.	The geometric average of any series of 10 consecutive samples shall not exceed 5000 nor shall 20% of the samples examined exceed 10,000. The fecal coliform geometric average for the same 10 consecutive samples shall not exceed 1000.	At the average low flow of 7-day duration expected to occur once in 10 years the following DO values shall be maintained: In rivers capable of supporting: Intolerant fish, cold-water species (trout, salmon)--Not less than 6 at any time; Intolerant fish, warm-water species (bluegill, bass)--Not less than 5; Tolerant fish, warm-water species (catfish, carp)--Not less than 4; Tolerant fish (carp, bullheads)--Average daily DO not less than 4, nor shall any single value be less than 3; Principal anadromous fish migrations in warm-water rivers--Not less than 3 during migrations.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and alimes which are or may become injurious to the designated use.	In rivers capable of supporting: Intolerant fish, cold-water species (trout, salmon) Intolerant fish, warm-water species (bluegill, bass) Tolerant fish, warm-water species (carp) Ambient nat. 32° to max. 32° to 35° 36° to nat. 32° to 59° 60° to nat. max.	Maintained between 6.5 and 8.8 with a maximum artificially induced variation of 1.0 unit within this range. Changes in the pH of natural waters outside these values must be toward neutrality (7.0).

Sources: Michigan State Department of Natural Resources, Water Resource Commission, Use Designation Areas for Michigan's Intrastrate Water Quality Standards (Lansing: Department of Natural Resources, Water Resource Commission, 1969), pp. 6-8.

These additional water quality standards for DISSOLVED OXYGEN apply to inland lakes naturally capable of supporting:

Intolerant fish, cold-water species (trout, whitefish, cisco)

- a. In warm-water lakes with little water exchange which are capable of sustaining cool stratum of well-oxygenated water throughout the summer (above a hypolimnion with very little oxygen): maintain more than 6 mg/l of dissolved oxygen throughout the epilimnion and the upper one-third of the thermocline during the entire stagnation period. At all other times the dissolved oxygen concentration must be maintained at natural levels except in prescribed mixing zones.
- b. In lakes capable of sustaining high oxygen values throughout the hypolimnion during periods of stagnation: maintain dissolved oxygen values greater than 6 mg/l throughout the entire lake.
- c. In lakes which serve as principal anadromous fish migration routes: maintain more than 5 mg/l of dissolved oxygen throughout the epilimnion and the upper one-third of the thermocline in stratified lakes during periods of migration. In unstratified lakes maintain more than 5 mg/l of dissolved oxygen throughout the entire lake during periods of migration.
- d. In shallow, unstratified cold-water lakes: maintain dissolved oxygen greater than 6 mg/l throughout the entire lake.

Intolerant fish, warm-water species (bass, pike, panfish)

- a. In warm-water lakes with little water exchange: maintain dissolved oxygen values greater than 5 mg/l throughout the epilimnion and the upper one-third of the thermocline during the entire summer stagnation period. At all other times the dissolved oxygen concentration must be maintained at natural levels except in a prescribed mixing zone.
- b. In warm-water lakes with a high rate of water exchange: maintain oxygen values greater than 5 mg/l throughout the epilimnion and the upper one-third of the thermocline during the entire summer stagnation period. At all other times the dissolved oxygen concentration must be maintained at more than 5 mg/l except in areas where natural oxygen depressions occur.

These additional water quality standards for TEMPERATURE apply to inland lakes naturally capable of supporting:

Intolerant fish, cold-water species (trout, whitefish, cisco)

- a. Small warm-water lakes with little water exchange which are capable of supporting trout in the thermocline or hypolimnion and shallow, unstratified cold-water lakes shall not be artificially warmed.

b. Large warm-water lakes with little water exchange which are capable of supporting trout in the thermocline or hypolimnion shall not receive a heat load which would warm the thermocline or hypolimnion. Surface waters may be warmed 10°F when ambient temperature is less than 45°F and 50°F when ambient temperature is greater than 45°F. Maximum limit is 85°F.

c. In lakes which serve as principal anadromous fish migration routes the temperature of the epilimnion shall not be elevated more than 50°F above ambient during the times of migration, and shall, in no instance, interfere with migration. If ambient water temperatures in the migratory channels during the times of migration exceed 65°F they may not be artificially increased to greater than 70°F.

Intolerant fish, warm-water species (bass, pike, panfish)

In warm-water lakes incapable of supporting trout: surface waters may be warmed 10°F when ambient temperature is less than 45°F and 50°F when ambient temperature is greater than 45°F. Maximum limit is 85°F.

Anadromous fish migrations

Warm-water rivers that serve as principal migratory channels for anadromous fish species and that have ambient water temperatures in excess of 65°F during the times of migration may not be artificially warmed to greater than 70°F. At other times of the year the standards for intolerant fish, warm-water species in rivers apply.

APPENDIX B

REFERENCE INFORMATION FOR PARAMETERS

APPENDIX B

REFERENCE INFORMATION FOR PARAMETERS

Parameter	Min. Sample Volume ^a (ml.)	Preservative ^a	Max. Storage Time ^a (hours)	Analytical Method ^b
1. bacterial	100	4°C + darkness	24	Milipore Filter
2. biochemical oxygen demand	2000 (depends on sample source)	None	6-10 (Max. of 24 hrs. if very low organic content)	5 Day BOD Test
3. nitrite	100	4°C + 40 mg HgCl ₂ /l	24	Diazotization
4. nitrate	250	1 ml H ₂ SO ₄ /l of sample	48	Brucine
5. ammonia	250	1 ml H ₂ SO ₄ /l of sample	48	Distillation Method
6. total Kjeldahl	250	4°C	48	Kjeldahl
7. orthophosphates	100	filtration when sampled frozen below (-10°C) +40 mg HgCl ₂ /l	24	Stannous Chloride

Parameter	Min. Sample Volume ^a (ml.)	Preservative ^a	Max. Storage Time ^a (hours)	Analytical Method ^b
8. chlorides	50	None. Store at cool temperature	indefinite	Potentiometric
9. sulfates	100	Store at cool temperature	48+	Turbidometric
10. dissolved solids	100	Store at cool temperature	24	Filterable Residue
11. suspended solids	100	Store at cool temperature	24	Non-filterable Residue
12. pH	100	None	None	Glass Electrode
13. Mercury (metals)	100	5 ml 1 + 1 HNO ₃	6 (months)	Atomic Absorption ^c
14. chlorinated hydrocarbons (DDT, dieldrin)	1 gallon glass	Store in cool place	few hours	Gas Chromatographic ^d
15. color	100	Store in cool place	24	Color discs field test
16. turbidity	250	Store in cool place	8	Nephelometric

Parameter	Min. Sample Volume ^a (ml.)	Preservative ^a	Max. Storage Time ^a (hours)	Analytical Method ^b
17. temperature	in situ	None	None	thermometer field
18. specific conductivity	100	Store in cool place	48+	specific conductance cell of non-platinum electrode

^aFlorida Department of Pollution Control, Ambient Water Sampling Procedures, Tallahassee, n.d. (Mimeographed.)

^bAmerican Public Health Association, American Water Works Association and Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewaters, 13th ed. (New York: American Public Health Association, Inc., 1971), many pages.

^cW. J. Traversy, Methods for Chemical Analysis of Waters and Wastewaters, Water Quality Division, Inland Waters Branch, Dept. of Fisheries and Forestry (Ottawa, Canada: Water Quality Division, 1971), p. 74.

^dA. S. Y. Chau, Analysis of Chlorinated Hydrocarbon Pesticides in Waters and Wastewaters, Water Quality Division, Inland Waters Branch, Dept. of the Environment (Ottawa, Canada: Water Quality Division, 1972), p. 3.

APPENDIX C

PRIVATE LABORATORY ANALYTICAL COSTS

APPENDIX C

PRIVATE LABORATORY ANALYTICAL COSTS^b

<u>Test</u>	<u>Price Per Sample*</u>
Alkalinity-total	\$ 4.50
Alkalinity-bicarbonate	4.50 ^a
BOD	20.00
Chlorides	4.50
Coliform-fecal	12.00
Coliform-total	12.00 ^a
Hardness	7.50
Hydrocarbons-chlorinated	40.00
Mercury	18.00
Nitrogen-nitrate	12.00
-nitrite	12.00
-total Kjeldahl	12.00
Phosphate-ortho	7.00
pH	4.50
Solids-dissolved	9.00
-suspended	9.00
Streptococci-fecal	12.00
Sulfates	7.50
Turbidity	5.00

*10% discount for five or more water samples at one time for identical tests.

^aCosts not listed, but assumed to be same as another similar test for the same parameter.

^bDu Bois Water Quality Management Service, "Individual Chemical and Trace Metal Test Prices," Cincinnati, Ohio, n.d.

APPENDIX D

ILLUSTRATIONS

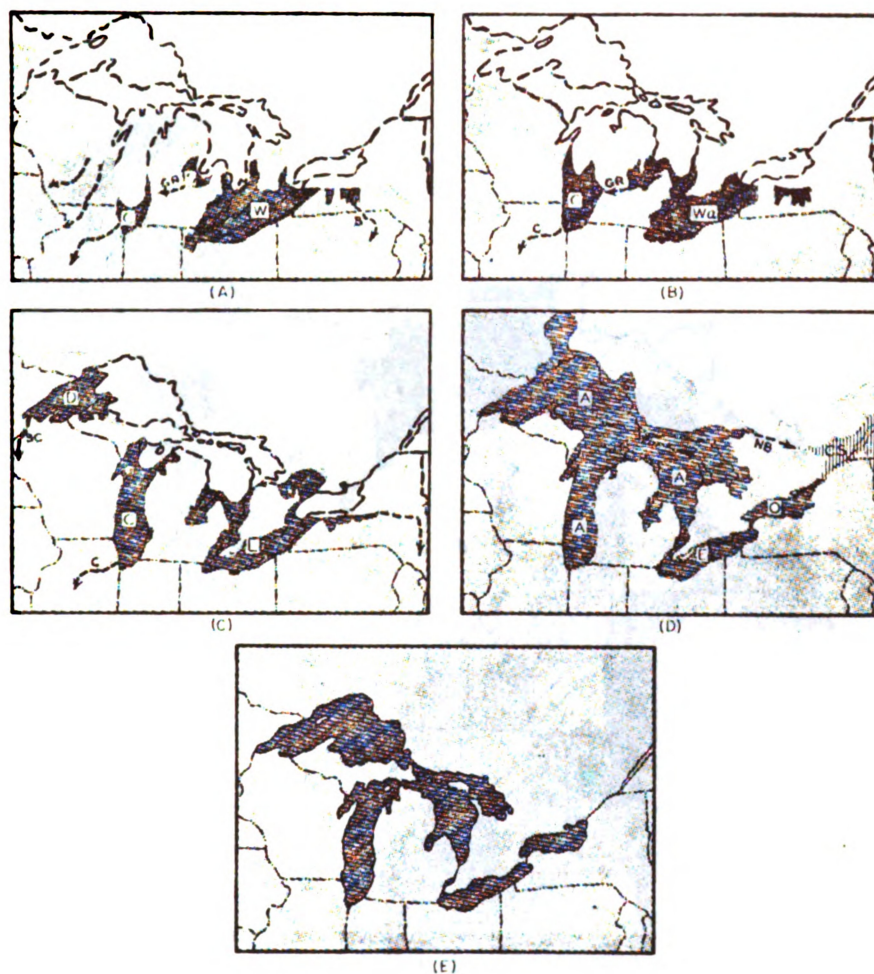


Figure 1. Developmental stages in the formation of the Great Lakes accompanying recession of the Pleistocene continental glaciation. Processes are described in the text.

Note:	A--Lake Algonquin	NB--North Bay Outlet
	C--Lake Chicago	O--Lake Ontario
	c--Chicago River	S--Lake Saginaw
	CS--Champlain Sea	s--Susquehanna River
	D--Lake Duluth	sc--Saint Croix River
	E--Lake Erie	W--Lake Whittlesey
	GR--Grand River	Wa--Lake Warren
	L--Lake Lundy	

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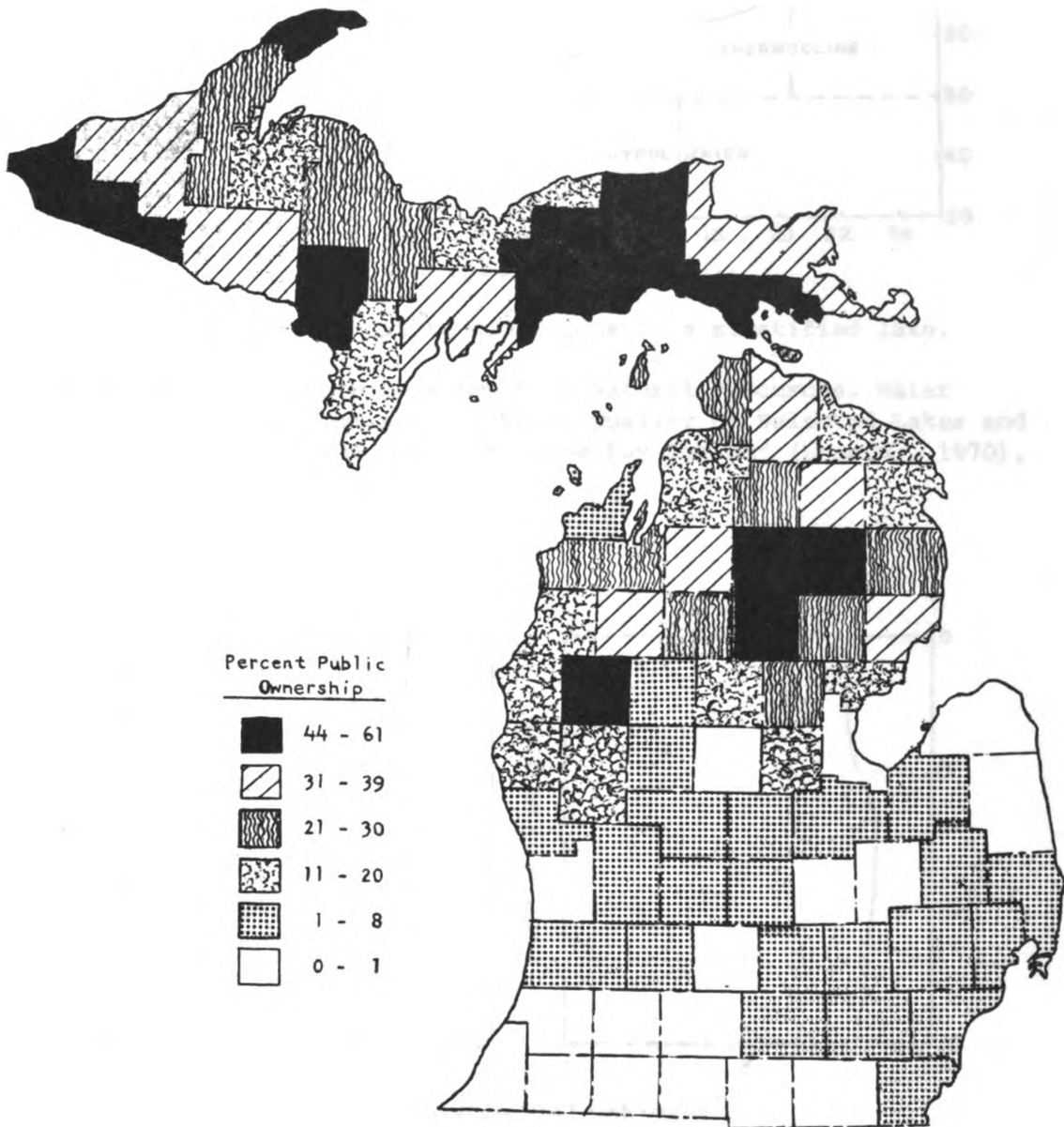


Figure 2. Public land ownership in Michigan.

Source: Michigan State Department of Natural Resources, Water Resources Commission, "A Summary of Water and Related Land Resources in Michigan (Lansing, 1966), p. 63.

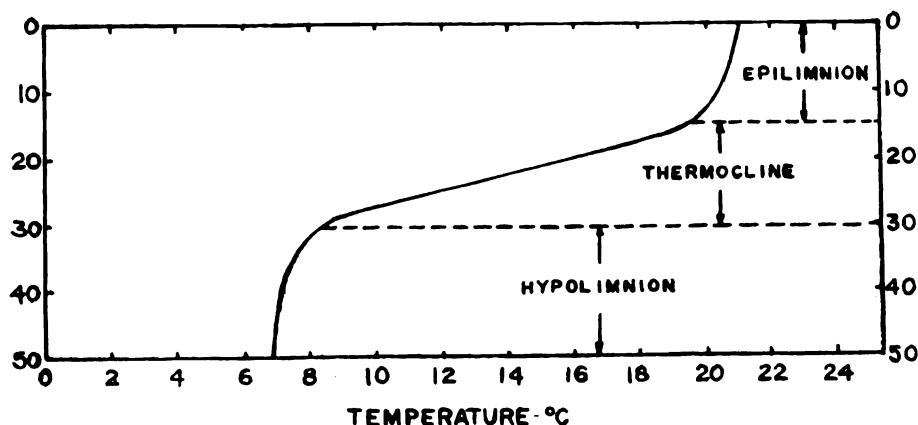
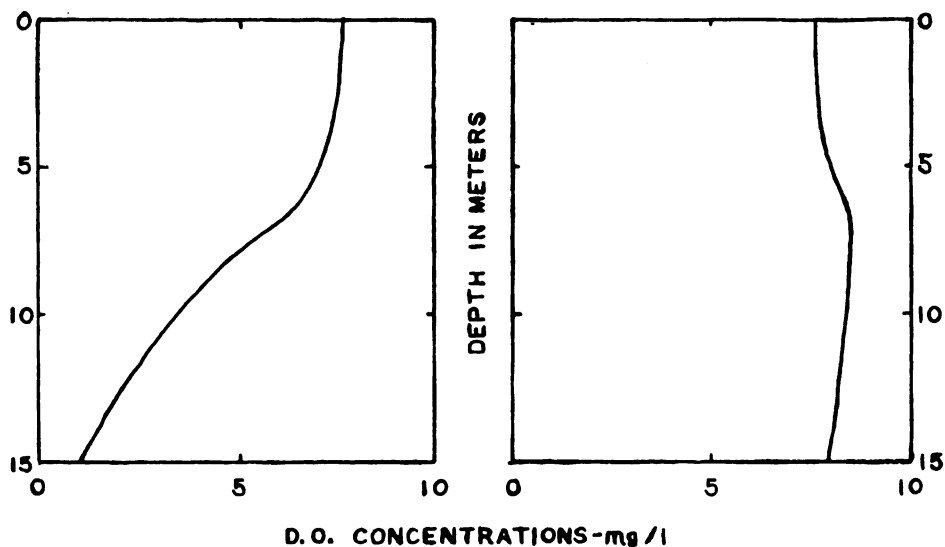


Figure 3. Summer temperature conditions in a stratified lake.

Source: Michigan State Department of Natural Resources, Water Resources Commission, "Water Quality of Selected Lakes and Streams in the Grand Traverse Bay Region" (Lansing, 1970), p. 16.



Clinograde Oxygen Profile

Orthograde Oxygen Profile

Figure 4. Clinograde and Orthograde Oxygen Profiles.

Source: Michigan State Department of Natural Resources, Water Resources Commission, "Water Quality of Selected Lakes and Streams in the Grand Traverse Bay Region" (Lansing, 1970), p. 17.

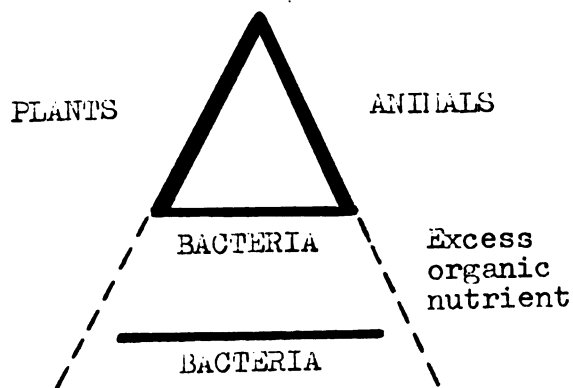


Figure 5. Organismal and nutrient balance in lakes undergoing eutrophication.

Source: National Academy of Sciences, Eutrophication: Causes, Consequences, Correctives (Washington, D.C.: National Academy of Sciences, 1969), p. 333.

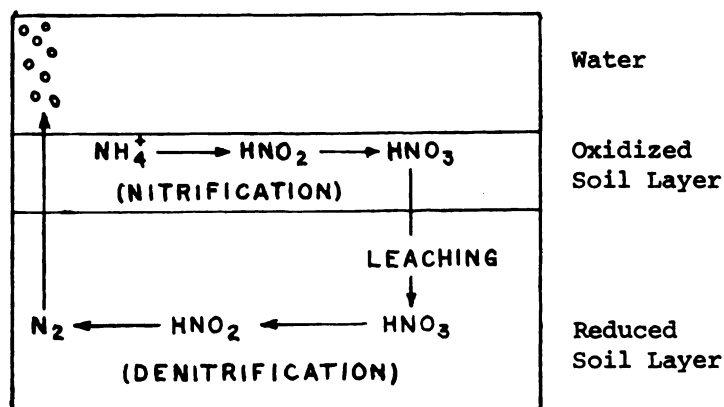
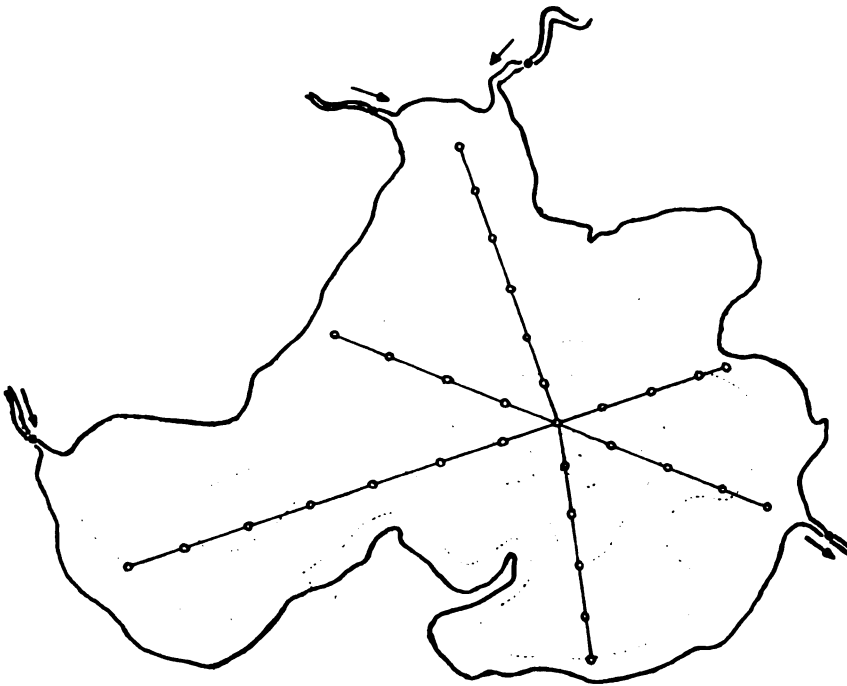


Figure 6. A schematic diagram of the processes by which ammonia fertilizer can be lost from a waterlogged soil.

Source: Ted L. Willrich, and George E. Smith, ed., Agricultural Practices and Water Quality (Ames: Iowa State University Press, 1970), p. 28.



- Routine Sampling Sites
- Transect Sampling Sites--
Periodic or Seasonal Collections

Figure 7. Diagram of a natural lake basin showing suggested sampling sites. Samples taken from points on transaction lines on a periodic or seasonal basis are valuable to determine vertical water characteristics and the benthic standing crop.

Source: U.S. Department of Interior, Federal Water Pollution Control Administration, The Practice of Water Pollution Biology (Washington, D.C.: Government Printing Office, 1969), p. 51.

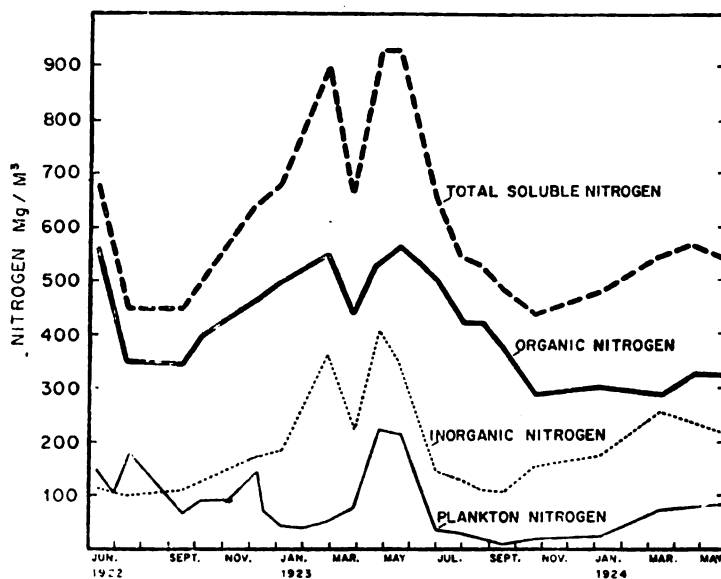


Figure 8. Seasonal variation in the quantity (milligrams per cubic meter) of various forms of nitrogen in Lake Mendota, 1922-1924.

Source: George K. Reid, Ecology of Inland Waters and Estuaries (New York: Van Nostrand Reinhold Company, 1961), p. 185.

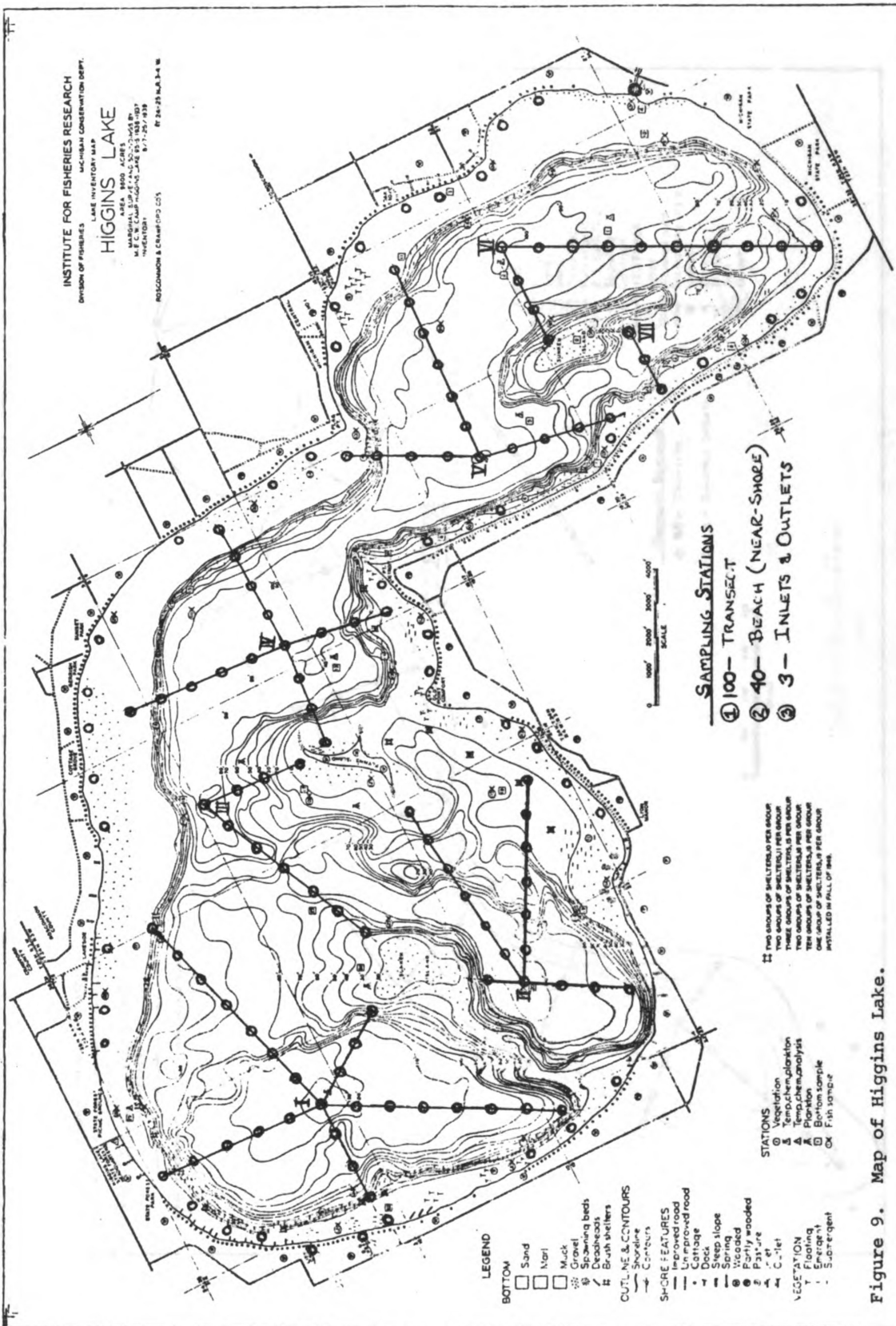


Figure 9. Map of Higgins Lake.

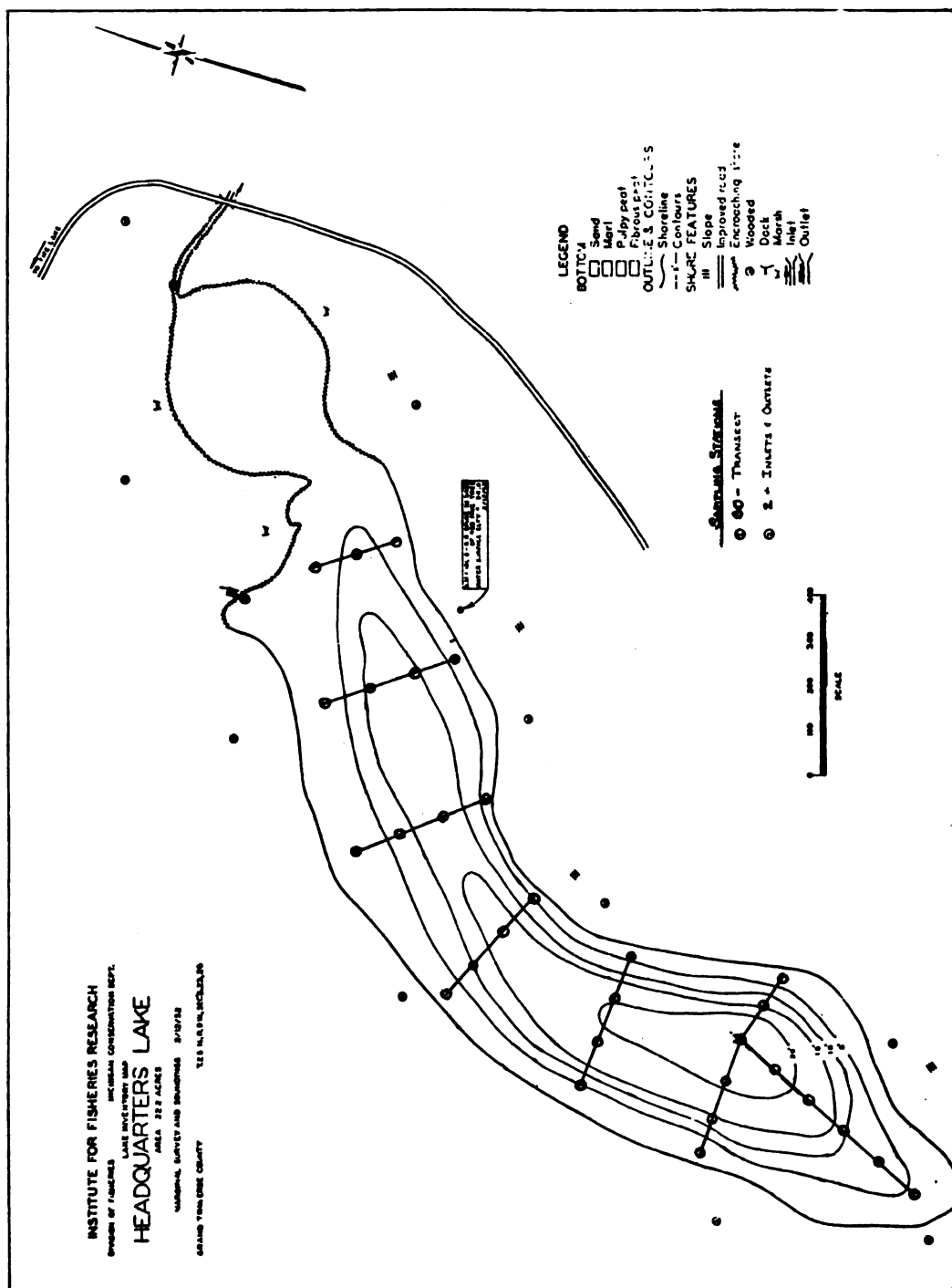


Figure 10. Map of Headquarters Lake.

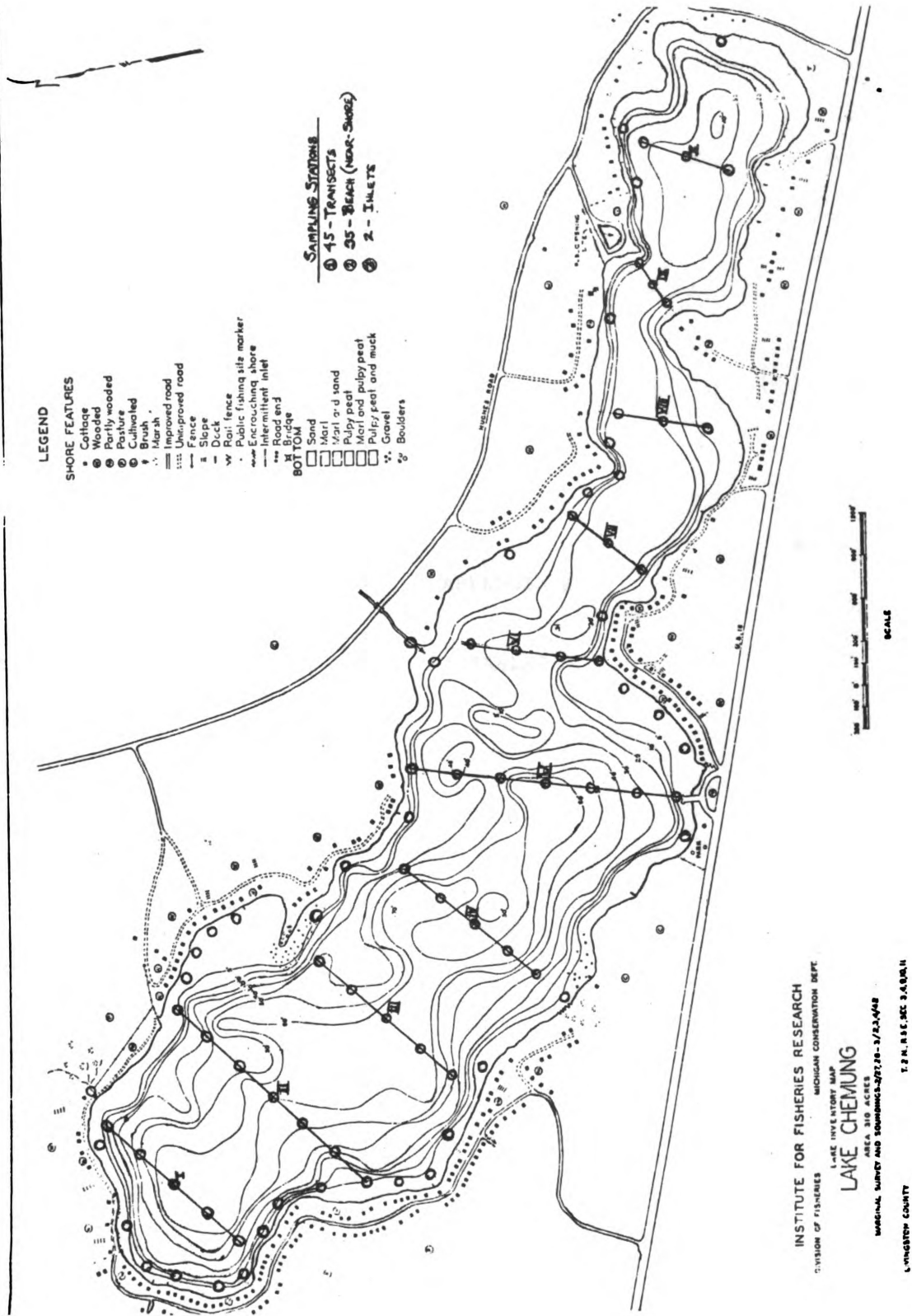


Figure 11. Map of Lake Chemung.

APPENDIX E

TABLES

TABLE E-1.--Extremes of Nutrient Concentration in Drainage Water,
1969.

Location	N		P		K		Ca		Mg	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
ppm										
Ferden Farm	8.1	0.9	0.2	0.01	6.8	0.8	117	69	31	24
Davis Farm	7.2	1.8	0.1	0.01	6.0	0.7	106	73	31	24
Hey Farm	11.1	0.3	0.3	0.01	2.6	0.9	85	50	30	17
Muck Farm	2.8	0.2	0.3	0.01	4.8	0.9	110	28	31	8
Deer Creek	4.4	0.4	0.2	0.01	4.9	0.7	107	51	28	16
Sloan Creek	3.7	0.3	0.2	0.01	5.3	1.2	108	51	31	13
Montcalm Creek- North	1.2	0.1	0.2	0.01	1.6	0.7	82	32	32	12
Montcalm Creek- South	1.8	0.2	0.3	0.01	1.9	0.3	70	36	30	11

TABLE E-2. Total Nutrients Added in Fertilizer and Lost in Drainage
Water.

Location	Added Each Year			Lost 1969		
	N	P	K	N	P	K
lb/acre/year						
Ferden Farm	80	35	32	11	0.1	4
David Farm	35	45	44	7	0.1	2
Muck Farm	50	15	80	17	1.3	23

TABLE E-3.--Total Nutrient Loss in Drainage Water, 1969.

Location	Nutrient - lbs/A				
	N	P	K	Ca	Mg
Ferden Farm	10.8	0.09	4.3	151	50
David Farm	7.4	0.08	1.7	109	74
Muck Farm	16.7	1.3	23.4	624	178
Deer Creek	3.2 ^a	0.10 ^a	3.5 ^a	152 ^a	41 ^a
Sloan Creek	3.1 ^a	0.14 ^a	4.2 ^a	141 ^a	42 ^a

^a8 months.

Source: A. E. Erickson, and B. G. Ellis, "The Nutrient Content of Drainage Water From Agricultural Land" (Research Bulletin 31 of Michigan State University, Agricultural Experiment Station, East Lansing, 1971), pp. 14-15.

TABLE E-4.--Nutrient Output and Ionic Composition of Drainage From Forested Watersheds in Northern Minnesota.^a

Watershed	Area (ha)	Nutrient Output (g/ha per day)					Ionic Concentration (mg/liter)				
		Ca	NH ₄	NO ₃	Organic N	P	Ca	NH ₄	NO ₃	Organic N	P
2	2,150	646	0.43	7.3	5.9	0.30	54	0.04	0.50	0.18	0.032
3	2,850	646	0.50	6.0	5.7	0.50	64	0.08	0.91	0.69	0.060
4	958	113	0.31	0.7	2.6	0.23	38	0.06	0.42	0.66	0.047
6	13,000	259	0.43	3.2	5.5	0.37	17	0.03	0.34	0.38	0.023

^aU.S. Forest Service data.

Source: National Academy of Sciences, Eutrophication: Causes, Consequences, Correctives (Washington, D.C.: National Academy of Sciences, 1969), p. 454.

TABLE 2-5.--Characteristics of Storm Water.

City	BOD mg/l	Total Solids mg/l	Suspended Solids mg/l	Coliform /l	Chlorides mg/l	COD mg/l
1. East Bay Sanitary District						
Minimum	3	726	16	4	300	
Maximum	7,700		4,400	70,000	10,260	
Average	87	1,401	613	11,800	5,100	
2. Cincinnati, Ohio						
Maximum Seasonal Means	12	260				110
Average	17		227			111
3. Los Angeles County						
Average 1962-63	161	2,909			199	
4. Washington, D.C.						
Catch-basin samples during storm						
Minimum	6		26		11	
Maximum	625		36,250		160	
Average	126		2,100	16,100	42	
5. Seattle, Washington	10					
6. Oxney, England	100	2,045				
7. Moscow, U.S.S.R.	186-285	1,000-3,500**				
8. Leningrad, U.S.S.R.	36	14,541				
9. Stockholm, Sweden	17-80	30-8,000		40-200,000		18-3,100
10. Pretoria, South Africa						
Residential	30			240,000		29
Business	34			230,000		28
11. Detroit, Michigan	96-234	310-914	102-213***	930,000**		
Criteria for:						
A. Potable water (to be filtered)				5,000	600**	10
(not to be filtered)				50		10
B. Body contact water				2,400	NA	

*New York State.

**Max.

***Mean.

Source: U.S. Department of Interior, Federal Water Pollution Control Administration, Water Pollution Aspects of Urban Runoff (Washington, D.C.: Government Printing Office, 1969), p. 21.

TABLE E-6.--Economic Analysis of Lake Improvements (50 Year Period Ending in 2020).

Item	Removal Land Based Equipment	Dredging to a Uniform 10' Depth	Building a New Lake	Dredging to Either a 10' Depth or to Hard Bottom
First Cost	\$2,500,000	\$4,320,000	\$334,000	\$954,000
Annual Charges	153,000	250,000	36,000	69,000
Interest on Investment	122,000	211,000	16,300	46,500
Amortization	13,000	21,000	1,700	4,500
Operation & Maintenance	8,000	8,000	8,000	8,000
Research & Development	10,000	10,000	10,000	10,000
Annual Benefits	161,000	161,000	161,000	161,000
Benefit-to-Cost Ratio	1.1	0.6	4.5	2.7

Note: The first costs of the different options were computed in Section 6. The annual charges consist of four items. First, an interest charge of 4 7/8 per cent of the first cost must be paid over a 50-year period. The first cost must also be amortized over that period. The cost of keeping lake weed free must be computed on an annual basis. Research must be constantly performed at Lake Lansing to evaluate the results of the lake improvements, so research costs are also included.

Source: Richard L. Sode, "Reconnaissance Report, Eutrophication Problem" (Mason, Michigan, 1969), p. 34.

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