Eutrophication is beginning in Lake Michigan

Through vigorous efforts of the press, thousands of people living in the Lake Michigan watershed are acquiring an awareness of the term "eutrophication." They are learning, also, that it relates in some manner to water pollution and water quality problems in the lake.

Many scientific studies of Lake Michigan have been carried out over the years by a number of agencies representing states and communities fronting on the lake. The resulting observations cover a historical period dating back to before the turn of the century, but the data improve in completeness only in recent times. Among recent Lake Michigan studies are those of the Great Lakes Research Division of the University of Michigan. The Center for Great Lakes Studies of the University of Wisconsin, and the studies of the Great Lakes Region of the Federal Water Pollution Control Administration. An appraisal of eutrophication in Lake Michigan has been made in connection with the FWPCA studies.

The results of all the studies mentioned above are substantially in agreement, and they collectively make up the story of what has been happening to Lake Michigan in recent times.

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and acquire a greater capability to grow algae and other forms of unwanted living matter. The algae frequently become so numerous that they make the water green and interfere in many ways with the continued usefulness of the water. This is one of the most common, objectionable symptoms of eutrophication. In addition, there are other more subtle symptoms of change that sometimes would be noticed only by the scientist investigator. Such subtle changes are, however, clues that slow-acting, long-range changes are taking place.

These changes include: decrease in transparency of the water; increase in total dissolved solids, especially nitrogen and phosphorus, which are needed for growth of substantial quantities of algae; loss of dissolved oxygen in the deeper layers; and changes in bottom-dwelling animals and microscopic plants. Before eutrophication has proceeded to an obvious and objectionable stage, it is necessary to examine the combination of these subtle clues to sense the existing conditions. In many cases, such scrutiny may reveal a forecast of things to come. Some changes such as these are now appearing in Lake Michigan.

Many scientists have been studying various aspects of the "personality" of Lake Michigan and have produced much valuable information. Dr. Alfred M. Beeton, of the University of Wisconsin in Milwaukee, was the first to perceive, assess, and describe clearly the responses of the Great Lakes, including Lake Michigan, to the eutrophying influences of human affairs in the watershed area.

Nutrient addition

One of the principal factors that affect the rate of eutrophication is the extent to which nutrients needed by algae enter the body of water. Under natural conditions, unaffected by the affairs of man, the input of nutrients in runoff from the watershed land and in precipitation is generally low, and the aging process proceeds at a slow rate. Cultural developments on the watershed, such as the establishment of cities and cultivation or other disturbance of the land, accelerate nutrient input.

The result of this input is shown clearly in a chart prepared some years ago by Dr. A. D. Hasler of the University of Wisconsin (Fig. 1). The influences of cultural development are superimposed on the natural aging process and accelerate it so that the terminal point is reached much more quickly. It makes no difference at what point on the time scale the human influence is brought to bear. The end result is always the same. The lake is...
brought more rapidly to a higher level of fertility, and greater crops of algae and other plants are produced than under natural influences alone.

The result of increasing nutrient input has been seen over and over again, throughout history, in every continent. This can be verified readily by reference to the well-known histories of the lakes at Madison, Wis.; Lake Washington, at Seattle; and in Europe, at Lake Geneva, Lake Zurich, and the Bodensee, to mention only a few.

Until recently, most studies of eutrophication have been concerned with fairly small lakes. Because of its size, one can expect that Lake Michigan will differ in the details of its response to the forces of eutrophication. There is no doubt, however, that even here these forces will be felt and produce undesirable change. The unfortunate end result is inevitable if preventive measures are not taken in time.

**Nitrogen and phosphorus**

Algal nutrients of special concern are nitrogen and phosphorus. Studies by FWPCA have shown that soils of the Lake Michigan basin yield phosphate to the runoff water at a rate of from 31 to 250 lb per sq mile per year. It is estimated that the annual input of phosphate to the lake from these sources is about 5,000,000 lb. This is about one-third of the total input; the remaining two-thirds comes from municipal and industrial wastes. Comparable figures for nitrogen are not available, but it is known that rivers tributary to the lake bring in 69 million lb annually. This is about 42 percent of the total input; the remainder comes from direct discharges and precipitation. Domestic sewage normally contains about 8 to 12 lb of nitrogen and 1.5 to 4 lb or more of phosphorus per person per year. Even after conventional secondary treatment, substantial amounts of these nutrients still remain to be discharged into surface waters.

Sewage contains other components, both organic and inorganic, that have stimulatory influences on algae growth. Most concern, however, has focused on inputs of phosphorus for the following reasons. First, algae can obtain phosphorus from the water even when it is present in exceedingly minute amounts. In many lakes, exhaustion of the phosphorus supply by algal growth seems to serve as a deterrent to further growth. Second, although nitrogen is also a vital nutrient for algal production, there are various largely uncontrollable sources of nitrogen input, such as fixation of nitrogen gas from the atmosphere by some species of algae themselves. And third, the input of phosphorus is more amenable to control than that of most other stimulants of algal growth. In any event, the quantity of algae a lake can grow is largely determined by the amount of nutrients available. There is evidence that continued input of nutrients can finally bring a lake beyond the point of no return—to the stage where continuous recycling of nutrients already present can result in production of nuisance growths of algae.

The tremendous mass of data gathered on the physical, chemical, and biological status of Lake Michigan indicate that the lake, as a whole, is beginning to show some early symptoms of accelerated eutrophication. The offshore areas differ from the inshore areas in the nature and extent of their responses to the input of nutrient-bearing pollutants. Consequently, it is desirable to examine them separately.

**Offshore areas**

The offshore, deep water areas of Lake Michigan do not now show substantial effects of pollution or the onset of eutrophication forces. They do, however, exhibit a combination of minor and subtle changes that suggest that the real beginnings of eutrophication are imminent.

The standing crop of algae, shown by periodic sampling during 1962 and 1963, has a low population density, between 100 and 300 organisms per ml. It is partly because of this low algal population that the water has a high transparency—in 1966 averaging 6 m, as shown by a secchi disk. This is less transparent than Lakes Superior and Huron but more transparent than Lakes Erie and Ontario. Unfortunately, there is no historical record of transparency to show if and to what extent water clarity is changing.

One study of primary productivity—roughly, the rate of algal growth—showed a rate in 1964 only slightly higher than in Lake Superior.

Two changes in species composition in the zooplankton have been noted. A water flea, *Bosmina longirostris*, has replaced another, *B. coregoni*. This is significant because a similar change occurred in Lake Zurich in Switzerland concurrent with and as evidence of eutrophication changes that were occurring there. In Lake Zurich, as well as in Lake Michigan, pollution is the prime source of nutrient input. Another small organism, called *Diatomus oregonensis*, has appeared and became prominent in Lake Michigan since 1927. What this means, beyond the fact that change is occurring, is not now clear.

The same three principal kinds of bottom-dwelling animals occur now in offshore areas as were observed in 1931 and 1932. These same organisms commonly are found in other lakes that are not eutrophic. Recent studies by the Great Lakes Research Division of the University of Michigan have shown, however, that these animal populations have increased markedly. This is probably a response to enrichment of the bottom sediments.

Except in the south end of the lake, where chemical quality of the water is declining, offshore water presently is of high quality. Nevertheless, indications of gradual chemical buildup are apparent. Total inorganic nitrogen concentration averages 0.19 mg per L and total phosphate is approximately of 0.02 mg per L. Concentrations of these two nutrients in the offshore waters have not yet reached levels that frequently cause nuisance growths of algae. In his studies, Beeton noted that, in 90 years, total dissolved solids increased 30 mg per L, sulfate 13 mg per L, and chloride about 6 mg per L. These increases are not great, but if no preventive action is taken, levels characteristic of eutrophication will be reached.

Some data on dissolved oxygen concentrations in deep waters of the lake are available for 1954, 1955, 1960, 1961, and 1966. Between 1955 and 1966, the oxygen content decreased slightly. In 1954-1955, the oxygen...
values equaled or exceeded 90 percent of saturation in 35 percent of the samples taken; in 1966, 90 percent saturation was exceeded in only 10 percent of the samples. If such decreasing oxygen is more than a momentary variation, it should be viewed with concern as a symptom of movement toward eutrophication.

**Inshore areas**

In contrast to the offshore waters, the inshore areas have changed drastically and in many ways under the influence of human activities. In recent years, both attached and free-floating algae, *Cladophora* and others, have frequently appeared in nuisance proportions at various harbor and waterfront areas around the lake.

These attached growths periodically break loose under wave action and wash ashore to litter the beaches in slimy windrows. Resulting nuisances have occurred repeatedly at many locations along the lake. In the summer of 1967 (Fig. 2), algal growths of this kind were more onerous than previously. They also appeared in new places and were more luxuriant than they had been. The growth of such masses of algae is a direct response to concentrated high levels of nutrients brought into the lake by way of municipal sewage, land runoff, urban drainage, industrial wastes, and other sources. In Lake Erie, luxuriant growths of *Cladophora* seem to have been a forerunner of the more widely dispersed free-floating or planktonic growths of algae that now exist there.

Overabundant planktonic algae also have caused problems. Among such problems are shortened filter runs and other difficulties at water treatment plants in cities using lake water. Taste and odors caused by algae have occurred in water supplies in several North Shore cities.

In the southern end of the lake, there is ample evidence of deterioration of chemical water quality in areas adjacent to population centers. Total inorganic nitrogen and soluble phosphate were found to be highest here. Along with Green Bay, Wis., these are the areas of greatest algal growths, sometimes to the extent that water transparency diminished to less than 1 m.

At Green Bay, high nutrient input brought soluble phosphate to an average concentration of 0.07 mg per L, sometimes reaching as high as 0.6 mg per L. In Milwaukee harbor, soluble phosphate averaged 0.44 mg per L or 15 times the concentration considered critical for the production of nuisance growths of algae, and sometimes reached as high as 1.4 mg per L. Many other examples of high nutrient availability could be cited, but these are indicative of nutrient conditions existing in many of the inshore trouble spots.

**Chicago records**

According to long-term records available at Chicago, plankton algae increased at an annual rate of 13 new organisms per ml between 1936 and 1958. They also reached three times the numbers found in offshore waters. Such conditions of accelerated eutrophication exist and usually extend lakeward in some form or other at many points around the lake.

Further evidence of lake deterioration is seen in the nature and density of bottom animal populations in many of these areas. In general, there has been a shift over the years from a normal assemblage of animals characteristic of clean water to dense populations of one or two kinds, such as sludgeworms and bloodworms, commonly taken as evidence of organic pollution. Figure 3 shows the population density distribution of sludgeworms in 1962. Inshore areas of pollution in which the populations of bottom animals are thus impaired total 3475 sq miles along the southern perimeter of the lake, almost uninterrupted from Port Washington to Muskegon. Although not shown, simi-
lar conditions also occur over some 28 sq miles of lower Green Bay, as well as locally at a number of sites.

Considerations for the future

While the deep water areas of Lake Michigan give only a suggestion of creeping eutrophication, the lake's response to increasing nutrients in the inshore waters is obvious and shows that the lake can respond when nutrients for plant growth are abundant. Lake Michigan, as a whole, is now at an early stage in the eutrophication process, a point that was passed through by Lake Erie at some point in the past. In the future, nutrient levels will increase until, finally, the entire lake becomes involved. With certain reservations, Lake Erie can be viewed as a prototype and a preview of what can happen in Lake Michigan if nutrient-bearing waste input continues unabated.

Using available data, existing nitrogen and phosphorus input-output balances for Lake Michigan (Table 1) can be examined. In doing so, two points are noted: First, the estimated inputs of nitrogen and phosphates are substantial. Second, both nitrogen and phosphate retentions in Lake Michigan are high—81 percent for nitrogen and 95 percent for phosphate.

| TABLE 1—ANNUAL INPUT AND OUTPUT OF NUTRIENTS FOR LAKE MICHIGAN, 1953-1954 |
|-----------------------------|-----------------------------|
| Nitrogen Phosphates         | 166.1                       |
| Input (mil lb)              | 14.6                        |
| Output (mil lb)             | 32.2                        |
| Retained (%)                | 81.0                        |
| Retained (%)                | 95.0                        |

While the percentage of retention may vary considerably among lakes and among different nutrient elements, substantial retentions are not unusual. This retention, together with changes that have been permitted to occur over the years in the inshore waters, the low flushing rate of the lake, the awareness of what has happened to Lake Erie and other lakes, and the emerging evidence of subtle chemical changes in water quality, emphasize the need for action now.

Forecasts indicate that the population of the Lake Michigan basin will increase from a 1960 level of 4.2 million to 12.1 million by the year 2020, industrial wastes will increase by a factor of three, chlorides in the lake will build up from a 1965 level of 7 to 12 mg per L, and sulfates will increase from 20 to 29 mg per L. One can only expect that nutrients, such as nitrogen and phosphorus, although complicated by their biological involvement, will also increase in something the same pattern. If these changes are permitted to occur, there seems little doubt that the problems of the inshore waters will become more frequent and more distasteful. They also will be extended lakeward and gradually affect all of Lake Michigan. There is no doubt that the factors that stimulate eutrophication will function in Lake Michigan as they do in any other lake. There remains only the question—how long will it take? Whether this requires 50, 100, or 1000 years, it can be prevented only by restoring the inshore areas to an acceptable state and by preserving the offshore waters in their present condition. In the light of what is now known about Lake Michigan, a policy to keep nutrient input from all sources at the lowest possible level should be established without delay.

REFERENCES

KEY WORDS
Eutrophication; Stream Pollution.