Review of recent technical information concerning the adverse effects of once-through cooling on Lake Michigan

Prepared for the
Lake Michigan Enforcement Conference
September 19-21, 1972, Chicago, Ill.

by
Thomas A. Edsall and
Thomas G. Yocom

U.S. Fish and Wildlife Service
Bureau of Sport Fisheries and Wildlife
Great Lakes Fishery Laboratory
Ann Arbor, Michigan 48107

September 19, 1972
Revised November 1, 1972

ARLIS
Alaska Resources
Library & Information Services
Anchorage, Alaska
CONTENTS

Introduction

Effects of water intakes
  Mortalities caused by impingement of fish on intake screens
  Mortality of fish that are too small to be impinged on
  intake screens
  Potential entrainment of fish fry at intakes of the Cook
  and Palisades plants
  Potential mortality of whitefish fry

Effects of discharges
  Concentration of fishes by heated effluents
  Mortality of fish concentrated by heated plumes
  Entrainment of fish fry in discharges
  Facilitation of predation
  Effect of elevated temperatures on incubating eggs of lake
  herring and lake whitefish
  Effect of temperature on the reproductive success of yellow
  perch and other fishes

Disease
  Concentration of pollutants by fish
  The effects of temperature on phosphorus release from Lake
  Michigan sediments
  Planktonic algae
  Zooplankton
  Periphyton and benthic invertebrates
  Chlorine

Acknowledgements

Bibliography
INTRODUCTION.

The report entitled "Physical and ecological effects of waste heat on Lake Michigan" presented at the Lake Michigan Enforcement Conference in 1970 provides the general basis for the present report. This earlier report established the critical nature of the beach zone waters in the fishery productivity of the lake, presented evidence to show that these waters were biologically and physically discrete from the deeper offshore waters, and focused attention on the fact that all cooling water withdrawals and waste heat discharges occur in the beach zone. The report also showed that the volume of the beach zone waters is small—only about 4.4 cubic miles or 6.8% of the volume of the entire lake—and therefore that the impact of withdrawal of water and discharges of heated water would be quickly felt.

The 1970 report showed clearly that the potential for damage to this shallow water ecosystem by the electric power generating industry, which is the major user of cooling water on Lake Michigan, is indeed great. The projections presented showed that by the year 2000 the cooling water requirements of the electric power industry located around Lake Michigan would be 91,000 cubic feet per second, and that this rate of use would require passing about 1% of the beach zone water of the entire lake through the cooling system of power generating plants daily. The report also described in detail the kinds of immediate and long-range effects that were expected to occur as a result of the use of Lake Michigan waters for the dissipation of waste heat by once-through cooling. Subsequent
studies have substantiated the existence of most of the effects that could reasonably have been expected to occur and be measured within a 2-year period.

The information presented by the Department of Interior and other agencies and groups at the 1970 Lake Michigan Enforcement Conference, at state thermal pollution hearings, at meetings of the Lake Michigan Enforcement Technical Committee, and in the present paper, reasonably demonstrates that the use of Lake Michigan for the dissipation of waste heat by once-through cooling will create a situation that by the year 2000 will be intolerable and perhaps irreversible. Serious damage to the Lake Michigan ecosystem, including the destruction of fishes and fish food organisms and the acceleration in the rate of eutrophication of the inshore waters is already occurring.
EFFECTS OF WATER INTAKES

Mortalities Caused by Impingement of Fish on Intake Screens

Fish mortalities in generating plant cooling systems are extremely heavy under certain conditions and in certain areas. Upon entry the fish encounter one or more sets of screens. The first set, which may be in the mouth of the intake pipe or structure, generally is not designed to prevent the fish from being drawn through the intake ports and into the cooling water system. Fish and other objects that pass through the intake ports (and screens or grates, when present) next encounter a coarse "trash screen" that is within the plant proper. Most trash screens are fixed installations consisting of a set of parallel vertical bars spaced several inches apart. Fish and other objects that collect on the trash screen are removed manually or with a mechanical rake and disposed of on land. Fish and other objects that pass through this coarse trash screen immediately encounter a fine-mesh (usually about 3/8 inch) vertical traveling screen constructed of woven wire that is designed to remove anything that is too large to pass easily through the heat exchanger tubes. Fish that reach but cannot pass through the trash screen and the vertical traveling screen are impinged upon the screens because of the high water velocity at these points in most generating plant cooling systems, and remain there until the screens are cleaned. The frequency of cleaning is generally a function of the amount of material collected on the screens; consequently the interval between the time a fish is impinged upon the screen and the time it is removed by the cleaning device may vary from a
minute or less to a few hours or more. Screen-cleaning devices and modes of operation of the screens in existing plants, for the most part, are not designed to prevent mortality of fish trapped on the screens. Typically, fish trapped on the intake screens of the Great Lakes generating plants are collected along with other debris and either disposed of on land or returned to the lake in a manner that almost certainly results in their death.

Few published estimates of the numbers of fish drawn into plant cooling systems and impinged upon screens are available because such studies have not been conducted or because the results have not been made public. A picture of the potential severity of the entrainment and impingement of fish upon generating plant intake screens is just now starting to emerge, and apparently is causing widespread concern.

The record of impingement fish kills at the Indian Point generating plant on the Hudson River in New York (U.S. Atomic Energy Commission, 1972c) gives insight into the magnitude of the problem at one plant and an idea of the apparent difficulty of finding a satisfactory means for protecting fish from being killed in once-through cooling systems. Although early records for the Indian Point plant appeared to be inadequate to demonstrate the true magnitude of the impingement kills, these records show that kills large enough to cause the company to expend considerable sums of money to correct the situation occurred as early as March 1963 and apparently were repeated in the years following. Some mortalities were recorded in 1967. In the 67 days from November 6, 1969, to January 11, 1970, 1,310,345 fish were killed on the plant intake
screening. Although most of the fish were white perch, 137,649 were striped bass. In early January 1971, 75,000 white perch, striped bass, and other species were killed in several days while two pumps were being tested. When two of the six circulating pumps on unit number two were tested in late February 1972, the Applicant removed 30,000 to 40,000 white perch per day from the intake screens and the total estimated kill during the 4- to 5-day test period was 150,000 to 175,000 fish. Of the fish reported killed at Indian Point, more than 60% were white perch; 22 other species were represented.

The Consolidated Edison Company, which operates the Indian Point plant, was fined $1,638,160 for the fish kills that occurred from January 11 to February 26, 1972 (Sport Fishing Institute, 1972). According to the U.S. Atomic Energy Commission (1972a), the estimated impingement kill for the new unit at the Indian Point station will be 437 to 593 pounds (about 30,000 to 38,000 fish) per day, if that plant is permitted to operate.

Several mortalities of fish drawn into generating plant cooling systems have been recorded in Long Island Sound. An estimated two million young menhaden were reported killed in August and November of 1971 at Waterford, Conn. (unpublished data, Monitoring and Data Support Division, U.S. Environmental Protection Agency); at least two truckloads of fish (mostly small menhaden, but also including a few small white perch) were killed at the Port Jefferson (N.Y.) generating plant on January 26-28, 1966 (Jensen, 1970); and a heavy entrainment of young herring was reported in the winter of 1952 at the Glenwood Landing, N.Y., power generating plant (Buffalo News, December 9, 1952).
Records of fish kills resulting from impingement on intake screens of plants drawing water from the Great Lakes have been difficult to locate, but we have compiled what we believe is almost certainly an incomplete list. No records of mortalities resulting from impingement of fish on intake screens were found for intakes drawing water from Lake Superior or Lake Ontario. Records of such mortalities at water intakes in Lake Huron, the Detroit River, Lake Erie, and Lake Michigan are presented below.

A fish kill at a generating plant at the mouth of the Saginaw River on Saginaw Bay, Lake Huron, was observed in December 1970 (Jackson, 1971). The kill was attributed to the discharge of fish from the intake screens on which they were impinged into a canal in which the water temperature was 17° F warmer than the 32° F intake water temperature. The duration of the kill was unknown but an estimated 4,760 distressed, severely distressed, and dead fish (mostly gizzard shad, but also including rainbow smelt, suckers, carp, shiners, channel catfish, bullheads, crappies, pumpkinseeds, and yellow perch) were observed on December 6. No attempts were made to determine the total number of fish stressed or killed on December 7-10 or to determine if the mortality continued beyond December 10.

According to the Detroit Free Press (Oct. 2, 1965) heavy fish kills at the Saginaw-Midland water intake in the summers of 1963 and 1965 were reported at a meeting of the Michigan section of the American Waterworks Association. In 1963 the stationary screens at the intake
were reported to be almost completely plugged with alewives, and in 1965, when the plant was pumping 50 million gallons of water per day, 2,499 gallons of fish (mostly alewives) were removed during plant operations in June and July. As many as 430 gallons of fish were recorded in one day.

An estimated 2 to 3 tons of fish died from mechanical causes on November 11-13, 1952, when a large run of gizzard shad from the Detroit River entered the intake pipe of the Parke-Davis Company plant in Detroit (Miller, 1960).

The Buffalo News for December 8, 1955, reported that enough gizzard shad had entered the intake pipe of the Pennsylvania Electric-plant on the shores of Lake Erie to cause a one-hour power failure.

About 60,000 emerald shiners were killed on April 2, 1972, after they were drawn into the intake of a generating plant in Erie Harbor at Erie, Pa. (unpublished data, Monitoring and Data Support Division, U.S. Environmental Protection Agency).

Large mortalities of a number of species of fish have been observed at the Detroit Edison Company's Monroe plant on Lake Erie (Memorandum from J. Truchan, Michigan Water Resources Commission, to F.B. Frost et al., May 1, 1972). On April 7, 1972, Michigan Water Resources Commission personnel collected and weighed a total of 1,357 pounds of fish which apparently represented that day's catch of fish from the intake screens of that plant. Additional fish that had overflowed the collection basket were not weighed. The estimated species composition by weight was yellow perch, 60%; carp and goldfish, 20%; and forage fish and others, 20%. 
Because the screens operate automatically at this plant, Commission personnel were unable to determine the time interval that had elapsed since the screens were last cleaned. However, a Detroit Edison employee studying the problem apparently removed and weighed all fish killed on the screens on April 4-6. He reported collecting 300 to 600 pounds per day during this period. The Michigan Water Resources Commission Report stated that ordinarily these fish are removed from the screen, pumped into a sump well, and then automatically ground up and pumped into the plant's ash pit.

One of the earliest reports of a fish kill at water intakes in Lake Michigan is a description of the alewife problem at the Waukegan generating station at Waukegan, Ill. (Danson, 1967). This report described the sometimes massive impingement of alewives on the plant's vertical traveling screens and the plugging of condenser tubes by alewives that had bypassed the screens as a result of a construction defect in the screen assembly. The report stated that alewives were impinged on the screens May 18-June 18, 1961; May 7-11, 1962; for an unstated period in 1963 beginning on May 6; and May 5-July 11, 1964. The chlorination of the intake water was apparently responsible, in part, for the massive impingements that occurred on certain dates. Further kills were reported in 1965 and 1966 (Sally W. Jones, Chicago Tribune, letter of August 11, 1972, to T. Edsall): In 1965, alewives jammed the intake of the Waukegan power plant and caused a large generator to burn out (Chicago Tribune, issue of February 8, 1966); and on April 27, 1966, so many alewives entered the Waukegan plant that one 204,000-kilowatt generating unit had to be shut down completely and two others operated at only 50% capacity.
Alewives have also been reported entering water intakes of two steel companies (Sally W. Jones, letter of August 11, 1972, to T. Edsall). They entered the intakes of U.S. Steel Corporation's Gary (Ind.) Works in spring 1966 in sufficient numbers to sink a net strung across the mouth of the intake; a steel cable was finally required to resuspend the net. Inland Steel Company's Indiana Harbor Works has also experienced difficulty with fish (presumably alewives) and at times has had to shut down all 12 condensers at their Lake Michigan pumping station to rid them of fish. Inland Steel reduced the severity of the kills by installing a net across the pumping station inlet.

Operating records on file at the Chicago Central District Water Filtration Plant indicate occasional heavy fish kills there and at the South Plant. During April and May 1965 as many as 30,000 pounds of adult alewives (about 450,000 fish) per hour were removed from the vertical traveling screens of the Central District Plant during daily peak periods. Alewives also have repeatedly clogged the water intake screens at the South Filtration Plant, where a total of 407,000 pounds of fish were removed from 1965 through 1972. Fish loads usually reached a maximum during early May, except in 1969 when the peak was on July 21. The annual kill ranged from 21,000 pounds in 1965 to 123,000 pounds in 1971 and averaged about 51,000 pounds per year.

A study conducted by the U.S. Environmental Protection Agency (1972) in November 1971, to determine the rate at which eggs of lake whitefish and lake trout were drawn into the cooling water intake of Big Rock Power Plant at Charlevoix, Michigan, revealed that "many ripe male lake trout"
were drawn into the intake of this plant. The actual numbers of lake trout observed in the intake forebay was not given nor was the fate of these fish discussed. Few fish were taken in the pumping device used to sample the intake water for fish eggs, but the 3-inch-diameter suction hose used for sampling was probably highly unsuitable for collecting fish. Nevertheless, the one sucker and two chubs captured on November 9 represented a potential 24-hour plant intake of about 150 suckers and 300 chubs.

A continuation of this study at the Escanaba (Mich.) Power Plant, November 30-December 4, 1971, resulted in a catch of 37 smelt on November 30. Expansion of this number to include the total inflow suggested that about 1,000 smelt were drawn into the plant during the 8-hour sampling period on November 30 and that about 3,000 smelt could have been taken into the plant during the 24 hours of plant operation encompassing that sampling date. Since the data in the Environmental Protection Agency report did not include the size of the suckers, chubs, and smelt taken in the Big Rock and Escanaba sampling operations, we were unable to determine whether these fish were large enough to have been impinged on the plant screens.

A massive fish kill caused by impingement on screens and clogging of condensers occurred in late January and early February 1971 at the Consumer Power Company's Campbell plant on the eastern shore of Lake Michigan (Memorandum from J. Truchan, Michigan Water Resources Commission, to F.B. Frost et al., February 17, 1971). Michigan Water Resources Commission personnel investigating the incident determined that (1) the
kill, first reported to them on February 4, had been in progress for the previous 7 to 10 days; (2) several hundred thousand fish had been killed by impingement; (3) these fish were mostly gizzard shad, but alewives and yellow perch were also killed; (4) the dead fish had been discharged into the outlet canal and washed back into Lake Michigan; (5) dead fish were not visible in the 10 to 20 acres of ice-free open water around the mouth of the discharge canal on February 4; (6) similar problems of fish impingement on the plant's traveling intake screens have occurred in other winters at the Campbell plant; and (7) on these occasions the fish were also disposed of in the discharge canal. The problem was attributed to the recirculation of warm effluent water to prevent ice formation at the intake. An area of warm water more than a mile long was created, which apparently acted to attract fish into the area where they could be drawn into the plant.

Information on the impingement of fish on the intake screens of the Palisades plant (near-South Haven, Michigan) in 1972 was made available in a document (Consumers Power Company, 1972) filed with the U.S. Atomic Energy Commission on July 1, 1972, and was very recently made available in part to other agencies. A portion of the information was also presented at the 1972 annual meeting of the American Fisheries Society on September 10 by Dr. Robert Benda, Biology Department, Aquinas College, Grand Rapids, Mich. (Benda, 1972).

Fish were collected from the screens during two periods by different workers. Data were collected by plant maintenance personnel with the
assistance of the company's aquatic biologist from January 23 to May 15, 1972 (Consumers Power Company, 1972). During this 114-day period, 2,220 fish of 14 species were removed from the intake screens of the plant. Among these were 967 alewives, 927 sculpins (presumably slimy sculpins), 103 yellow perch, 68 smelt, 5 lake trout, 11 rainbow trout, and 3 salmon. Subsequent collections were made by Consumer Power Company's environmental study personnel (presumably including Dr. Benda), who were stationed at the site from May 16 to August 25 (Benda, 1972). In this 102-day period a total of 51,235 fish of 17 species (weight, 4,995 pounds) were removed from the plant screens. Included were 28,272 alewives (2,262 pounds), 8,608 yellow perch (2,085 pounds), 7,343 slimy sculpins, 4,738 spottail shiners, 1 chinook salmon (13 pounds), 14 lake trout, and 1 brown trout.

Some of the fish were partly decomposed and were apparently dead before they were drawn into the plant; most of the others, which were presumably drawn into the plant alive, had suffered mechanical damage ranging from open wounds to descaling and hemorrhaging, and some of these were dead when they were removed from the plant screens.

The plant was in almost continuous operation from May 16 to August 25 with an intake flow of 405,000 gpm (Benda, 1972) and the numbers of fish removed from the plant screens were probably representative for that portion of the year. Evaluation of the kill data for January 23 to May 15 is difficult, however, because information on the volume of water pumped through the plant cooling system was not given. That the plant was not in continuous operation during this earlier period is suggested by a comparison of the numbers of fish collected from the plant screens...
in the two periods with information on the seasonal distribution and abundance of fishes in southern Lake Michigan (Wells, 1968).

The sampling period of May 16 to August 25 coincided reasonably well with the periods of heavy or peak abundance of hickories, smelt, trout-perch, and adult yellow perch in water 18 to 30 feet deep in southeastern Lake Michigan, as shown by Wells (1968). The peak abundance of slimy sculpins, however, occurs in February through mid-April at the 18- to 30-foot depth range (Wells, 1968); consequently, the large catch of sculpins reported by Benda (7,343 fish with the peak catch in early June) suggests that extremely heavy annual entrainment mortality could be expected for this species, with peak impingement occurring during the winter and early spring at the Palisades plant. (Evidence for heavy winter entrainment of slimy sculpins at the Point Beach generating plant near Manitowoc, Wis., is presented later in the present report.) Although sculpins ranked second in the winter mortality reported at Palisades (Consumers Power Company, 1972), the numbers reported to have been entrained were much lower than would have been anticipated, in view of the large numbers taken in early June (Benda, 1972) and the data of Wells (1968).

A substantial portion of the time of heavy to peak abundance of adult alewives (age I and older) in water 18 to 30 feet deep in southeastern Lake Michigan also precedes the sampling period reported by Benda (1972). The data of Wells (1968) show that adult alewives were scarce or absent at these depths on March 11, but reached nearly peak abundance for the entire year on April 15 and May 5. With the exception of the combined
catch of 280 alewives on February 4 and 5, most (62%) of the 967
alewives taken before May 16 were captured on April 24 through May 15.
Thus although alewives appeared at about the expected time in the catches
made before May 16, the numbers of these fish reported were considerably
lower than would have been expected from the data on seasonal trends in
abundance for this species as shown by Wells (1968) and the catches made
after May 15 reported by Benda (1972).

Young-of-the-year alewives, which are pelagic during most of their
first summer of life, do not become large enough to be impinged on the
screens of the Palisades plant until the late fall of their first growing
season. Large numbers of these fish are on or near the bottom in water
18 to 30 feet deep in October and November; thus, the annual catches of
alewives on screens can be expected to be substantially greater than
those recorded if the Palisades plant operates throughout the year with
an intake flow of 405,000 gpm.

The times of peak abundance in water 18 to 30 feet deep in south-
eastern Lake Michigan for species other than those discussed by Wells
(1968) have not been well documented; the available information indicates,
however, that burbot, lake herring, lake whitefish, and most trout and
salmon can be expected to become more abundant at these depths in the
fall than in other seasons. Spawning lake trout were shown to be abundant
near the intakes of the Palisades and Cook generating plants in the fall
of 1971 (report for cruise XII, R/V Kaho, November 16 to December 2, 1971,
The collection of a 13-pound chinook salmon on the Palisades plant's screens (Benda, 1972) suggests that the entrainment of adult lake trout is a possibility, especially during the spawning season when they are abundant in the area of the plant intake. As mentioned earlier, entrainment of spawning lake trout was documented at the Big Rock generating plant, Charlevoix, Mich. (U.S. Environmental Protection Agency, 1972).
Mortality of Fish that are too Small to be Impinged on Intake Screens

Fish and other organisms small enough to pass through the 3/8-inch-mesh traveling screen and the condensers encounter a wide range of additional stresses during their passage through the rest of the plant cooling system. They may be damaged or killed by (1) collision with the internal surfaces of the cooling system, including the traveling screens, pump impellers, and the heat exchanger surfaces; (2) thermal stress caused by the heat added to the cooling water during passage through the heat exchanger; (3) gas bubble disease or the formation of air embolisms caused by pressure and temperature changes in the cooling system; and (4) exposure to chlorine and other biocidal chemicals used to clean cooling system surfaces. The stresses encountered during passage through a plant, when not fatal, may have severe debilitating effects on the entrained organisms and cause their normal life processes to be disrupted for a significant period of time after they leave the plant cooling system.

One of the earlier major efforts to determine the effects of generating plants on aquatic organisms in this country was conducted at the Contra Costa plant in California by Kerr (1953). He showed that, of the 35 million fingerling striped bass produced annually in the San Joaquin River delta area, about 3.5 million would be drawn through the Contra Costa generating plant. He estimated a maximum loss of about 44,000 striped bass fry due to temperature effects alone during passage through the plant. However, Coutant (1970a) in a review of Kerr's (1953) paper noted that the high survival predicted for striped bass fry passing through the plant did
not take into account the effects of exposure of the fry to maximum temperatures from the time they left the condenser until they reached the point where the effluent is mixed with cooler receiving water. This additional exposure to elevated temperatures could have significantly decreased survival, especially among fry entrained during periods of peak summer temperatures.

The high survival of striped bass fry passing through the Contra Costa plant predicted by Kerr (1953) also apparently did not take into account the damage to fry that would occur as a result of collision with pump impellers and other structures in the cooling water system. This omission is surprising because the high mortality of young-of-the-year and small yearling striped bass after even brief impingement on the plant's traveling screens cited by Kerr strongly suggests that mortality due to mechanical damage could far exceed that due to elevated temperatures alone, especially during the cooler months of the year.

Information presented in the Indian Point environmental impact statement (U.S. Atomic Energy Commission, 1972a) stated that "during June and July of most years from 30 to 50% of the striped bass larvae which migrate past Indian Point from upstream spawning areas are likely to be killed by entrainment." The report concludes that "operation of Indian Point Units Nos. 1 and 2 with the present once-through cooling system will adversely influence the fish populations that use the area for spawning and initial periods of growth and development," and that "recruitment rates and standing crops of several species may be appreciably lowered in response to the increased mortality caused by entrainment of eggs and larvae and the impingement of young of the year."
Sampling conducted at the Vienna (Md.) generating station on May 10 and 12, 1971 (Flemer et al., 1971a), indicated extremely high mortality (99.7%) of striped bass eggs passing through the plant cooling system. Large differences in the numbers of eggs entering and leaving the cooling system indicated that a high percentage of the eggs had disintegrated during passage through the plant. Sampling of fish and larvae (species not stated) at the Chalk Point (Md.) generating plant on August 12, 1971, also revealed very high mortality (92.4%) during passage through the plant cooling system (Flemer et al., 1971b).

Marcy (1971) also showed that mortality of fish fry was extremely high when they were entrained in the cooling water system of the Connecticut Yankee Atomic Power Company's generating plant at Haddam Neck, Conn. He found that no young fish of nine species survived passage through the plant to the lower end of the 1.14-mile discharge canal (travel time was about 51 minutes) when the discharge temperatures were above 86° F. Temperatures in the canal were above 86° F during 95% of the period from June through August when the larvae and juvenile fish were abundant near the plant's intake. Approximately 97% of the fish passing through the plant were alewives and the closely related blueback herring. Marcy's data also showed that the passage of these two species through heat exchangers to the point of discharge into the upstream end of the discharge canal (which took only about 93 seconds) also caused high mortality. For example, on June 30 when the intake temperature was 72° F and the water temperature was 82.7° F, about 65% of the entrained
larvae were killed during the 93-second period; and on July 2, when the intake temperature was 71.6° F and the water temperature was 92.3° F, the mortality of larvae was 83%. According to Marcy (1972) an average of about 179 million fish larvae were killed annually during passage through the cooling system of the Haddam Neck plant in 1969 and 1970.

An extremely heavy kill of entrained fish larvae (almost entirely young menhaden, although some young flounder were also killed) was recently documented at the Brayton Point plant of the New England Electric Company on Mount Hope Bay (R.I.). A 24-hour study conducted by the U.S. Environmental Protection Agency revealed that 164.5 million menhaden larvae had been killed during passage through this plant's cooling water system on July 2, 1971. Subsequent sampling showed that this kill continued through July and well into August; the minimum 24-hour kill observed during this period was about 7 million fry in late August. The death of these fry was attributed to mechanical damage suffered during plant passage (Clarence Tarzwell, personal communication).

Few data exist to show the kinds and numbers of fish eggs and fry that are drawn into and passed through the cooling systems of Great Lakes power generating stations. One study was conducted at the Point Beach (Wis.) generating station from March 3 to May 27, 1971, and from November 4, 1971, to March 3, 1972. A similar study was also conducted at the Oak Creek (Wis.) generating plant from March 22 to April 22, 1971. Results of these studies were presented at the Wisconsin State hearings on thermal standards in the form of a memorandum dated July 9, 1971, to F.H. Schraufnagel.
from J.R. Bell (Wisconsin Electric Power Company and Wisconsin-Michigan
Power Company, 1971a). The results of both Point Beach entrainment
studies are also presented in a recent Wisconsin Department of Natural
Resources report by Krueger (1972).

Plankton nets fished on 14 dates in the period from March 3 to
May 27, 1971, at Point Beach caught plankton, sculpins, and smelt eggs
but no eggs or fry of whitefish or herring. However, according to
calculations based on data given by Krueger (1972), about 30 billion
gallons of water were passed through the plant cooling water system from
March 3 to May 27 (the plant was not in operation from April 3 through
April 17), and only about 168,000 gallons were strained through the
sampling nets—that is, only 0.005% of the total cooling water flowed
through the sampling nets. Since the volume of water passed through the
sampling nets was extremely small, relatively large numbers of eggs or
fry of other species could have passed undetected through the plant. For
example, if only one whitefish egg had been captured, it would have
theoretically indicated that about 185,000 other whitefish eggs had
passed through the plant during the sampling period. Since no whitefish
eggs were collected, we can only conclude that less than 185,000
whitefish eggs passed through the plant during the sampling period.

The significance of an entrainment of "less than 185,000 whitefish
eggs" is obviously difficult to assess. (This difficulty points clearly
to the need for much more intensive sampling efforts if we are to accurately
evaluate the effect of entrainment on organisms that may exist at low densities in Lake Michigan.) The data for the March 3 to May 27 study, however, are useful in providing a gross numerical estimate of the numbers of sculpins and of smelt eggs that passed through the cooling water system at the Point Beach plant.

The July 9, 1971, memorandum from Bell to Schraufnagel indicated that one sculpin was taken on each of the 8 sampling days during the period March 3 to April 29. The expansion of these sculpin catches proportionately on the basis of the total volume of water sampled and the total volume of water passed through the cooling system, yields an estimate of more than 4 million sculpins that theoretically passed through the Point Beach plant cooling system during the 41 days that the plant was in operation from March 3 to April 29. Since no sculpin weights were given in the Bell memorandum, it is impossible to make an estimate of sculpin biomass passed through the Point Beach plant. The value of 4 million sculpins is also difficult to assess, but sculpins are generally recognized to be important in the diet of lake trout and some other fishes. The heavy intake entrainment of sculpins (presumably slimy sculpins) during late winter and early spring is entirely consistent with the data of Wells (1968), which shows that late winter and early spring should be the time of greatest abundance of this species at the water depth at which the Point Beach plant water intake is located.

An estimate of the number of smelt eggs entrained at the Point Beach plant must be based on the report that "a few" smelt eggs were captured
on May 4 and 5 and that none were taken in samples collected earlier (April 29) or later (May 19). About 52 million gallons of water passed through the plant in the 150-minute sampling period on May 4, of which 0.023% or about 12 thousand gallons were strained by the collecting net. If the "few" smelt eggs reported captured were, for example, 10 eggs, then an expansion of the catch on the basis of the volume of water sampled as a fraction of the total flow through the plant yields estimates of about 4,333 smelt eggs that passed through the plant in 150 minutes, and more than 400,000 eggs in the 24 hours bracketing the sampling period. On the same basis of estimation, large numbers of smelt eggs could also have passed through the plant in the 24 hours bracketing the sampling period on May 5. Although no smelt eggs were taken in samples collected on April 29 and May 19, no sampling was conducted from April 30 to May 3 and from May 6 to May 19 and it is entirely possible that smelt eggs were also passing through the Point Beach plant during a portion of this time.

The data for the Oak Creek entrainment study given in the memorandum of July 9, 1971, from Bell to Schraufnagel do not lend themselves to calculation of the actual number of smelt and smelt eggs that passed through the plant. It appears, however, that the first smelt were taken on about April 1, 1971, and by mid-April smelt eggs were reported as "numerous" in the samples; the numbers of smelt and smelt eggs passing through the plant at these times could have been extremely large. When sampling was discontinued on April 22, smelt eggs were still being passed through the plant, apparently in large numbers.
A report containing data on the entrainment of fish eggs and fry at the Palisades plant (Consumers Power Company, 1972) was recently submitted to the U.S. Atomic Energy Commission. According to the company, 13.4 million gallons of water (erroneously listed as 3.4 million gallons by Benda, 1972) were passed through a number 20 mesh (mesh aperture, 0.076 mm) Wisconsin style plankton net with a 5-inch diameter opening in 300 hours of sampling. A catch of 918 fish eggs (826 of these on June 15) and 4 fry (all on June 8) was reported. Expansion of these catches on the basis of the volume of water sampled to the total volume passing through the plant during the 300 hours of sampling indicates an entrainment of 344,336 eggs and 1,500 fry. Further expansion of the egg catches to cover the 888 hours of plant operation from May 17 to June 22 indicates that slightly more than 1 million eggs may have passed through the plant during this period. Although it is possible that some of the eggs taken may have been expelled from ripe fish that were drawn into the plant cooling system, the potential loss of eggs is the same as if they had been spawned naturally in the lake and then been drawn into the plant. Expansion of the fry catch to cover the period from May 17 to June 22 is not warranted because the records indicate that fry were taken only on June 8.

Although the available data indicate an entrainment of slightly more than 1 million fish eggs and about 1,500 fry at the Palisades plant from May 17 to June 22, these numbers are felt to be only a small fraction of the numbers of eggs and fry that actually passed through the cooling system of the plant during this period. Unless the net was fished immediately in front of the opening of the intake pipe where it discharged into the
intake forebay, the actual volumes of water strained would have been far smaller than those reported and the catches would therefore represent a far larger entrainment of eggs and fry than indicated by the expanded totals. Furthermore, it is extremely unlikely that the net used to collect the eggs and fry could have effectively strained a flow of water with a velocity of 9 feet per second because of the fine mesh of the netting material. Even number 2 netting (mesh aperture, 0.366 mm), which is probably the largest mesh that collects eggs and fry of Lake Michigan fish effectively, would perhaps not strain water rapidly enough to give a highly reliable sample in a flow of water with that velocity. Further support for the contention that the numbers of fry captured in these studies (Consumers Power Company, 1972) is not representative of the actual entrainment can be had from the data presented in the following section describing densities of fish fry at the Palisades plant intake.
Potential Intake Entrainment of Fish Fry at intakes of the Cook and Palisades plants.

The Great Lakes Fishery Laboratory studied the distribution and abundance of fish fry along the eastern shore of Lake Michigan in the spring and summer of 1972. The study is still underway, and although many of the samples have not been analyzed, the data for the collections made at the Cook and Palisades plants on six sampling dates from May 6 to July 20 are available and are presented here.

Fry were collected with a plankton tow net 1/2 meter in diameter, at the surface and at depths of 1, 2, 3, and 4 meters (3.3, 6.6, 9.8, and 13.1 feet). Fry from each sample were sorted by species and counted and the density of fry at the various depth levels was calculated on the basis of volume of water filtered by the net as it was being towed. The densities of alewife, perch, and smelt fry per 1,000 cubic meters of water at the various depths sampled are given in table 1 for each sampling date. No fry were taken at either the Cook or Palisades plants on May 6. Smelt were captured at both plants on May 27, but none were taken on any of the other sampling dates. Perch and alewives were first taken on June 20 at both plants. Perch fry were most abundant in the samples collected on June 20 through July 11, whereas alewife catches were heaviest on July 11 and July 20. These differences in time of appearance of fry in the samples and times of peak abundance are in agreement with information on the spawning and hatching times for these species in Lake Michigan, which indicates that smelt should have appeared first.
Table 1. Estimated number of alewife, perch, and smelt fry per 1,000 cubic meters of water at various depths at the cooling water intakes of the Cook and Palisades generating plants in 1972

[Unpublished data, L. Wells, U.S. Fish and Wildlife Service, Great Lakes Fishery Laboratory, Ann Arbor, Mich.]

<table>
<thead>
<tr>
<th>Plant, species, and sample depth (meters)</th>
<th>May 6</th>
<th>May 27</th>
<th>June 20</th>
<th>June 29</th>
<th>July 11</th>
<th>July 20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cook</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alewife</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>23.7</td>
<td>23.7</td>
<td>9.4</td>
<td>6400.7</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2003.7</td>
<td>797.7</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>379.8</td>
<td>835.7</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>23.7</td>
<td>0</td>
<td>414.8</td>
<td>1196.5</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>23.7</td>
<td>0</td>
<td>607.7</td>
<td>-</td>
</tr>
<tr>
<td>Perch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>71.2</td>
<td>9.4</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>23.7</td>
<td>23.7</td>
<td>47.4</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>47.4</td>
<td>9.4</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>23.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18.9</td>
<td>-</td>
</tr>
<tr>
<td>Smelt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>37.9</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td><strong>Palisades</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alewife</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>56.9</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>693.1</td>
<td>702.7</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>23.7</td>
<td>0</td>
<td>788.2</td>
<td>332.3</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>151.9</td>
<td>332.3</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>37.9</td>
<td>180.4</td>
</tr>
<tr>
<td>Perch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>28.4</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>94.9</td>
<td>0</td>
<td>189.9</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>71.2</td>
<td>0</td>
<td>104.4</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>28.4</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>23.7</td>
<td>0</td>
<td>104.4</td>
<td>0</td>
</tr>
<tr>
<td>Smelt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>9.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>18.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>37.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>18.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1/ The sample collected at the 4-meter stratum at the Cook Plant intake was misplaced or lost.
in the samples followed by perch and finally alewives. Few smelt, perch, or alewife fry should have been present in the lake on May 6, and the peak abundance of alewives should have occurred in late July or early August.

In table 2 we have attempted to estimate the numbers of fry of each of these three species that would be drawn into the cooling water intakes of the generating plants in a 24-hour period encompassing each of the sampling dates. We assumed that the Cook and Palisades plants were drawing in water continuously at the rate of 1,645,000 and 405,000 gallons per minute, respectively. Because we did not have information on the dimensions of the current field at the water intakes, we took the liberty of "redesigning" them so that all of the water used for cooling would be withdrawn from a single stratum of water 1 meter thick. Table 2 presents the estimated number of organisms that would be entrained from each depth stratum if the entire cooling water requirements of the plant were met by drawing water only from that stratum. For example, if the Cook plant water intake was drawing in 1,645,000 gallons per minute from the 4-meter depth stratum, 5,453,000 alewife fry and 170,000 perch fry could have entered the plant cooling water system in 24 hours on July 11.

By way of further example, if we had designed the Cook plant intake so that it would draw equal amounts of water from both the 3- and 4-meter depth strata, the estimated total number of alewives drawn into the plant on July 11 would be the average of 3,749,000 and 5,453,000 fry from the 3- and 4-meter strata, respectively, or 4,601,000. By the same logic, the number of perch fry entrained in the same period would have been the average of 0 and 170,000 or 85,000.
Table 2.--Estimated number (thousands) of alewife, perch, and smelt fry that would be drawn into the Cook and Palisades generating plant cooling systems in 24 hours if cooling water is drawn at the rate of 1,645,000 and 405,000 gallons per minute, respectively from a single water stratum 1 meter thick.

<table>
<thead>
<tr>
<th>Plant, species, and withdrawal depth (m)</th>
<th>Cook</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Palisades</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May 6</td>
<td>May 27</td>
<td>June 20</td>
<td>June 29</td>
<td>July 11</td>
<td>July 20</td>
</tr>
<tr>
<td>Alewife</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>213</td>
<td>213</td>
<td>84</td>
<td>57,432</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17,979</td>
<td>7,157</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3,408</td>
<td>7,499</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>213</td>
<td>0</td>
<td>3,749</td>
<td>10,736</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>213</td>
<td>0</td>
<td>5,453</td>
<td>-</td>
</tr>
<tr>
<td>Perch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>639</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>213</td>
<td>213</td>
<td>425</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>425</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>213</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>170</td>
<td>-</td>
</tr>
<tr>
<td>Smelt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>340</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Alewife</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>126</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>15,311</td>
<td>1,552</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>52</td>
<td>0</td>
<td>1,741</td>
<td>734</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>335</td>
<td>734</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>84</td>
<td>399</td>
</tr>
<tr>
<td>Perch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>63</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>210</td>
<td>0</td>
<td>420</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>157</td>
<td>0</td>
<td>231</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>63</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>52</td>
<td>0</td>
<td>231</td>
<td>0</td>
</tr>
<tr>
<td>Smelt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-0.5</td>
<td>0</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>42</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>84</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>42</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Obviously, the intake designs we have assumed for the purpose of discussion are not those of the Cook and Palisades water intakes, but we believe that, in the absence of information on the current fields, this approach provides the most effective means for describing the potential entrainment of fish fry at these plants. We also hope that the data presented will encourage the utilities to collect the information needed to convert these fry densities into potential entrainment rates on the basis of more precise knowledge of the current field around their cooling water intakes. Despite the limitations placed on the analysis of our data, we feel that these data show clearly the potential for entrainment of very large numbers of fish at these two plants. Because the potential entrainment of several million fry in a 24-hour period can hardly be considered a minor problem, the use of Lake Michigan waters for the dissipation of waste heat by once-through cooling should be given careful consideration by resource and pollution control agencies when they make recommendations concerning thermal standards for Lake Michigan.
Potential Mortality of Whitefish Fry

The lake whitefish population is probably at or near its all-time low in the southernmost end of Lake Michigan. Limited sampling along the eastern shore of the lake suggests, however, that the population may be making a comeback. Commercial fishing for whitefish has been banned in Michigan waters of southern Lake Michigan, but is continuing in the northern part of the lake, under intensive management by the Michigan Department of Natural Resources. A sport fishery for this species is also developing in Traverse Bay in northern Lake Michigan.

Although no whitefish fry were taken by the field staff of the Great Lakes Fishery Laboratory during sampling in 1972 at the Palisades and Cook plants, we were not able to conduct sampling in the shallow water close to the shoreline where the fry would be expected to be most abundant in the early spring.

Young-of-the-year whitefish are among the Great Lakes fishes that are susceptible to being drawn into cooling water intakes. Newly hatched whitefish are near the surface in very shallow water in early spring when water temperatures are low (Hart, 1930; Hogman, 1971), but when water temperatures in these areas approach 68° F the young whitefish move away from the shoreline to deeper, slightly cooler waters (Hogman, 1971). Although Emery (1970) found young-of-the-year whitefish in 65.7° F water in Lake Huron, Reckahn (1970) reported that the bulk of the population is usually found where the 62.6° F (17°C) isotherm intersects with the bottom. In northern Lake Huron water temperatures along the shoreline first
reached 62.6° F in early July; by mid-September the 62.6° F isotherm had moved offshore and had reached the bottom at a depth of about 67 feet (Reckahn, 1970). All cooling water intakes for power plants on the Great Lakes lie along the shoreline, inside the 67-foot depth contour. If we assume that young whitefish would be acclimated to their preferred temperature when it is available, then in an average year, young-of-the-year whitefish in Lake Michigan could be expected to be acclimated to 62.6° F from early to middle July through early to middle September, and in some years from middle June through early October (Fig. 1).

A recently completed study of the temperature tolerance of whitefish fry (Great Lakes Fishery Laboratory, unpublished data) together with the information on the preferred temperatures of the whitefish now make it possible to evaluate the potential effect of power plant operation on this species.

Information on both the temperature rise across the condenser heat exchanger and the time required for an organism to pass through the heat exchanger and discharge pipe to the point of discharge into the lake (given in Argonne's technical summary—Argonne National Laboratory, 1972) permits us to determine the effect that passage through the cooling systems of the Palisades or Zion (Ill.) plants would have on whitefish fry. The Palisades and Zion plants will elevate the temperature of their cooling water 25-28 and 22° F, respectively, and organisms passing through these plants would be at maximum elevated temperatures for about 0.5 and 3 minutes, respectively. According to Fig. 2, these are almost exactly the exposures that would cause 50% mortality from heat shock alone in whitefish fry acclimated to 62.7° F.
Data given in an environmental impact statement prepared by the U.S. Atomic Energy Commission (1972a) indicate that organisms passing through the Kewaunee (Wis.) nuclear power plant would be exposed to temperatures 20° F above intake temperatures for about 2.2 to 4.7 minutes. Whitefish fry entrained at the Kewaunee plant could therefore also be expected to have 50% mortality from heat alone during passage through the plant when intake temperatures are about 62.7° F.

Whitefish fry that are not killed by elevated temperatures or other causes during passage through the cooling systems of Lake Michigan power generating plants would probably be made more susceptible to capture by predators concentrated in or near the plume. The subject of predation on thermally shocked fish is discussed in a later section of this report.
Figure 1. Average Lake Michigan temperatures. Temperatures were measured on the bottom at 18 to 36 feet; dashed line indicates one standard deviation above the average. (Figure from U.S. Department of the Interior, 1970.)
Figure 2. Lethal temperatures and exposure times for young-of-the-year whitefish acclimated to 62.6° F. Based on unpublished data of the Great Lakes Fishery Laboratory.
EFFECTS OF DISCHARGES

Concentration of Fishes by Heated Effluents

The effects of waste heat discharges from power generating plants on Lake Michigan and its organisms are many and varied. Most of these were outlined in the report entitled "Physical and ecological effects of waste heat on Lake Michigan" (U.S. Department of Interior, 1970).

Perhaps the most readily observable biological effects of the discharge of waste heat into Lake Michigan are the changes in the spatial and temporal distribution of organisms. Some of these changes are the direct result of thermal additions but others result from the generation of water currents as the effluent is released into the lake and the addition of chemicals such as chlorine to the lake water.

The attraction of fishes and some invertebrates to warm water in the winter and to cool water in the summer is widely recognized natural phenomenon and need not be documented here. The observed attraction of fishes to heated effluents during the cooler portions of the year appears to be an extension of this innate tendency of fishes to seek temperatures near those that are optimum for growth; this subject has been reviewed by Coutant (1970a, 1972).

The concentration of fish by heated plumes in Lake Michigan was described in a recent report summarizing the recent technical information concerning thermal discharges in Lake Michigan (Argonne National Laboratory, 1972) in a report by Benda (1972), and in letters from Stephen Spigarelli of Argonne National Laboratory (dated October 6, 1971), and Glenn A. Reed, Manager of the Nuclear Power Division of

Collectively these sources show that in summer the elevated temperatures in the discharge areas may attract some species of warmwater fishes—including carp, alewives, smallmouth bass, spottail shiners, perch, and gizzard shad—while repelling coldwater species such as trout and salmon. During the other months of the year, when effluent temperatures are below about 65°F, both warmwater and coldwater species may be attracted to the discharge area in large numbers.

Although the concentration of fishes in heated effluents where they can be caught by anglers has been described by the utilities as a benefit resulting from the dissipation of waste heat by once-through cooling, there are a number of potentially adverse aspects of this situation that must also be considered. Some of these undesirable effects are discussed in later sections of this report dealing with the effect of temperature on the accumulation of pollutants by fish, the effect of temperature on the incidence and severity of disease outbreaks, and the use of chlorine as a biocide.

It has been clearly shown by Marcy (1967) in studies at the Connecticut Yankee Atomic Power Company's plant at Haddam Neck, Conn., on the Connecticut River, that the concentrations of fishes in heated effluent may also cause severe weight loss among individuals of some species. They showed that tagged brown bullheads and white catfish that remained in the discharge canal (where feeding opportunities were limited but metabolic demands were high) lost an average of 20% of their body weight (some lost as much as 60%) in 4 months during the winter.
of 1968-69. Poor physical condition was also noted among individuals of these species living in the discharge canal in the summer.
Mortality of Fish Concentrated by Heated Flumes

It is widely recognized that fish and other aquatic organisms have upper and lower temperature limits for all of their vital life processes, including growth and reproduction, and that when these limits are exceeded the organism functions at reduced efficiency or dies. Most fish and other strongly swimming or otherwise mobile organisms of Lake Michigan are able to avoid or escape when the temperature of heated discharges is elevated gradually to the lethal level. However, sudden, sharp increases in the discharge temperature may cause mortality of even strong swimmers such as large fish, particularly when the heated effluent flows through a confined area containing fish. For example, a kill of about 1,000 game fish (mostly striped bass 10 to 14 inches long) resulted from a sharp rise in condenser cooling water temperature at Thompkins Cove, N.Y., June 7, 1971 (personal communication, Monitoring and Data Support Division, U.S. Environmental Protection Agency).

Substantial kills at power generating plants on the California coast have also been recorded recently. One biologist of the California Department of Fish and Game quoted in an article in the Los Angeles Times (dated February 6, 1972) estimated that 4 to 25 tons of fish are killed each month by power generating plant operations along the California shoreline between Ventura and San Diego (a distance of about 200 miles). M. Morford, a U.S. Fish and Wildlife Service biologist, quoted in the same Los Angeles Times article reported that a single kill of between 5 and 6 tons of fish occurred at one plant in July 1971; this kill at the San Onofre plant was also described in a memorandum dated August 19, 1971.
from L. H. Cloyd of the California Department of Fish and Game to J. B. Gilbert of the California Water Resources Control Board. The kill resulted from a "heat treatment" to control mussels and other marine growth in the plant's cooling system. During heat treatment, which usually occurs twice a month at this plant, the direction of water flow through the cooling system is reversed and fish present in the intake pipe between the intake structure and the intake screens are exposed to water of at least 105° F.

According to the Los Angeles Times article, the fish killed at most plants along the California coast are put into powerful garbage grinders and discharged through an outfall to the sea.

Although fish can be killed by sudden temperature elevations, the situation created by a sudden interruption of heat input (when a plant is shut down) at times when receiving water temperatures are near the annual minimum is potentially more hazardous to fishes in most situations.

A number of low-temperature mortalities of marine fish have been reported. The most recent of these was a massive kill which occurred on the weekend of January 29-30, 1972, following an operational shutdown of the New Jersey Central Power and Light Company's plant on Oyster Creek, a tributary to Barnegat Bay. Water temperature in the Creek dropped from about 59° F to about 37° F at the time of the kill. Menhaden, anchovies, bluefish, striped bass, and herring were among the species killed (Smithsonian Institution, 1972).

According to Jensen (1970) a kill of several hundred bluefish occurred at the Northport (N.Y.) generating plant on Long Island Sound.
in January 1970. In a detailed account of the incident, Silverman (1972) reported that underwater observations indicated that as many as 10,000 dead bluefish may have been lying on the bottom in the area in front of the discharge canal. He stated that the bluefish were attracted to the warm effluent from the plant during their fall southward migration. Cooling of the surrounding waters eventually prevented the bluefish from leaving the heated area and the mortality occurred when the fish were denied continued access to the heated effluent to which they had become acclimated.

Mortalities due to plant shutdown in winter have also occurred in fresh water. A heavy kill of fish occurred in the Susquehanna River at the Pennsylvania Power and Light generating station at Yorkhaven, following a shutdown at about 5 p.m. on February 3, 1971, which caused the discharge temperature to drop from about 72° F to about 38° F (which was the river temperature) in about one hour (Commonwealth of Pennsylvania, 1971). Dead fish were present the following morning, and an official count on the afternoon of February 6 revealed 15,383 dead game fish in the area. The total kill must have been much larger because the count did not include dead game fish shorter than about 6 inches or any carp or other nongame fish. A large percentage of the dead fish also could easily have sunk beyond the limit of vision or have drifted out of the area surveyed.

A large fish kill was recorded at the J. M. Stuart power generating plant on the Ohio River in late January 1971, following plant shutdown and a drop in the discharge temperature from about 72° F to about 40° F (Norris and Gammon, unpublished MS). Temperature reductions began on the
evening of January 21 and the plant was back in normal operation on the
morning of January 23. The site was visited several days later (on January 30)
and dead fish in the area were collected and identified. The majority
of the 7,540 dead fish were yearling gizzard shad, but 10 other species,
including catfish, freshwater drum, sunfish, white bass, and white crappie
were also found.

The only records of fish mortalities caused by low temperature shock
in the Great Lakes area are those for kills that occurred on January 1,
1967 (300,384 fish) and January 2, 1968 (250,585 fish) at Fremont, Ohio,
in the Sandusky River—a major tributary to Lake Erie (Ohio Department
of Natural Resources, Division of Wildlife, Investigation Code numbers
72-23 and 72-31, respectively); these mortalities occurred at a sugar
processing plant which released heated water into the river. Mortalities
on January 17, 1967, in Sandusky Bay (78,751 fish) and December 24, 1968
(3,000 fish) in the Sandusky River attributed to power generation (U.S.
Congress 1969, page 376) may also have resulted from low temperature
shock.

Although the attraction of large numbers of fish to the heated
effluent from the Point Beach plant has been documented, the Wisconsin
Electric Power Company stated that no fish kills or other adverse effects
at the plant followed 20 operational shutdowns occurring primarily in
the winter (Wisconsin Electric Power Company and Wisconsin-Michigan
Power Company, 1971b). This statement is not surprising because ice
cover during much of the period when low-temperature kills could occur
would tend to make the sighting of dead or dying fish difficult. Also,
observations made at the Great Lakes Fishery Laboratory during studies of the low-temperature tolerance of white bass, lake trout, and ciscoes revealed that when these fish were in cold shock they sank or swam to the bottom and became inactive. Those that died did not float to the surface as was usually observed among fish that died at upper lethal temperatures. The absence of reports of winter mortalities may also be related to the relative scarcity of "observers of opportunity" at this time of year. And finally, as was clearly shown by Jackson (1971) and in a memorandum from J. Truchan of the Michigan Water Resources Commission to F. B. Frost, et al. (dated February 17, 1971), there may be a tendency for winter fish kills at power generating plants to go unreported.

In the apparent absence of data on the effects of winter operational shutdown on fish and other aquatic organisms in Lake Michigan, we consider it worthwhile to examine data on the maximum temperature rise of cooling water passing through Lake Michigan power generating plants and published data on the lower-lethal temperatures of Lake Michigan fishes to determine if there is a potential for a low-temperature mortality if these plants shut down during the winter. Table 3 shows the temperature decreases required to cause 50% mortality in different Lake Michigan fishes acclimated to various temperatures. For example, a sudden temperature decrease of only 8°F will cause mortality of coho salmon acclimated to 41°F.

The lower lethal temperature data for yellow perch (Hart, 1947), brook trout (Fry, Hart, and Walker, 1946), and deepwater sculpin (Westin, 1968), however, indicate that these species would probably not be killed by winter shutdown of power generating plants now operating or under construction on Lake Michigan.
Table 3. Temperature decreases following cessation of heat input that would cause 50% mortality in different species of fish acclimated to various temperatures.\(^1\)

\([\text{Natural lake temperatures following cessation of heat input must be equal to (or less than) those shown in parentheses to cause 50% mortality.}]\)

<table>
<thead>
<tr>
<th>Species</th>
<th>Acclimation temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>41</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>(33)</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>3/</td>
</tr>
<tr>
<td></td>
<td>(34)</td>
</tr>
<tr>
<td>Cisco</td>
<td>3/</td>
</tr>
<tr>
<td></td>
<td>(37)</td>
</tr>
<tr>
<td>Gizzard shad</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>(32)</td>
</tr>
<tr>
<td>Emerald shiner</td>
<td>4/</td>
</tr>
<tr>
<td></td>
<td>(35)</td>
</tr>
<tr>
<td>White sucker</td>
<td>5/</td>
</tr>
<tr>
<td></td>
<td>(37)</td>
</tr>
</tbody>
</table>

\(^1\)Sources of lethal temperature data: Coho and chinook salmon - Brett (1952); lake herring - Edsall and Colby (1970); gizzard shad - Hart (1952); and emerald shiner and white sucker - Hart (1947).

\(^2\)This acclimation temperature is near the upper-lethal temperature for the species and is probably avoided.

\(^3\)Mortality of 50% when fish are acclimated to a temperature slightly higher than 43° F and cooled rapidly about 11° F to about 32° F.

\(^4\)Mortality of 50% when fish are acclimated to a temperature slightly higher than 54° F and cooled rapidly 22° F to about 32° F.

\(^5\)Mortality of 50% when fish are acclimated to a temperature slightly higher than 62° F and cooled rapidly about 30° F to about 32° F.
No lower-lethal temperature data were available for a number of important species; probably, however, whitefish and brown and rainbow trout may resemble lake herring in this characteristic, and spottail shiners may resemble emerald shiners. Smelt and alewives are both temperate marine species that can be expected to be intolerant of sudden cooling.

Table 4 shows, for each of the power generating stations in Lake Michigan, the various species that could be expected to experience mortality from operational shutdown when receiving water temperatures are at or approaching the seasonal minimum. The table is based on the known temperature rise imparted to the cooling water passing through these plants, as given by the Argonne National Laboratory (1972), and on the information given in table 3 of the present report.

The data shown in table 4 are conservative, for two reasons: (1) The lowest possible acclimation temperature shown in table 3 for each of the species was used to demonstrate the potential for mortality; and (2) some of the plants listed in table 4 may recirculate a portion of their cooling water during the winter, thereby creating heated plumes with maximum temperatures greater than those obtained by assuming that the intake water temperature was 32° F and simply adding the "maximum" temperature rises shown in table 4 for each of the plants.

It has not been demonstrated that the species listed in tables 3 and 4 and other species mentioned in the text are indeed winter residents in the discharge plumes of all of these plants. However, at least three sources of information suggest strongly that there are reasons for concern: (1) The reported mortality of at least two of these species
Table 4. Lake Michigan power generating plants at which cold-shock death of various fishes could occur as a result of operational shutdown 1/  

[+ indicates 50% mortality for populations residing at minimum acclimation (effluent) temperatures shown in table 3.]

<table>
<thead>
<tr>
<th>Plant name</th>
<th>Maximum temperature rise (° F)</th>
<th>Coho salmon</th>
<th>Chinook salmon</th>
<th>Lake herring</th>
<th>Gizzard shad</th>
<th>Emerald shiner</th>
<th>White sucker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulliam</td>
<td>13.3</td>
<td>+</td>
<td></td>
<td>+</td>
<td>++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kewaunee</td>
<td>20</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Point Beach</td>
<td>19.3</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Port Washington</td>
<td>9.1</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Edgewater</td>
<td>29.7</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Lakeside</td>
<td>8.3</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Valley</td>
<td>23.2</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Oak Creek</td>
<td>12.7</td>
<td>+</td>
<td></td>
<td>+</td>
<td>++</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Zion</td>
<td>20</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Waukegan</td>
<td>13.5</td>
<td>+</td>
<td></td>
<td>+</td>
<td>++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>State Line</td>
<td>13.3</td>
<td>+</td>
<td></td>
<td>+</td>
<td>++</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>D. H. Mitchell</td>
<td>9.9</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Bailly</td>
<td>19.6</td>
<td>+</td>
<td></td>
<td></td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Michigan City</td>
<td>13.0</td>
<td>+</td>
<td></td>
<td>+</td>
<td>++</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>D.C. Cook</td>
<td>21.4, 16.2</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palisades</td>
<td>25</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>J. H. Campbell</td>
<td>19.3</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>B.C. Cobb</td>
<td>14.8</td>
<td>+</td>
<td></td>
<td>+</td>
<td>++</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Big Rock</td>
<td>23.7</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

1/ Sources of data: Table 3 of this report; Argonne National Laboratory (1972).
2/ The temperature rise is greater than the value shows when the heated effluent is recirculated through the cooling system.
3/, 4/, 5/ See footnotes with corresponding numbers on table 3.
at the Campbell plant in late January and early February of 1971; (2) the information in the published literature on the temperature preference of Lake Michigan fishes; and (3) the reported attraction of some of these species to heated effluents in winter. Clearly high priorities should be attached to conducting an inventory of the fish populations in and around heat effluents of each of these plants during the cooler months of the year, and to recording the frequency of operational shutdowns at Lake Michigan power generating stations during these months.
Entrainment of Fish Fry in Discharges

When heated water is discharged into Lake Michigan, large numbers of fish fry and other small, weakly swimming organisms will receive thermal, hydraulic, and chemical shocks under certain conditions of water temperature and plant operation. The problem may be particularly acute where high velocity jet-type discharges are used because of the large volumes of surrounding unheated, lake water (containing fish larvae and other organisms) that are drawn into and rapidly mixed with the heated effluent. Fish that have grown beyond the fry stage may also enter or be drawn into heated effluents, even where the discharge velocity is low. Meldrin and Gift (1971) reported that some fish (usually the smallest members of his test populations) were not responsive to temperature change and appeared to be unable to avoid areas in a thermal gradient where high temperatures produced thermal stress or death. They observed this lack of an avoidance response to high lethal temperatures ("low thermal responsiveness") in 10 species of fish, including striped bass, white perch, and alewife; low thermal responsiveness usually occurred when acclimation temperatures were below 60° F or when water temperatures were changing rapidly (as at the plume-receiving water interface).

The only data on the heat dose that organisms could be expected to accumulate when entrained in a jet-type discharge plume was presented in the Zion Environmental Impact Statement (U.S. Atomic Energy Commission, 1972c). This report stated that organisms swept into the discharge of the Zion nuclear power plant would be at a specific isotherm for a maximum of 3 minutes. Unpublished data of the Great Lakes Fishery Laboratory
show that susceptibility to predation increased significantly when young-
of-the-year whitefish acclimated to 64.4° F (their preferred temperature is 62.6° F) were given a 1-minute exposure at 84.2° F. (The Zion plant will have a 20° F temperature increase across its heat exchangers.)

Similar effects would be expected for other species; but data are not yet available for quantitative analysis. Additional discussion of this effect of sublethal exposure to heated effluents is presented in the section immediately following.
Facilitation of Predation

Most research on the adverse effects of power plant cooling systems has dealt with lethal temperatures of organisms. Much less work has been done on sublethal effects and still less on long term (genetic, population fitness) effects. Evidence is beginning to accumulate that sublethal exposures to thermal, chemical, or mechanical shocks at power plants can have a significant effect on the ability of the affected fish to survive.

Various investigators have found that one major effect of such sublethal exposure is a reduction in the ability of exposed fish to avoid predation (Coutant, 1970b; Yocom and Edsall, in preparation; Goodyear, 1972; Sylvester, 1972). Coutant demonstrated statistically significant increases in predation rates at thermal doses of only 10% (chinook salmon) and 20% (rainbow trout) of the doses causing complete loss of equilibrium. Yocom and Edsall demonstrated that lake whitefish fry are made significantly more vulnerable to predation by yellow perch when given a 1-minute thermal shock at various temperatures comparable to those that would be encountered during passage through a power plant cooling system or following entrainment in a heated discharge. Measuring catch per unit effort, they showed that perch captured shocked fry much more readily than fry that had not been shocked. Most of the shocked fry in this experiment retained equilibrium throughout the test.

Gritz (1971) found that in a thermal plume at the Pittsburg (Calif.) Power Plant, the analysis of stomach contents of striped bass suggested that young king salmon were more vulnerable to predation in the plume than outside it. He could not determine if the increased vulnerability was due
to heat shock or to predator concentration, because both conditions occurred together. The data of Yocom and Edsall (in preparation) also suggest that predation probably is higher in a plume than outside it, presumably due to the higher metabolic rate and greater appetite of predators in the warmer plume waters.

Similar effects are anticipated but have not yet been demonstrated for sublethal chemical and mechanical damage to prey fishes. Sublethal chlorine concentrations have been shown to reduce fecundity in fathead minnows (Arthur and Eaton, 1971), and it would be surprising if studies did not reveal that sublethal concentrations of chlorine reduce the ability of prey to avoid predators, though if predators are also subjected to chlorine they may also be debilitated.

The probability of fragile fish larvae being damaged by collision with internal surfaces of the cooling system (see Marcy, 1971) and rendered less able to escape the predators concentrated in and around the plume is high. Fish may also be damaged if subjected to sharp changes in angular velocity when they are entrained in the high velocity discharge of some of the power plants, though to our knowledge this has not been demonstrated. Pressure changes encountered in plant passage may also be sufficient to produce air embolisms in fry. These embolisms, even if not lethal in themselves, may buoy fry to the surface, keep them in the warmest portion of the plume, and subject them to increased thermal shock thereby making them more vulnerable to predation. This may be especially true where adult alewives and other predators of fry collect in large numbers in plume areas.
These debilitating thermal, chemical, and mechanical effects probably all sometimes occur simultaneously; the shocks from different sources would then be additive and the effect on prey vulnerability would be increased correspondingly.
Effect of Elevated Temperatures on Incubating Eggs of Lake Herring and Lake Whitefish

The effect of thermal discharges on the rate of development and survival of eggs and larvae of Lake Michigan species that spawn in fall and winter was outlined earlier as an area of concern (U.S. Department of the Interior, 1970). This concern was intensified when Federal biologists recognized that heated water discharged into Lake Michigan when lake temperatures were less than 39° F would probably sink and cover large areas of the lake bottom on which the eggs of these fishes would be incubating. Recent studies by the Great Lakes Fishery Laboratory and by Argonne National Laboratory have made a preliminary quantitative analysis of this potential problem possible.

A method for determining the developmental rate, by step-wise multiple regression, of eggs exposed to fluctuating temperatures was described by Colby and Brooke (in press) for lake herring. The effect of temperature on rate of development is given by the general relation

$$D^\wedge R_{ij} \propto \frac{1}{day}$$

where developmental rate ($D^\wedge R$) for any chosen day (i) and developmental stage (j) is proportional to the reciprocal of time. Each stage has different constants and the generalized equation for each developmental stage is:

$$D^\wedge R_{ij} = ab c^x d^y e^z$$

where $x$ is the temperature in degrees Centigrade and $a$, $b$, and $c$ are constants. Hatching times of lake herring eggs in nature, predicted from temperature data collected on the spawning grounds and developmental rate data from the above equation, were within 1 (0.8%) and 2 days (1.4%) of those actually observed in nature in 1969 and 1970, respectively.
The general equation developed by Colby and Brooke (in press) and the data of Brooke (in preparation) for developmental rates of whitefish eggs incubated at constant temperatures were used by Brooke, Berlin, and Stone (in preparation) to predict the hatching time of whitefish eggs incubated in the laboratory on a variable temperature regime approximating that on the spawning grounds in Lake Michigan. Hatching occurred 5 days (3.5%) earlier than predicted by the equation.

Times to hatching of eggs of lake herring and lake whitefish calculated from the developmental rate data of Colby and Brooke (in press) and Brooke (in preparation), the temperatures of Figure 1, and a spawning date of November 30, were 155 days (May 3) for herring and 143 days (April 21) for whitefish. Average water temperatures during incubation were 2.44° C for lake herring and 2.07° C for whitefish eggs.

Data on the sinking thermal plume at the Point Beach nuclear power plant at Two Creeks, Wis. (Hogland and Spigarelli, in press), permit an evaluation of the effects of this plant on the eggs of lake herring and whitefish that could have been incubating at various locations in the discharge area. They showed the percentage of time that the temperature at various stations was greater than "natural" for the period March 18-April 3, 1971. If these excess temperatures are applied to the "natural" temperatures of Figure 1 for the duration of the period when these temperatures were below 4° C, we see that development was not significantly accelerated at stations 243 and 368 (hatching advanced 2 to 3 days; table 5), and was only slightly faster at station 182 (hatching advanced 5 to 6 days); at stations 176 and 248, however, hatching would have occurred 10 to 13 days early and at station 297 hatching would have been advanced by 16 to 20 days.
Table 5.—Days to 50 percent hatch of lake herring and lake whitefish eggs at various locations in the thermal plume of the Point Beach plant, Two Creeks, Wis. [In parentheses are the number of days that hatching would be advanced by elevated bottom water temperatures caused by the sinking plume. Station numbers are those of Hoglund and Spigarelli (in press). Hatching times of 155 and 143 days, respectively for lake herring and whitefish were predicted from the "natural" temperatures of table 3.]

<table>
<thead>
<tr>
<th>Species</th>
<th>Station number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>176 182 243 248 297 368</td>
</tr>
<tr>
<td>Lake herring</td>
<td>145 (10) 150 (5) 153 (2) 145 (10) 139 (16) 153 (2)</td>
</tr>
<tr>
<td>Lake whitefish</td>
<td>131 (12) 137 (6) 140 (3) 130 (13) 123 (20) 141 (2)</td>
</tr>
</tbody>
</table>
The number of days by which incubation periods for the two species would be shortened by the heat from the sinking plume are minimum values because the minimum excess temperature elevations given by Hoglund and Spigarelli (in press) were used in our calculation; for example, they stated that the temperatures at station 248 were more than 1.5° C higher than natural temperatures 32.8% of the time, more than 2.6° C higher 14.4% of the time, and more than 4.0° C higher 3.0% of the time. In our calculations we assumed that the temperatures were exactly 1.5° C above natural (rather than at some value between 1.5 and 2.5) 32.8% of the time, were 2.6° C above natural (rather than between 2.6 and 3.9° C) 14.4% of the time, and 4° C above natural (rather than between 4 and some higher value) 3.0% of the time.

The adverse effects of advancing the hatching time of these species on fry survival was discussed in detail earlier (U.S. Department of the Interior, 1970; U.S. Atomic Energy Commission, 1972d). A shortening of the incubation time by about 2 weeks would be expected to have a very significant adverse effect on whitefish eggs (U.S. Atomic Energy Commission, 1972d), and undoubtedly also on lake herring eggs.
Effect of Temperature on the Reproductive Success of Yellow Perch and Other Fishes

Recent studies by the Duluth National Water Quality Laboratory (DNWQL) have described the effect of water temperature on the reproductive success of the yellow perch. The results of these studies were recently summarized by Donald Mount, Director of DNWQL (as quoted by Milburn, 1972):

The level of reproductive success among perch held at 39° F for about 6 months (70% fertile eggs, 53% normal larvae) was approximately twice as great as for fish held at 43° F for about 6 months (35% fertile eggs, 31% normal larvae) and approximately four times as great as for fish held at 46 and 50° F for about 6 months (16 and 21% fertile eggs, 13 and 7% normal larvae). Exposure to the above temperatures for periods less than 6 months lowered reproductive success at each temperature. The data indicate substantial impairment of yellow perch reproduction by an increase in winter temperature of approximately 4° F above 39° F, the lowest temperature tested. It is expected that the reproduction of closely related species such as sauger and walleye, may be impaired by similar increases in winter temperature.

Yellow perch in Lake Michigan normally spend about 6 months in water at temperatures near or below 39° F, and thus fulfill the requirement that the DNWQL study suggested. Wells (1968) showed that perch of age groups II and older began moving from their summer inshore habitat into colder, deeper water by mid-October, and were most abundant by early November in water with temperatures near 39° F. They remained in offshore waters where temperatures were below 39° F from February through mid-April (no data for December or January).
Since the DNWQL study clearly showed that reproductive success of yellow perch held at temperatures at 43° F or higher was markedly reduced, and since the normal behavior of the species takes it to water near or below 39° F in winter, yellow perch that are attracted to the heated effluents of power generating stations can probably be expected to have reduced reproductive success. Evidence that yellow perch are attracted to thermal discharges in Lake Michigan during the winter was given by J. Truchan, Michigan Water Resources Commission (memorandum to F. B. Frost et al., dated February 17, 1971), who reported midwinter kills of yellow perch at the intake of the Campbell plant of the Consumers Power Company when the heated effluent from the plant was being recirculated in the intake area.

Mount's concern (as quoted by Milburn, 1972) for the effects of increased water-temperatures on the maturation of gonads and reproductive success of the walleye is shared by S. L. Spencer, Chief of the Fisheries Section, Alabama Game and Fish Division. In a letter dated October 18, 1972, he stated that attempts to obtain viable fry from the eggs of walleyes living in the very warm portion of a generating plant discharge canal on the Tombigbee River were unsuccessful. Although walleyes taken from the heated discharge at the time when the fish would normally be spawning apparently had fully developed gonads and were successfully stripped in the hatchery, the eggs did not develop normally and no live fry were obtained.

Studies by Brungs (1971) and Hokanson et al. (in press) suggest that the fathead minnow and the brook trout may also be among those fishes that require low prespawning temperatures to achieve normal maturation and optimum reproductive success.
Disease

The lethal, directive, and controlling effects of temperature on aquatic vertebrates have been well documented (Fry, 1967); the role of temperature in the pathobiology of fishes has been perhaps somewhat less exhaustively explored, but the effect of elevated temperatures on the incidence and severity of infection is clearly evident. Ordal and Pacha (1967) observed from the literature that it was evident that most fish diseases are aggravated by increased water temperatures, and demonstrated in later studies with young salmonids that high water temperatures drastically increased the effects of kidney disease, furunculosis, vibrio disease, and columnaris.

*Saprolegnia parasitica* commonly attacks live fish and may play an important role in the death of apparently otherwise healthy whitefish as they approach spawning condition; young whitefish, whitefish eggs, and trout are also susceptible to attack (Florinskaya, 1969). *S. parasitica* is encountered throughout the year at water temperatures from about 33° to 68° F, and has optimum development at about 43° to 60° F (Florinskaya, 1969); heated effluents (including sinking winter plumes) will increase the rate of development of this undesirable fungal parasite.

Evidence for the involvement of temperature in a bacterial epizootic resulting in a massive kill of white perch in Chesapeake Bay area in the summer of 1963 was presented by Mihursky et al. (1970); the increased incidence of columnaris disease resulting from the elevation of water temperatures in the Columbia River was reported by Stroud and Douglas (1968); and the role of elevated temperature and bacterial infection
(as cited by Brett, 1956) in the near obliteration of the sockeye salmon in the Columbia River in 1941 has been demonstrated.

Furunculosis occurs commonly among brown trout and is also seen in rainbow trout. Male brown trout approaching spawning condition are highly susceptible to infestation with furunculosis and secondary infestations of _Saprolegnia_. Fungal infestations, possibly in combination with furunculosis or other bacterial diseases, present a serious problem along the Wisconsin shore of Lake Michigan to male brown trout when these fish enter the warmer waters near shore in search of spawning grounds. Mortality of adult male brown trout reached 88% in 1968 and nearly 100% in 1970; few fungus-related infections were reported in 1969 and 1971, however (Great Lakes Fishery Commission, 1966-1972). Most of the mortalities of male brown trout occurred before females arrived on the spawning grounds, seriously reducing the reproductive potential of this population. Heavy fungal infections, possibly in combination with bacterial infestations, have also been observed in recent years in spawning brown and rainbow trout that have ascended Michigan streams tributary to Lake Michigan. Steelhead trout also displayed heavy fungal infestations in the spring of 1968 (Michigan Department of Conservation, 1969). Kidney disease has also been reported in coho salmon from Lake Michigan; in 1970, 5 of 273 fish examined were infected.

Fish not already infected with disease organisms may acquire the disease through contact with other fish that act as carriers. Fish that have acquired immunity to columnaris disease through exposure to natural infection were found to harbor the organisms and release them in a cyclic manner (Fujihara, Olson, and Nakatani, 1965). Heated
effluents from power generating stations may serve as reservoirs of infection by attracting fish and increasing the probability of non-diseased fish coming in contact with infected fish.

The fungus infection of invertebrates in a heated discharge on Lake Michigan has also been observed. According to the Northern Indiana Public Service Company (1971), large percentages of *Eurytemora affinis* and *Daphnia retrocurva*, the two most abundant species in the thermal plume of the Bailly plant (near Gary, Ind.) were heavily infected with fungus. Collections of these species made outside the thermal plume showed no evidence of fungus.
Concentration of Pollutants by Fish

The effect of elevated temperatures on the concentration of pollutants by fish has not received consideration in any of the previous Lake Michigan Enforcement Conferences. Studies at the Great Lakes Fishery Laboratory have shown that lake trout exposed to water containing approximately 0.20 ppb methylmercury for 8 weeks accumulated almost twice as much (2.16 ppm) at 10° C as at 5° C (1.28 ppm); rainbow trout that were exposed for 10 weeks to water containing about 0.20 ppb methylmercury at 5°, 10°, and 15° C accumulated an average of 0.94, 1.34, and 1.86 ppm, respectively. The Fisheries Research Board of Canada (1970) has also reported a positive correlation between water temperatures and concentrations of mercury in fish.

Although concentrations of methylmercury in fish from Lake Michigan are generally low, some fish already contain levels that are close to the interim guideline level of 0.5 ppm set by the U.S. Food and Drug Administration. For example, the average concentration of methylmercury in five lake trout (26.0-28.7 inches long) collected from Grand Traverse Bay, Lake Michigan, October 19, 1971, was 0.4 ppm (W. Willford, personal communication).

The toxicity of various pollutants to fish also appears to increase with increased water temperature. Macek et al. (1969) concluded that the toxicities of most pesticides increase with increases in temperature, and de Sylva (1969) has suggested that a number of chemicals used in the...
operation of power generating stations, or from industrial sources, may affect fish more acutely at higher temperatures.

Fishermen concentrate substantial amounts of fishing effort in the heated effluents from power plants; the levels of mercury and other pollutants in the fish they catch there, however, may be significantly higher than in fish outside the heated areas. The discharge of waste heat into Lake Michigan may concentrate fishes and thereby increase the catch by anglers, but this situation may not be beneficial to the fish or to the anglers who eat their catches.
The Effects of Temperature on Phosphorus Release from Lake Michigan Sediments

A study is underway at the Great Lakes Fishery Laboratory to determine the effect of temperature on the release of total filterable phosphorus from the bottom sediments of Lake Michigan. In samples held under anaerobic conditions, the amount of phosphorus released was nearly 4 times greater at 77°F than at 43°F. The initial concentration of phosphorus in the water above the sediment was about 25 ppb; during 7 days of incubation the concentration rose to 1,350 ppb in samples at 77°F and to 350 ppb in those held at 43°F. Additional studies will be conducted under aerobic conditions to permit an evaluation of the effect of heated effluents on phosphorus release from sediments in areas of Lake Michigan with well-oxygenated bottom waters.
Planktonic Algae

The major trends among the planktonic algae populations in Lake Michigan were summarized in a report presented at the Lake Michigan Enforcement Conference in September 1970 (U.S. Department of Interior, 1970). A more recent summary by Copeland and Ayers (1972) suggests that little new information has been developed since 1970.

Temperature has been shown to play an important role in determining rates of primary production. Morgan and Stross (1969) showed that temperature increases stimulated photosynthesis at temperatures of 60.8°F or less, but inhibited it at temperatures above 68°F. At high ambient temperatures they found permanent inhibition of photosynthesis in phytoplankton that had passed through a power plant. During chlorination, all phytoplankton passing through the plant was killed.

Zieman (1970) found that phytoplankton species diversity decreased when temperatures were 9°F above intake temperature for the Turkey Point generating station, and that blue-green algal mats increased when discharge temperatures were 78.8 to 82.4°F. Trembly (1960,1965) reported that, in areas of the Delaware River heated by effluent from the Martin's Creek Power Plant, the number of total phytoplankton species decreased but that the number of blue-green algal species increased. Slack and Clark (1965) found that heated water in the Susquehanna River reduced the number of algal species.
Despite these observations, the effects of heated plumes on the productivity of planktonic algae relative to the suppression of desirable species and the encouragement of blooms of undesirable forms has not been clearly established. Studies apparently have not been conducted at all seasons of the year and interpretation of the results of those that have been conducted is made difficult because of the movements of discrete water masses, each carrying its own assemblage of planktonic algae through the sampling areas. It is possible that residence times of algae in the heated effluents are not long enough to create algal blooms in response to elevated temperatures, but to our knowledge this has not been conclusively demonstrated.

Most discharge sites are potentially productive areas because of the nutrients released by organisms that are killed during passage through the plant. The entrainment of large volumes of water containing planktonic phytoplankton, especially at plants equipped with high velocity jet-type discharges, and the buoying of these algae into the well-lighted surface waters (Pulis, 1971; Reynolds, 1972) in this warmed, nutrient rich water mass appears to create a favorable situation for increased production. Chlorination may more seriously debilitate the desirable forms of algae entrained (though to our knowledge this has not been shown) thereby favoring production of undesirable species of algae.

These considerations viewed with respect to evidence of studies of periphyton production presented in the following section suggests that net increases may be occurring among populations of planktonic algae in heated plumes in Lake Michigan.
Zooplankton

Data on the effects of passage through the plant on zooplankton are difficult to evaluate but some general trends have emerged. According to McNaught (1972) the greatest mortality in zooplankton passing through power plant cooling systems is caused by mechanical or abrasive damage. In a study at the Waukegan plant, he found that mortality due to abrasion varied from 3.1% when small zooplankters were most abundant in his samples to 11% when larger zooplankters were most abundant. During the period of the study, an average of only 0.7% of the zooplankton passing through the plant was killed by thermal stress. The higher mortality from mechanical effects was observed because lethal temperatures were not reached during passage through the plant. However, in other studies where lethal temperatures have been reached, mortalities of zooplankton have exceeded 80%, and only 7-10% of the total was attributed to abrasion (Coutant, 1970a). Milburn (1972) estimated that 100% of the zooplankton passing through the J.M. Stuart Station during July and August was killed by heat effects alone when discharge temperature reached 95-99° F. Mortalities of 29-55% recorded at the Big Rock Power Plant during November and December 1971 were attributed to both mechanical and thermal damage that occurred during passage through the plant (Grosse Ile Laboratory, 1972).

Chlorination can also be a major cause of zooplankton mortality. During chlorination, all zooplankton passing through the cooling system
is killed (U.S. Atomic Energy Commission, 1972d). Zooplankton can also be killed by chlorination when it is drawn into a thermal plume. This effect could be especially severe at plants with high velocity discharges because according to Brauer et al. (1972), this type of discharge produces high concentrations of zooplankton in the outfall region.

Zooplankters that survive passage through plant cooling systems often suffer serious sublethal effects. Heinle (as cited by Coutant, 1970a) found that populations which had experienced thermal and mechanical shocks during passage through the plant had reduced reproductive potential even when the exposure temperatures were below the laboratory-determined lethal temperatures; he also found that zooplankton which survived chlorination had reduced reproductive potential. Passage through the plant has also been shown to reduce the hatchability of zooplankton eggs (Coutant, 1970a).

Because mortalities due to abrasion are size dependent (McNaught, 1972), passage through the plant could change the community structure of the zooplankton by selecting against the larger zooplankters. It is not known if this happens, because of the often rapid turnover rates of different zooplankton species.

The magnitude of the problem of zooplankton mortality caused by once-through cooling is best shown by the data of McNaught (1972). He stated that when lethal temperatures are not exceeded, only about 7% of the plankton...
passing through the Zion plant would be killed; even this low mortality rate would cause an annual kill of 1,210,000 pounds of zooplankton at the Zion plant. On the basis of the estimated annual kill of zooplankton at the Zion plant (McNaught, 1972) and the projected cooling water requirements for the electric power generating industry (equivalent to a daily cycling of 1% of the beach zone waters of the entire lake in the year 2000--U.S. Department of Interior, 1970), we could anticipate an annual kill of about 9.8 billion pounds of zooplankton in Lake Michigan by the year 2000 if power development with once-through cooling is permitted. A mortality of this magnitude would certainly be detrimental to the zooplankton populations of the beach zone waters of the lake. The organic matter released to the lake by this amount of dead zooplankton would be recycled at lower levels with probable increases in the bacterial and algal populations and corresponding losses in production of desirable fishes at the higher trophic levels.
Periphyton and Benthic Invertebrates

Although a clear picture of the effects of heated discharges on the planktonic algae has not yet emerged, the periphyton communities seem to be responding to the heated effluents in a predictable manner. For example, Buck (1970) reported that planktonic communities in and above a thermal discharge in the Connecticut River were similar, but that dissimilarities in the attached forms indicated the importance of water temperature in regulating dominance. Phyto-periphyton samplers placed above the discharge were dominated by diatoms, whereas those placed in the discharge were dominated by the blue-green Oscillatoria and Macrocvstis. When diatom-dominated sampler slides from above the effluent were placed in the heated effluent, dominance shifted to the blue-green algae. Although the planktonic communities above and in the thermal discharge were qualitatively similar, the numbers of organisms were 4.3 times greater in the effluent than above it, after the plant had been in operation for 1 year. In the year before the plant began operating the numbers had been the same in both areas. The thermal effluent appeared to have its greatest effect on phytoplankton numbers in the spring, summer, and fall, when natural temperatures were increasing or high.

Studies by Spigarelli and Prepejchal (1972) at the Point Beach plant during the summer of 1971 showed significantly greater periphyton production at near-field plume stations (0.35 gram per square meter per day) than at far-field stations (0.10 gram per square meter per day) at temperature elevations of less than 3.6° F. Winter stimulation of periphyton growth by sinking plumes also may be significant (Hoglund and Spigarelli, in press).
There is evidence that thermal effluents may also increase productivity in the benthic invertebrate community. Truchan (1971) found that the number of benthic species was significantly greater at the outfall of the Consumers Power Company's Campbell plant than at sampling sites 1/2-mile and 3 miles from the outfall. The number of individuals at the outfall was also greater though not statistically so. Truchan stated that this increase could be due to increases in temperature or natural organic materials, or both, caused by cycling Pigeon River water through the plant. Seeburger (1968) reported similar results in a study of benthos at the Upper Peninsula Power Company's Marquette, Mich., plant on Lake Superior at the mouth of the Dead River. Beer and Pipes (1968) reported increased benthic productivity off Commonwealth Edison's Waukegan plant discharge site in Lake Michigan; since this plant, in contrast to the Campbell plant, cycles no river water, increased productivity is presumably due to thermal rather than organic loading.
Chlorine

Three methods have been used to prevent formation of organic slimes in heat transfer units of power plants. Though heat-shock defouling has apparently been used with some success, the most common methods of prevention and removal of slimes have been (1) addition of chemicals to the water, or (2) passing mechanical devices or suspensions through the heat transfer units (Draley, 1972).

Chlorine, generally in the form of hypochlorite or gaseous chlorine, is widely used as a biocide in generating plant cooling systems. It is added intermittently to the intake water in concentrations varying from about 1 to 3 ppm (Basch, 1971; Brook and Baker, 1972; Masser, 1972). Free chlorine tends to form chloramines with ammonia when it is present. These chloramines are much less effective than the gas as defouling agents (Draley, 1972), and, in areas where biological oxygen demand and ammonia levels are high, large amounts of free chlorine (gas or hypochlorite) may have to be added to achieve effective treatment. In addition, chlorine residues have been found to persist much longer than was previously estimated (National Water Quality Laboratory, 1972).

Unfortunately, all of these forms of chlorine are toxic to aquatic organisms—and often in concentrations well below those used in power plants. The addition of chlorine may reduce primary production in cooling waters by more than 90% (Hamilton et al., 1970). Since some species are more sensitive than others to chlorine and its compounds, the species composition in the water near the discharge can be significantly altered. During chlorination, all of the planktonic organisms, including fish
larvae, that pass through the plant are killed and probably large numbers are affected in the plume (U.S. Atomic Energy Commission, 1972d). Residual chlorine concentrations (all chlorine forms) as small as 0.05 ppm are highly toxic to rainbow trout (100% mortality after a 96-hour exposure; Basch and Truchan, 1971; Truchan and Basch, 1971). Danson (1967) reported that chlorination of cooling water was partly responsible for the plugging of intake screens with dead alewives at the Waukegan power plant. Because some fishes tend to congregate in the warmer waters of the discharge and surrounding mixing area, the use of chlorine must be carefully controlled. The effect of chlorine as a toxicant increases in warm water, where pH tends to be depressed (U.S. Atomic Energy Commission, 1972a). Trout and salmon appear to be the most sensitive fish species, and scuds, cladocerans, and protozoans are among the most sensitive food organisms (National Water Quality Laboratory, 1972). Arthur and Eaton (1971) tested a wide range of chloramine concentrations and found that only those below 0.0034 and 0.0165 ppm had no significant effect for a long-term test on amphipods and fathead minnows, respectively.

There is evidence that some fishes are able to detect and avoid chlorine. Trout have been shown to show a slight avoidance response to concentrations of chlorine as small as 0.001 ppm (Sprague and Drury, 1969). Steelhead trout, sunfish, gizzard shad, suckers, and various minnows have been observed avoiding discharge waters when chlorine was present (Basch, 1971; Massey, 1972). On the other hand, fish have been observed dying by the thousands within minutes of the start of chlorination in power plants (Truchan and Basch, 1971). These fish, which included gizzard shad, bullheads, crappie, carp, and yellow perch, began surfacing when chlorine concentrations were 0.09 ppm (Truchan and Basch, 1971).
If the application of chlorine during the period of the year when lake temperatures approach the annual minimum causes fish to leave the heated effluent, the possibility exists that they would be killed by low-temperature shock.

Two other major groups of organisms can be directly affected by chlorinated discharges. During the winter, when thermal plumes sink, benthic organisms in the discharge region could suffer severe losses from chlorine because most members of this community lack the mobility needed to avoid such changes in their environment. A similar effect would be felt by the psammo-littoral community of inshore waters whose members by and large lack adequate mobility. These tiny organisms that live in water filling the interstices of sand are an important food source for shore birds and larval fish, and their loss would be strongly felt by organisms of higher trophic levels. The available information indicates that both the benthic and psammo-littoral communities are largely composed of invertebrate species that are highly sensitive to chlorine (U.S. Atomic Energy Commission, 1972d).

Some standards for safe chlorinating procedures have been set by the Environmental Protection Agency (U.S. Atomic Energy Commission, 1972b). Unfortunately, chlorine levels are difficult to assess, and measurement techniques at some plants appear to lack adequate precision. Basch (1971) found a sixfold difference between values of chlorine measured by him and those obtained by power plant personnel. Thus the plant could have been chlorinating at a level six times greater than that necessary or recommended.
The National Water Quality Laboratory has recommended that for intermittent chlorination the total residual chlorine should not exceed 0.1 ppm for 30 minutes per day or 0.05 ppm for 2 hours per day, but indicated that these should be considered as preliminary recommendations because of the scarcity of data on the toxicity of chlorine for short term exposures (National Water Quality Laboratory, 1972).

More data are needed on the acute and chronic tolerances to chlorine of organisms that occur in the plume regions. Preliminary evidence indicates that sublethal doses of chloramine can cause marked reductions in egg production in fish and invertebrates (Arthur and Eaton, 1971). If chlorine concentrations lethal to fish occur as far as 2 miles from the discharge site (U.S. Atomic Energy Commission, 1972c), sublethal effects may certainly occur at much greater distances.

In summary, the available data indicate that procedures other than chlorine treatments should be used for defouling condensers, to avoid damage to aquatic organisms.
Yates M. Barber of the Bureau's Office of Environmental Quality, Washington, D. C., shared in the development of many of the ideas that form the basis for this paper. Many members of the staff of the Great Lakes Fishery Laboratory also aided materially in the completion of this manuscript.
BIBLIOGRAPHY


Brooke, L. T. (in prep.) Effect of constant temperature incubation on survival and development of eggs of lake whitefish (Coregonus clupeaformis). Great Lakes Fishery Laboratory, Ann Arbor, Michigan.


