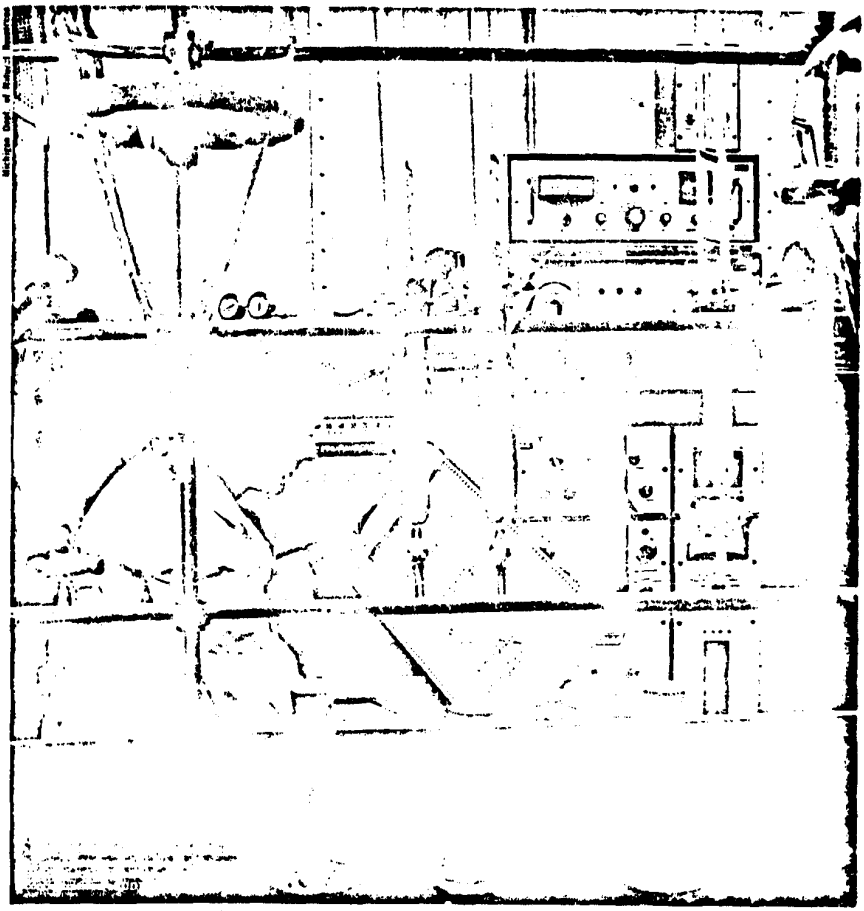

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Many long-lived pollutants have ultimate biological effects no matter how thoroughly diluted in our waterways.



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# ASSAULT ON A LAKE

By Julian McCaull

AUGUST 2, 1885 WAS A BAD DAY FOR CHICAGO. The people of the city were first knee-deep in water from a six-inch torrential downpour and later elbow-deep in raw sewage that poured out of their water taps. The two events were closely associated: Stormwaters had flushed out the sewers and carried sewage into Lake Michigan to the city's domestic water intake two miles from shore. The sewage was sucked into the intake and made the return trip to the city, through the pipes carrying the city water supply. The result was an epidemic of typhoid fever that lasted several years and that prompted a number of engineering improvements to break the sewage/drinking-water cycle.

These and subsequent improvements have counteracted waterborne diseases, but have not prevented the modern pollution difficulties that plague Chicago. The situation there illustrates serious shortcomings in current water pollution control strategy and theory which hinder our efforts to solve problems in Lake Michigan and elsewhere.

Lake Michigan pollution became serious enough in the late 1960s to prompt Illinois Governor Otto Kerner to request an interstate conference under the provisions of the Federal Water Pollution Control Act. On January 31, 1968, the first session of the conference was held in Chicago. During 1968-71, a series of 19 more sessions were held at which state and federal officials, scientists, businessmen, and conservationists talked over the problems of the lake. The objective was to formulate a series of recommendations to be endorsed by the federal government and written into regulations by the four states surrounding Lake Michigan (Wisconsin, Illinois, Indiana, and Michigan). The proceedings of the sessions, which were divided formally into three official conferences, appear in a 9,000-page, twenty-volume series which provides the basis for most of this article.[1]

Conference speakers documented a long list of ills plaguing the lake: There were industrial pollutants including oils, phenols, chlorides, sulfates, polychlorinated biphenyls, phthalate plasticizers, and many other chemicals. There was the rising level of phosphate nutrients from municipal sewage and agricultural runoff that already had produced overfertilization of inshore waters, thereby causing widespread eutrophic problems. Conditions favorable to eutrophication were intensified in the summer of 1967 by phosphate nutrients from the decaying carcasses of five billion tons of dead alewives. These small fish belong to an ocean species that was introduced into the Great Lakes by man, but which became only partially adapted to the freshwater environment



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Environmental Protection Agency

The alewife, a small ocean fish introduced into the Great Lakes by man, was only partially adapted to its new freshwater environment. In the summer of 1967 five billion tons of alewives died in Lake Michigan.

and thus particularly vulnerable to natural temperature changes. Coho salmon introduced into Lake Michigan to prey on the alewives and to provide sport fishing had acquired very high levels of DDT which made many of them unfit for commercial sale.[2] Residue levels of DDT and its breakdown products were also high in other species of fish, including lake trout, whitefish, lake herring, and carp. The problems with the fish, some experts concluded, were symptoms of serious biological changes brought about by the above-mentioned industrial, municipal, and agricultural activities and others that included the dumping of toxic dredging wastes into the lake, the discharge of hot water used for cooling in power plants, and pollution from harbor and shipping operations.

In data provided to him by the Department of Water and Sewers, Mayor Richard Daley summarized the Chicago situation:

"We know the problem of water pollution is increasing. During the past twenty years the City of Chicago has had to increase the amount of chlorine used [as a disinfectant] to achieve water safety from fifteen to twenty-five pounds per million gallons. This is an increase of 67 percent. We have had to increase the activated carbon dosage, to remove objectionable odors and tastes, from 24 to 41 pounds per million gallons, and other chemicals used to remove suspended matter from 103 to 119 pounds per million gallons. These are increases of 71 and 15 percent respectively."

The experience in Chicago has been similar to that in other urban areas of the United States.

## Diversion

A careful look at the individual ills besetting Lake Michigan, which are representative of those plaguing water resources elsewhere, reveal certain conceptual flaws in water pollution control that, until corrected, make solutions seem remote. An example of how these problems have developed began when Chicago set out almost a century ago to break the link between sewage and drinking water. The main countermeasure was something called "diversion." This simply meant—and means today—routing sewage or other polluted material away from one area, but into another. The Chicago River had received Chicago's sanitary and industrial wastes during the infancy of the city, but unfortunately that river carried the wastes into Lake Michigan, right where the city withdrew its drinking water. First, water intake tunnels were built two miles out into the lake. Then, in 1871, the Illinois and Michigan Canal was modified to force the Chicago River to carry its load of wastes the other way, into the hinterland of Illinois. It seemed in the 1870s that sewage outlet and water intake had been safely separated. By 1885, however, increased drainage into the Chicago River had forced the river back into its natural flow into Lake Michigan. This flow became a disease-bearing flood in August of that year, as we have seen. To solve this problem, a canal was opened in 1900 that joined the Chicago River with the Des Plaines River, which flowed into the Illinois River and thence into the Mississippi. As a result, the Chicago River, today bearing treated sewage and industrial wastes, flows westward into Illinois rather than eastward into Chicago's water supply.

All this seemed fine to Chicago residents, but Canadians and people living in other states bordering the Lakes feared their own Great Lakes water supplies might disappear down the Chicago River. As a result, the amount of water that Chicago could draw from Lake Michigan to force the river away from the city was limited by administrative and court decisions.

Despite parallel limitations on the amount of Lake Michigan water that can be withdrawn elsewhere in Illinois, heavily populated suburbs north of Chicago, in what has been designated the North Shore Sanitary District, have been authorized to plan similar diversion schemes to keep their waste effluents out of the lake. The systems would divert discharges from a series of primary community waste treatment plants for further treatment elsewhere and then carry the wastewater to the same drainage system that ultimately takes the treated Chicago wastes into the Illinois River.

All of this leads to the question: What happens to the wastes now being funneled into the Illinois and thence into the interior river system of the United States? Toxic materials in the wastes, such as chlorinated hydrocarbon pesticides and chemical insulators known as polychlorinated biphenyls (PCBs), are long-lived and can be carried great distances in the water.

Beyond this, the technique of diversion itself poses some serious questions. Diversion, as it has been applied over the years, has become something more formidable than a limited technique: It has developed into a concept which is widely applied to waste disposal problems. As with a number of other concepts in sanitary engineering, it has gained an established position that has yet to be fully assessed in light of modern pollution problems. In fact, the concept has been extended by modern engineering techniques to include uses far beyond the emergency needs of nineteenth-century Chicago.

As an example, one of the most elaborate extensions of the diversion idea was proposed recently by R. T. Jaske and W. A. Reardon of the Battelle Pacific Northwest Laboratories.[3] The investigators pointed out that a detailed study by Battelle scientists done for the U.S. Atomic Energy Commission showed that the reduced flow of the Ohio River, and to a lesser extent of the Mississippi, during the late summer and early fall limited the number of nuclear power plants that could be built along the rivers, since the discharge of heated cooling water from the plants would not be diluted enough during these periods of low water to meet environmental standards for stream temperature. Rather than installing expensive cooling towers or other arrangements to recycle cooling water, Jaske and Reardon proposed tapping the Great Lakes to cool the power plant condensers and at the same time to increase stream flow to dilute municipal sewage discharges. Citing the Chicago diversion as one historical precedent for their plan, the Battelle scientists pointed out that this elaborate scheme is within current technological capabilities since the engineering problems are similar to those dealt with in building the Grand Coulee



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Dam in Washington state. They favor two sites in particular. One was on Lake Erie near the inland headwaters of the Allegheny River, the other at Cleveland, also on Lake Erie. At each site, four 1,500-megawatt nuclear power plants would be built. Water would be drawn from Lake Erie to cool the condensers and then directed south, perhaps through reservoirs, to the Ohio River system to maintain an increased year-round flow in the river to accommodate other nuclear power plants. The eight 1,500-megawatt plants would discharge up to 28,000 cubic feet per second into the Ohio River system. At Pittsburgh, where the Allegheny empties into the Ohio, the minimum year-round flow of the Ohio would be some 25,000 cubic feet of water per second. This rate would be nearly twice the average low water rate that now prevails during five summer months each year.[4]

As another feature, the authors suggested diversion of Lake Superior water to the Mississippi via the St. Croix River. This, coupled with the diversion of Lake Erie to the Ohio, which flows into the Mississippi, would, in addition to assisting the nuclear power industry, benefit another proposed diversion project in the lower Mississippi. That project is the $10 billion Texas Water Plan to create a new water supply for agriculture in the West Texas highlands. The Texas Water Plan would require the diversion of some 15,000 to 22,000 cubic feet per second of the Mississippi River by canal into Texas. Increased flow of the Mississippi achieved by diversion of the Great Lakes might insure that water could be drawn off without lowering the level of the lower Mississippi and hence disrupting navigation.

The justification for the Great Lakes diversion scheme was couched primarily in economic terms, with considerable weight given to savings in municipal waste treatment costs as well as to savings in power plant equipment. The savings in waste treatment would occur because the increased stream flow from diversion would promote two other elements in the lexicon of conventional waste treatment theory. Those elements are "flow flow augmentation" and "dilution." These terms mean that when stream flow is artificially increased or augmented, it can more effectively dilute polluted water, with a greater capacity for dissolved oxygen, coincident increase in biological activity, and consequent improved degradation of organic wastes.[5] However, many long-lived pollutants have ultimate biological effects no matter how thoroughly diluted, and nutrients that survive the secondary treatment process produce eutrophication. Furthermore, the economic savings in waste treatment in the Great Lakes diversion plan are derived from reduction in the degree of planned treatment, and hence the investment necessary for treatment facilities. This reduction in investment would mean the escape of even more long-lived pollutants and nutrients since they require expensive advanced treatment for removal.

In addition, monumental hydrological, environmental, and ecological questions not considered by the authors of the Great Lakes diversion plan must be pondered. For example, sunlight might reach a greater proportion of bottom plant life in the already shallow Lake Erie, enabling the vegetation to utilize the nutrients, and thus intensify eutrophic conditions. Canals and cooling water conduits might provide a route for migration of unwanted species of fish into the Ohio River just as other manmade structures have opened the way for undesirable species elsewhere in the Great Lakes (see below).

The purpose in discussing the Great Lakes plan here is not to weigh its merits, other than to indentify some of the questions that must be answered. Rather, the plan illustrates the way in which the techniques of diversion and augmented flow, and the concept of dilution, can be carried to extremes by modern technology. Associated with the concept of dilution is that of the "mixing zone." This term refers to lateral, vertical, and longitudinal forces, particularly those caused by turbulence, that disperse pollutants to a certain concentration within a given time and area in a stream or other body of water.[6] The mixing zone concept is an important consideration in the setting of stream quality standards, which in the United States are generally determined by the allowable concentration of pollutants in the stream, rather than by permissible concentrations in waste discharges. Formulas are used to calculate the anticipated mixing and dispersion of pollutants in a given stream. This enables officials to determine, for example, whether waste discharges from a proposed industrial plant would raise pollution levels above the established standards. Although longitudinal mixing in particular can extend far downstream from the point of discharge, the area of most intense mixing is adjacent to the discharge pipe. This no-man's land of high pollution is one price that must be paid for disposing of wastes in waterways.

## Heating the Lake

This problem was stressed at the Lake Michigan conference session on March 23, 1971, by Dr. Donald I. Mount, director of the National Water Quality Laboratory, Duluth, Minnesota: "A mixing zone I feel by definition is a place where receiving water standards are not met. That is, the conditions are less than we are striving to achieve in the receiving water. . . . So the question you ultimately come to is how much sin is acceptable?"

The answer depends upon who is being questioned. The problem to which Dr. Mount addressed his comment was the degree to which heated cooling water from power plants and other industries should be permitted to warm Lake Michigan. Industrial representatives argued that there was no sin, since heated effluents would do no meaningful harm to the lake. Investigators from the U.S. Fish and Wildlife Service, on the other hand, foresaw serious damage to aquatic life and an increase in eutrophication if anything but slightly heated effluents were permitted.

As of September 1970, one nuclear and 23 fossil fuel power plants were operating at Lake Michigan. Five additional nuclear and one fossil fuel plant were under construction and scheduled for operation by 1974. An additional nuclear plant was proposed but has not yet been planned. The growth of industrial and municipal power needs, coupled with the inviting cool waters of Lake Michigan, made it clear that sites for other new plants would be requested.

The installed generation capacity in 1968 on Lake Michigan was 7,600 megawatts; the projected estimate for the year 2000 is 73,500 megawatts, of which 43,934 would be in nuclear plants. This estimate was made at the conferences by Yates M. Barber, staff assistant of the U.S. Bureau of Sport Fisheries and Wildlife on the basis of projections developed in a Canadian study[7] and by the U.S. Federal Power Commission. Mr. Barber added that the output of waste heat at full capacity would be 414.67 billion BTUs per hour in 2000, nearly 14 times the BTU output in 1968. Furthermore, the total volume of water discharged from the plants in the year 2000 would be equal to a stream heated 20 degrees F. above the existing lake temperature and flowing into the lake at a rate of 91,000 cubic feet per second. This flow, over a year's time, would be equivalent to a sheet of hot water 4.6 feet deep covering the entire 14.3 million acres of the lake surface.

The effect of this heat on Lake Michigan was estimated by an interstate committee on thermal waste established during the Lake Michigan conferences. Allowing for loss of heat from the discharges due to evaporation, convection, and radiation to the atmosphere, the committee estimated that by 2023 generating power capacity would have increased enough to raise the annual average temperature of the entire volume of the lake 2 degrees F., or from the 1969 average of 50 degrees to an average of 52 degrees. The magnitude of that increase, which was termed a conservative estimate by the committee, is clear if one compares it with natural temperature change in the lake. During the past 50 to 80 years, the temperature of the lake actually has declined by two degrees,



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apparently from natural causes. committee's projection means that in about the same length of time, human activities could nullify the natural change by raising the average temperature two degrees.

Though theoretically possible, this prediction assumes that the heat from the discharges will be mixed evenly throughout the entire volume of Lake Michigan. This in fact would not happen under present circumstances since the heat discharge is limited generally to nearshore areas. The point is that man's activities now have the theoretical capacity to alter natural conditions in water on a scale hitherto reserved to nature.

Furthermore, the theoretical change predicted by the committee was particularly conservative since only heat input from power plants was considered. Large amounts of heat also are injected into Lake Michigan from industrial and municipal

**The early patterns of thinking about waste disposal persist today with only a token integration of the insights provided by the biological sciences.**

activities. Representatives of state and federal fish and wildlife services estimated at the conferences that of 40.43 billion BTUs of heat per hour added to Lake Michigan by certain human activities in 1968, 10.58 billion BTUs, or about 25 percent of the total, were discharged from steel plants and municipal waste treatment facilities. The rest were in discharges from power plants. By the year 2000, according to the estimate, the heat input from those two non-power plant sources will have increased to 16.1 billion BTUs. This amount will be a proportionately smaller part of the total 430.77 billion BTUs per hour from all the activities in 2000, however, because of the far greater relative increase in heat input from power plants expected during 1968 to 2000.

The official conferees from the federal government and the four states surrounding Lake Michigan concluded, on the basis of the evidence presented, that although warming throughout the lake as a whole would not occur, waste heat discharges from the increasing number of power plants might warm a large fraction of the inshore waters several degrees. Furthermore, the interaction of two or more thermal plumes might intensify biological effects more than anticipated. The conferees determined that a single large plant discharging into a spawning ground or across a migratory route could disrupt the balance of the affected species not just there, but throughout the lake. They also agreed that an unknown percentage of aquatic organisms such as adult fish, fish fry, and plankton would be killed by heat, physical damage, or chemical poisoning when they passed through the cooling system of the power plants after being sucked into the intake. The conferees could not agree on a solution, however. The U.S. Environmental Protection Agency finally endorsed the position, proposed by the federal conferees, and initially by conferees from three of the four states, that at a maximum distance of 1,000 feet from the discharge the receiving water temperature should be no more than 3 degrees F. above the natural temperature of the lake. In addition, the near-surface temperature 1,000 feet from the pipe should not exceed specified readings established for each month to prevent excessive heat during critical periods in the life cycles of aquatic organisms. Requirements would also compel the construction of closed cycle cooling systems in large new power plants, as well as in some already in operation or under construction. As of this writing, only Indiana has subsequently agreed to the federal proposal. Wisconsin, Michigan, and Illinois now propose closed cycle systems solely for large power plants not yet under construction, not for those now in operation. Environmental Protection Agency officials hope to resolve the differences in a reconvened conference this September.

Even if the stricter control is ultimately enforced, it still will embody the mixing zone concept. In the face of uncertainties about the effect of thermal pollution, federal and state conferees at the Lake Michigan conferences fell back on this concept. In other words, by setting the temperature standard at a point 1,000 feet from the point of discharge, they gave the nod to the conventional practice of establishing a certain zone for wastes to disperse into water, even though their own findings pointed to the danger of localized damage from thermal pollution. The question "How much sin is acceptable?" raised by Dr. Mount thus was answered from the point of view of traditional waste disposal practice rather than from any comprehensive, underlying biological understanding.

## Radioactive Wastes

The cooling waste water discharge from the nuclear power plants at Lake Michigan also will contain other pollutants that defy the mixing zone concept. These are the radioactive wastes from the pressurized or boiling water reactor systems employed in the seven existing and/or proposed plants. Radioactive wastes produced at various points in the nuclear power plant system will be removed for treatment and disposal. The high-level wastes will be shipped off to land-disposal sites, but low-level, liquid wastes will be treated and eventually discharged with the cooling water. Among the radionuclides injected into the lake will be some which are potentially serious health threats, such as long-lived cesium-137 and the much shorter-lived iodine-131. Officials estimated that the total radioactivity of radionuclides thus discharged from the seven power plants will be about one curie per year. This estimate was exclusive of tritium, or radioactive hydrogen, which is a lesser health hazard and is not removed from the waste water.

Current federal regulations would permit an annual average of some 490,000 curies of radioactivity if mixed throughout the entire volume of Lake Michigan, according to estimates by the Committee on Nuclear Power Plant Waste Disposal established during the conference. The one curie per year level predicted for Lake Michigan power plant discharges thus seems inconsequential. This assumes, of course, that no nuclear accident occurs. "One serious nuclear accident on the shore of Lake Michigan," said F. W. Kittrell of the U.S. Department of the Interior, chairman of the committee, "although highly improbable, could release large quantities of long-lived radioactive materials into Lake Michigan where it would be uncontrolled and could have very serious effects on future use of the lake."

Barring such a catastrophe, the accumulation of radionuclides in the lake could still have serious effects. This was articulated at an earlier session of the conferences by R. J. Schneider, deputy regional director with the Federal Water Pollution Control Administration (now the Federal Water Quality Office): "The particular concern for Lake Michigan arises from the fact that it has a very small discharge rate, and any radioactive material entering into the lake will diminish only by natural decay. This may result in significantly increased levels of the longer-lived radioisotopes."

The rate at which the radionuclides accumulate also could be greater than indicated by the official estimate of a total of only one curie of radioactivity per year from the Lake Michigan nuclear power plants. That estimate may be overly optimistic on the basis of experience at six relatively small nuclear power plants which went into operation elsewhere during 1961-64. Four of the six plants discharged from 1.3 to 11.1 curies of radioactivity per year apiece," Mr. Kittrell observed. This indicates that the much larger nuclear power plants at Lake Michigan might have considerable difficulty meeting the official projection of a total of only one curie per year into the lake.

Nevertheless, the radioactive content of



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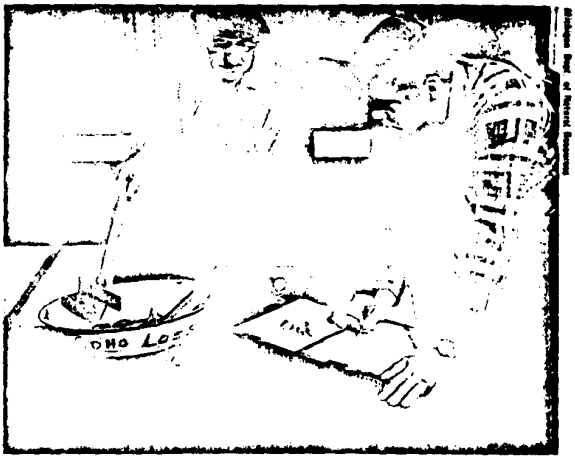


At right, counting the loss of coho salmon in the Wolf Lake Hatchery in 1968.

material dispatched into the lake each year still would be well within legal limits. The difficulty is that the long-lived portion of this material will persist in the lake, as pointed out by Mr. Schneider, and could produce a cumulative rather than an immediate threat. This would occur by concentration along the food chain, the same inexorable process that concentrates DDT from very small quantities in the water into much larger and more lethal quantities in higher animals. Treated radioactive wastes will be diluted in the cooling water discharge at carefully calculated rates to reduce radioactivity intensity below that permitted by U.S. Public Health Service drinking water standards. But biological magnification with respect to concentration will counteract the dilution process. Warned Mr. Kittrell: "There is a possibility of concentration of radioactivity locally in the aquatic life that serves as the food chain for fish, with a potential hazard to those who eat fish from the lake." He quickly added: "Experience with wastes from smaller nuclear power plants discharging to streams in Illinois and Wisconsin and to the lake in Michigan has not revealed such a problem, but it is one that must be evaluated when the larger plants go into operation on the lake."

## A Chemical Reservoir

The difficulty is that evaluation after the contaminants have been released could mean that the problem will become serious before it is officially acknowledged. This is illustrated by the pattern of damage from other long-lived contaminants, namely pesticides, in Lake Michigan. Even at the time DDT and its breakdown products were barely detectable in the waters of Lake Michigan, the chemical poison had accumulated to serious values in fish. This occurred after the pesticide was taken up by lower forms of animal and plant life in the lake. Each successively higher animal then fed on many pesticide-containing organisms from lower levels in the food chain; the food was metabolized and excreted, but the pesticides were retained. This led to a greater concentration of the chemicals in the higher animals than in the individual organisms that the animals ate. Ultimately, the greatest concentration of the chemical occurred in the animals highest in the food chain.

An average of nineteen parts per million (ppm) of DDT residues in canned Lake Michigan coho salmon prompted the Food and Drug Administration (FDA) to ban 32,000 pounds of the fish product from interstate commerce in 1969.[2] The action was particularly discouraging to Michigan wildlife officials who had sponsored a seven million dollar program to stock the salmon in Lake Michigan as a replacement for the lake trout. The lake trout was a large fish that was commercially important in Lake Michigan until the late 1940s, when its numbers were decimated by the parasitic attack of sea lampreys, fish that had worked their way up through the Great Lakes from the ocean.

The DDT in the salmon has not only made it unfit for eating, the pesticide also has been implicated in the reduction of the breeding capacity of the fish—another chapter in man-induced alterations of the biology of Lake Michigan. In 1968, coho fry tested by Michigan Department of Conservation scientists showed typical symptoms of pesticide poisoning, and larger than anticipated losses of young fish occurred in the hatcheries, according to Dr. Ralph A. MacMullen, director of that department. He told the February 6, 1968 session of the Lake Michigan conferences that:

"The concentrations are very close to those which have been shown to affect lake trout survival in some eastern states. And they actually exceed those which have been shown in British Columbia research to affect coho salmon under some conditions. We most certainly are close to the danger point. And we most certainly cannot stand a build-up."

Yet the build-up occurred, and seems unlikely to drop sharply for some time, despite bans on most widescale uses of DDT instituted after 1968 in Michigan and Wisconsin. In 1970, for example, coho salmon tested by the Great Lakes Fishery Laboratory had average DDT concentrations of 14.1 ppm. The average for 19 lake trout was 19 ppm, with the range from 11 to 28 ppm. These and other tests showed no downward trend from concentrations in past years, reported Dr. Donald I. Mount, director of the National Water Quality Laboratory in Duluth and chairman of the Lake Michigan Interstate Pesticide Committee, another body formed under the auspices of the Lake Michigan conferences.

The 1970 Great Lakes Fishery Laboratory tests also revealed an average dieldrin concentration of 0.27 ppm in the lake trout and 0.12 ppm in the larger coho salmon. These averages exceeded the maximum recommended value for this pesti-



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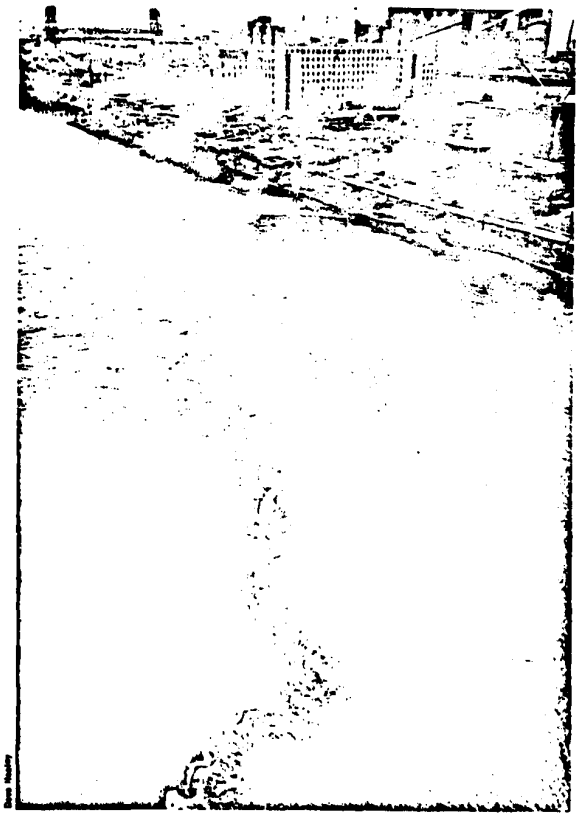

Detergent water flows from a hospital in New York City into the East River.

cide, a chemical cousin of DDT, which was set at 0.1 ppm in fish by Dr. Mount and colleagues. The FDA actionable level was set at 0.3 ppm, a value exceeded in a number of the fish tested by the Great Lakes Fishery Laboratory. The persistent levels of chlorinated hydrocarbon pesticides like DDT and dieldrin, despite closer regulation of the chemicals, is attributable to a number of factors. One is the presence in the environment of a widespread reservoir of the durable chemicals that has built up during the years since World War II and that will be with us for many years to come." Another is related to the age and growth of the fish tested, a factor that will be hard to assess until younger fish are examined in the coming years.

The chemical reservoir in the environment is the critical factor in the extent of long-term damage that will be done. Local bans on DDT use are only partial barriers to influxes from this reservoir. To give one illustration, Wisconsin investigators analyzed clams and other invertebrate animals near the mouths of rivers flowing into Lake Michigan and Lake Superior. In certain locations, they discovered somewhat high levels of dieldrin and set about to track down the upstream sources of the pesticide. In one case, the source turned out to be a wool-dying operation. Dieldrin was used to mothproof the wool, and some of the chemical was washed into the plant's sewage system and subsequently into a stream. Plant officials stopped using dieldrin for moth proofing, and everyone thought all would be well. New tests, however, indicated that lesser amounts of dieldrin were still in the plant's

**Man's activities now have the theoretical capacity to alter natural conditions in water on a scale hitherto reserved to nature.**



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effluent even though the pesticide was no longer used in the building. The puzzled investigators finally tested the virgin wool shipped into the plant for dying and discovered that it contained traces of dieldrin. They concluded that the wool had become contaminated even before it was sheered from the sheep's back, probably when the range animal was routinely treated with a dieldrin-containing disinfectant mixture.

Now, new chapters are being written in man's creation of environmental reservoirs of dangerous, long-lived materials. One has been created unwittingly by the accidental release of another chlorinated hydrocarbon called polychlorinated biphenyls, or PCBs for short. This material has been utilized for a number of industrial purposes, and now is widespread in the biosphere and has been concentrated along the food chain as has DDT.[10] In his report on the 1970 pesticide assays in Lake Michigan, Dr. Mount pointed out that lake water samples examined in one laboratory contained 50 to 75 parts per trillion of PCBs. By comparison, studies in the late 1960s by the Michigan Water Resources Commission indicated that the concentration of DDT was nearly always less than 10 parts per trillion in open lake water.

Concentrations of PCBs along the food chain already have been found in marine life, sea birds, and birds of prey.[11] The hazard of PCB is not yet completely understood and may be complicated by the fact that some PCB mixtures, especially those manufactured in Europe and Japan, appear to be contaminated with trace amounts of toxic impurities. Although concentrations in the environment are much smaller than those that are a direct threat to human health, levels of only a few parts per billion are toxic to some marine crustaceans, mollusks, and fish. The chemicals have affected the reproductive system in some birds, although apparently not as markedly as has DDT, and laboratory tests have shown that concentrations as low as 10 to 25 parts per billion inhibit the growth of two types of one-celled algae found in the ocean.[12] The environmental hazard is increased by interaction between PCBs, DDT, and other chlorinated pesticides, producing an effect that is greater than that caused by one of the chemicals alone.[13]

As to Lake Michigan, Dr. Mount concluded that "PCBs are probably a significant contaminant." He also warned of the need to investigate the effects of still other chemicals called phthalates, which are accumulating in the lake. These substances are widely used as plasticizers to impart flexibility to polyvinyl plastics. They also have been used in insecticides.[14] Their capacity to become concentrated along the food chain in the same fashion as DDT, even though chemically different from DDT, has been established at the Fish-Pesticide Research Laboratory in Columbia, Missouri.[15] Although the chemicals were of fairly low direct toxicity to fish, in tests at the laboratory levels as low as 3 parts per billion reduced the growth and reproduction rates of certain crustaceans. Dr. Foster Mayer, Jr., and colleagues at the laboratory said:

"Although phthalate esters cannot be impugned as an environmental hazard, their subtle effects on aquatic organisms resulting from long-term, sub-acute exposures is unknown . . . there are indications that these compounds can be detrimental to aquatic organisms at low chronic concentrations."

## Conclusions

The biological concentration of these various long-lived contaminants defied the concept of dilution upon which much waste disposal engineering rests. Thus, cesium-137 discharged from the Zion nuclear power plant north of Chicago, although diluted in the cooling water discharge, will be concentrated in vegetation watered by Lake Michigan and further concentrated by livestock that feeds on the vegetation. Or minute quantities of cesium-137 in the water will be concentrated some 9,500 times in the bodies of sunfish, some 3,000 times in the bodies of carp.[16] In any event, the radioactive potential of the material will be passed on to man at some point in the food chain even though the level of radioactivity in his drinking water is kept very low. Direct damage to the human body from ionizing radiation received in this way is probably not a threat; cumulative damage such as inducement of cancer over a long period of time is an uncertain possibility; some genetic effects that will affect human offspring in one way or another are a certainty that must be weighed against the benefits of nuclear power. In regard to the latter effect, authors of the definitive book *Water Quality Criteria*, prepared for the California Water Quality Control Board, said:

"For genetic effects, however, there appears to be no possible threshold dose below which some effect may not occur. Any amount of radiation, no matter how small, is bound to produce some mutations. Once completed, mutations are irreversible and almost all mutations are deleterious. Irradiation of a population from any source is bound to have some genetic consequences."[17]

The potential damage to human health is difficult to quantify, as is that from biological concentration of long-term pesticides, PCBs, phthalates, and a host of organic and inorganic chemicals that are accumulating in the environment. The important aspect here is that the history of the durable manmade pollutants reveals the multitude of ways in which nature reincorporates our wastes back into living systems, for better or for worse. The complexity of this biological process was far from the minds of sanitary engineers desperately struggling to devise a method to keep disease-bearing excrement out of Chicago's drinking water in 1885. Yet the early patterns of thinking about waste disposal persist today with a token integration of the insights provided by the biological sciences. Often enough, it is only when the damage has been done that biological investigation is instituted, even though by then it is already too late, as in the insecticide decimation of bird populations, or even more seriously, radiation-induced genetic changes in human beings. Today's technology of water pollution control is based on pragmatic concepts that need thorough reevaluation if a comprehensive science is to be developed. □

This article is drawn from Water Pollution, the second in a series of books entitled Environmental Issues by Virginia Brodine and other Environment staff members, and will be published by Harcourt Brace Jovanovich.

## NOTES

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