Restoring Damaged Lakes

Nothing so fair, so pure, and at the same time so large as a lake, perchance, lies on the surface of the earth. Sky water.
—Henry David Thoreau

Thoreau had obviously never seen anything like Medical Lake in Washington State as it was during the early 1970's. In summer, Medical Lake was filled with turbid water made dark green by dense growths of algae. Floating scums accumulated in windrows on the lee shore, spotted here and there with the putrefying corpses of fish that had suffocated from lack of oxygen in the water. Dense swarms of flying insects hovered over the lake, and much of the area was permeated by a noxious odor.

Medical Lake was in an advanced stage of eutrophication, the process in which lakes accumulate nutrients, become more productive, fill with decaying vegetation, and eventually become marsh and dry land. Eutrophication is a natural aging process, but it is accelerated sharply by increased loads of nutrients from septic tank drainage, outfall from waste treatment plants, fertilizer runoff from fields and lawns, and myriad other by-products of civilization.

Medical Lake may be an extreme example, but thousands of other lakes and ponds around the country show one or more symptoms of accelerated eutrophication. These symptoms restrict the use of water in municipal water systems, limit recreational uses of lakes, deplete stocks of sport fish, and generally degrade the environment. Yet it is only within the last few years that there has been any concerted effort to reverse some of these effects and to prevent future degradation.

A small number of states, particularly Wisconsin, Minnesota, and Washington, have had lake restoration programs for some time, but the major impetus for most recent activities has been the Clean Lakes Program of the Environmental Protection Agency (EPA). That program was first proposed in 1966 by Senators Walter Mondale (D-Minn.) and Quentin Burdick (D-N.D.), but was not passed until it became part of the Federal Water Pollution Control Act Amendments of 1972. The law requires states to survey and report on the quality of their freshwater lakes—no small task in states like Florida, which has more than 7,000, and Minnesota, which has more than 12,000—and authorizes funds to help restore the water quality of those that have become eutrophic.

Since January 1976, when the first grant was dispensed, EPA has awarded some $32 million for 76 lake restoration projects in 24 states. These grants are for actual projects in lakes rather than for research, but the monitoring and reporting requirements built into the grants promise to make the program effective for evaluating the efficacy of various restoration techniques. Only half a dozen EPA-sponsored projects have been completed so far, but the preliminary results look promising. At Medical Lake, for example, the amount of undesirable algae has been sharply reduced, nutrient concentrations have been reduced, the amount of daphnia and desirable phytoplankton has increased, and water quality has improved. Similar results have been reported elsewhere, and it now seems quite possible that much of the damage wrought by civilization can be reversed—at least temporarily.

The foundation for most current lake restoration projects was laid in the 1930's and 1940's when it was demonstrated that algae and many other freshwater microorganisms require carbon, nitrogen, and phosphorus in the approximate ratio of 100 to 15 to 1. In most clean lakes, lack of phosphorus restrains the growth of microorganisms that promote eutrophication. Industrial and domestic effluents, however, contain significant quantities of phosphorus, which disrupts the natural balance and promotes excessive growth of algae and other plant life.

The plant life is a nuisance of itself, and, when it dies and sinks, its decomposition depletes oxygen in the hypolimnion—the cold water region of a lake that has stratified into layers of different temperatures. Lake restoration techniques thus require limiting the influx of phosphorus and other nutrients to the lake, removing the nutrients that are already there, oxygenating the hypolimnion, or some combination of the three. The usefulness of various methods for achieving these goals was discussed at an EPA-sponsored National Conference on Lake Restoration held in Minneapolis last August.

Controlling the influx of nutrients is difficult and can be expensive, but it is also the most crucial method of lake restoration. Other restoration techniques can have little permanent impact unless the flow of nutrients is reduced. Efforts to reduce nutrient influx have shown great variations in scale.

Perhaps the greatest single effort toward limitation of nutrient inflow has been the reduction in the concentration of phosphates in laundry detergents. Prior to the reduction achieved in 1973, detergents had been estimated to contribute as much as 60 percent of the phosphorus in municipal sewage, and were thus a major pollutant of rivers and lakes. Concurrent with this reduction has been an increased emphasis on more complete removal of phosphorus in sewage treatment plants.

Conventional sewage treatment, known as primary treatment, is designed to remove organic materials whose decomposition in the recipient body of water would deplete oxygen stores; primary treatment typically removes less than 15 percent of phosphorus. More advanced, secondary treatment systems, such as activated sludge processes, can remove as much as 50 percent. Sophisticated, and expensive, tertiary treatment systems, which depend on chemical precipitation, adsorption, and other techniques, can remove as much as 98 percent of the phosphorus and are the techniques of choice when protection of waterways is important. Since 1968, EPA has granted more than $2 billion for construction of tertiary treatment systems for cities near the Great Lakes. The combination of the phosphate reduction in detergents and the completion of many of the tertiary treatment plants, says Charles Sutfin of EPA, is the primary reason for the recent improvements in water quality in the Great Lakes. It has also been of great

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benefit to many small lakes and streams.

Tertiary treatment is not possible, however, if wastes do not go through a central treatment plant. Sewage from homes on the shores of many lakes, for example, is treated in septic tanks rather than a central sewage-treatment plant. Septic tanks can be effective if they are properly maintained, Richard J. Otis of the University of Wisconsin told the conference; but most homeowners perform almost no maintenance. In most cases, he says, the simplest way to control effluent from the septic tanks is to organize management districts or similar organizations that take the responsibility for the systems out of the hands of the homeowner and give it to trained personnel who can ensure that the systems will be correctly sited, designed, constructed, and maintained.

Pollution from the watershed is also a problem. A study of Lake Minnetonka in Minnesota, for example, showed that the major source of phosphorus was urban debris carried by storm water runoff from the 518-square-kilometer watershed. Because of the large volume of water and the periodic nature of the flow, a treatment plant was not practical. Under a plan prepared by Eugene A. Hickok of Hickok and Associates, the storm water was routed through a marshy area, known as the Wayzata wetlands, before it entered the lake. Studies have since shown, Hickok says, that the wetlands retain 78 percent of all phosphorus in the water and 94 percent of the total suspended solids, with no measurable adverse effects on wildlife or vegetation. The nutrients appear to be removed from the storm water by a combination of physical entrapment, microbial transformation, and biological utilization. Results so far indicate that the diversion is producing a substantial reduction in algal growth in Lake Minnetonka.

In most cases, however, even a sharp reduction in the flow of nutrients into the lake cannot bring about a rapid improvement in water quality because the lake is already so overloaded with nutrients. Phosphorus dissolved in the water and trapped in vegetation and sediment can keep a lake eutrophic for years even though there is no other source of nutrients. Sediment is a particular problem because it is generally in equilibrium with the lake water: it accumulates phosphates when their concentration in the water is high and releases them when oxygen in the hypolimnion is depleted. In such cases, active intervention is necessary to improve water quality. The nature of the intervention depends on the conditions in the lake.

If sediment is not a major problem, it is possible to improve water quality in a lake by increasing the flowthrough of water, according to Eugene B. Welch of the University of Washington, thereby increasing the rate at which water in the lake is replaced. In this manner, algae and pollutants can be washed out of the lake even if the added water is high in nutrients. Dilution, which Welch says is a more desirable technique, requires increasing the flowthrough with water that has a lower concentration of nutrients than the lake water. If suitable water is available, this is an inexpensive technique because the only costs are for the facilities needed to deliver the water.

Two examples of lake restoration by dilution cited by Welch are Green Lake in Seattle and Moses Lake in eastern Washington. Green Lake received excessive nutrients from urban runoff, while Moses Lake is fed by a highly polluted creek. Low-phosphorus water from the Seattle municipal water supply was added to Green Lake so that the lake water was replaced about three times per year. Moses Lake received low-nutrient water from the Columbia River by an irrigation canal on three different occasions during the spring and summer of 1977. In each case, Welch says, the results were much better than expected and produced more than a 50 percent reduction in the concentration of nutrients in the lakes. Dilution has limited applicability, however, because there are few places where an adequate source of low-nutrient water is available.

Some Benefit from Harvesting

In most cases, then, some other way must be found to remove nutrients. One possibility might be programmed harvesting of aquatic plants and fish, which incorporate nutrients during growth. Some studies have shown, for example, that harvesting of plants from waste-water lagoons can remove 1100 kilograms of nitrogen and 200 kilograms of phosphorus per hectare in northern climates and more in the south. But in lakes, says Thomas M. Burton of Michigan State University, the amount of nutrients that can be removed by harvesting is probably less than a tenth of those values. Plant harvesting does remove substantial amounts of material that can decay and deplete oxygen in the water, he says, and it can also permit better water circulation. On the whole, though, the technique is of limited utility for nutrient removal.

Perhaps the best technique for nutrient removal is the use of chemical precipitants, agents that combine with phosphates to produce insoluble compounds that form a "floc" or "clump" that settles to the bottom, carrying algae and undesirable phytoplankton with it. In many cases, such treatment also covers the lake bottom with enough material to inhibit release of nutrients from the sediment.

The use of aluminum, iron, and calcium as chemical precipitants has been successful in waste-water treatment for more than 40 years, but the treatment of standing bodies of water is a relatively new procedure. Perhaps the first such use was in the Netherlands in 1962 when ferric chloride was applied to the Dordrecht reservoirs. Later in that decade, aluminum sulfate (alum) was used to inactivate phosphorus at Lake Långsjön in Sweden. Since then, most of the larger treatments have been performed in the United States.

Perhaps the best example of the use of chemical precipitants is Medical Lake, which has an area of 630,000 square meters. In the summer of 1977, Anthony F. Gasperino of Battelle Pacific Northwest Laboratories and Raymond A. Soltero of Eastern Washington University treated the lake with 936 metric tons of liquid alum. They used a homemade barge and application system that could release the alum on the surface or inject it directly into the hypolimnion. They made seven separate applications to the hypolimnion and four to the surface.

The results were dramatic. Water clarity increased sharply, and the total concentration of phosphates dropped by more than 80 percent. The total amount of phytoplankton dropped by more than 90 percent; undesirable species of blue-green algae were succeeded by green and flagellated species. Measurements of water quality made the following summer indicated that most of the improvement was maintained.

Similar treatments have been successful at lakes in Washington, Wisconsin, and Ohio, according to William H. Funk of Washington State University. The cost of the treatment has ranged from $150 per hectare for a light treatment up to about $350 per hectare for more polluted lakes, and the benefits have generally lasted for at least 3 years. Most of the work has been performed on small lakes, he notes, and he suggests that the technique may be useful only for lakes with a surface area less than 500 hectares.

Another material that has potential as a chemical precipitant is fly ash from power plants. Such use would solve a second environmental problem by providing a way to dispose of the ash.

Thomas L. Theis and his associates at the University of Notre Dame in 1977 applied fly ash to about 35 percent of Lake Charles, a highly eutrophic lake in Indiana. Fly ash contains free aluminum and silicon, which bind phosphates from the water. By applying the fly ash at a rate of about 740 tons per hectare, moreover, they were able to seal the bottom with a layer of fly ash 2 to 5 centimeters in thickness. Subsequent studies showed that there was little or no release of phosphorus and other nutrients from the sediment coated with fly ash. The technique needs to be studied further, however, because the fly ash contains heavy metals, which could be toxic to aquatic life if they were released from the ash.

Another alternative for lake restoration is aeration, which increases the water's oxygen content by mechanical mixing or agitation, injection of air, or injection of pure oxygen. Oxygenation is routinely used as a secondary treatment process in sewage treatment facilities and for cleaning industrial effluents, such as those from paper mills. There are also many reports in the literature about aeration of lakes, says Arlo W. Fast of Limnological Associates, Inc., but they are contradictory and confusing. Aeration can be a useful restoration option, he argues, but there needs to be a better understanding of where and when it should be used.

Aeration can be performed with or without breaking the thermal stratification of the lake. A good example where destratification has been achieved, Fast says, is the El Capitan Reservoir near San Diego. The reservoir is 62 meters deep at its deepest point, but before 1965, fish were limited to the top 8 meters because of lack of oxygen. In that year, a 31-meter length of perforated tubing was installed at the deepest point in the reservoir and connected to an electric compressor. This procedure resulted in a nearly complete destratification of the lake, caused a marked increase in the concentration of desirable phytoplankton, and permitted fish to proliferate in the entire body of water.

Hypolimnetic aeration has been used successfully in Europe for several years, but one of the first major demonstrations of the technique in this country occurred in 1973 when the Union Carbide Corporation undertook demonstration projects at Lake Waccabuc and the Attica Reservoir in New York and the Ottoville Quarry in Ohio. In all three cases, there was virtually no dissolved oxygen in the hypolimnion. In each instance, hypolimnetic water was drawn to a shore-based unit, aerated, and returned to the bottom. Air was injected at Lake Waccabuc, while pure oxygen was used at Ottoville and Attica.

Good results were obtained at all three locations, says Fast, who was in charge of the projects. Dissolved oxygen concentrations in the hypolimnion were raised to levels as high as 20 parts per million, more than enough to support life. Both Waccabuc and Ottoville were stocked with trout after the aeration project, and they survived well. At Waccabuc, furthermore, the concentration of phosphates in the water was reduced by 30 percent and a hydrogen sulfide odor in the water was eliminated. The only major potential problem with this technique, Fast notes, is supersaturation of the water with nitrogen when air is injected. Nitrogen bubbles released downstream from the lake or injection site can kill fish. This is not a problem when pure oxygen is injected.

Remove Sediment by Dredging

When the lake is extraordinarily polluted or when other techniques are not practical, the only remaining alternative may be the removal of the nutrient-laden sediment by dredging. Dredging can be an effective method of lake restoration, says Spencer A. Peterson of the EPA's Corvallis Environmental Research Laboratory, but there are several potential problems associated with it. The most important of these is excessive turbidity caused by the release into the water of small soil particles, organic molecules, and nutrients previously trapped in the sediment. These materials can create several problems.

The resuspended materials absorb sunlight and may heat the surface water to cause abnormal thermal stratification, Peterson says. As the material settles, it may remove desirable phytoplankton from the water. If there are many very small particles, or fines, in the material that is released, it may form a colloidal suspension instead of settling. Also, organic molecules, particularly synthetic organic materials such as polychlorinated biphenyls, may adhere to the smallest particles. Since these particles are the slowest to settle, the adhered pollutants tend to collect on the soil-water interface, where they may be more available to bottom-dwelling organisms because of the increased concentrations.

Many of these problems, Peterson says, can be at least partially overcome with newer dredging equipment that has been specially designed to minimize resuspension of sediments. In smaller lakes, the problem can be overcome by drawing down the lake before removing the sediment. The cost of the technique varies, depending primarily on the depth of the lake, the amount to be removed, and the accessibility of the dredging equipment. In general, though, dredging is the most expensive method of nutrient removal.

A good example of the use of dredging, says Peterson, is Long Lake, a 59-hectare lake in Oakland County, Michigan. Long Lake was highly eutrophic before a layer of sediment 1.25 meters thick was removed from the bottom between 1961 and 1965. The project, which cost $185,000 then, nearly doubled the average depth of the lake, created extensive new beach areas, and generally restored the lake to a pristine condition. There has subsequently been little further degradation. Similar success has been reported at other locations. Even with a drastic technique like this, though, there are no guarantees of success. Both Buckingham Lake and Washington Park Lake in New York were dredged in 1977, for example. A year later, Buckingham Lake has shown no significant improvement in water quality, while Washington Park Lake is clear and has far fewer undesirable plants.

To understand better why some projects succeed while similar ones fail, EPA is collecting extensive data from selected projects and requiring detailed progress reports on all projects it funds. These data will be analyzed by Peterson and his colleagues at the Corvallis Laboratory to determine which factors most influence the chances for success. This analysis is complicated, Peterson says, because each lake has unique topological features and pollution sources and because a multiplicity of techniques will generally be used at each location.

Peterson and his colleagues have selected about 20 lakes that combine the most common features of all the lakes being restored. Data from these will be analyzed by various techniques including nutrient mass balance modeling and a Lake Evaluation Index developed at the laboratory. The index combines various physical, chemical, and biological parameters to yield an objective assessment of water quality both before and after restoration. In this way, Peterson says, it should be possible to determine which restoration techniques are most successful under any particular set of circumstances, and thereby to place the art of lake restoration on a somewhat more scientific basis. And if that becomes the case, Thoreau's vision of the beauty and majesty of lakes might once more become reality.

—THOMAS H. MAUGH II