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Topical Briefs: Fish and Wildlife Resources and Electric Power Generation, no. 1

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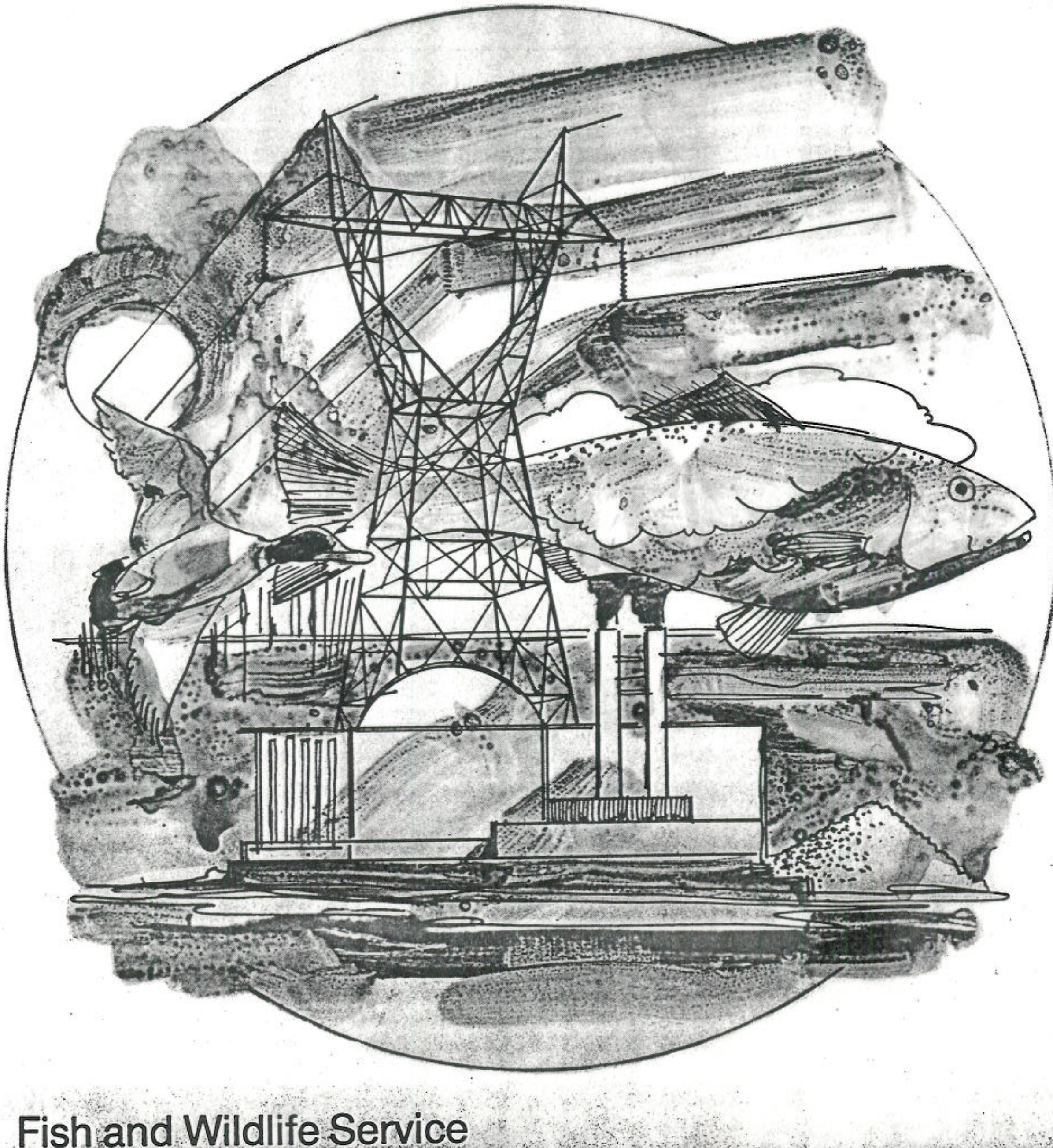

Fish and Wildlife Service

U.S. Department of the Interior

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IMPACTS OF POWER PLANT INTAKE VELOCITIES ON FISH

by

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Preface

The series Topical Briefs: Fish and Wildlife Resources and Electric Power Generation is published by the National Power Plant Team of the Power Plant Project to provide a set of concise summaries on topics related to electric power generation and transmission and their effects on fish and wildlife resources. The briefs are written for fish and wildlife biologists who review and make recommendations regarding electric power projects. Each brief contains background information on and a discussion of the particular topic, a selected bibliography of additional information sources, and, in some cases, a strategy to address the problem.

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IMPACTS OF POWER PLANT INTAKE VELOCITIES ON FISH

Abstract

This report outlines biological problems associated with power plant intake velocities. Information needed to assess impacts of intake velocities on fishery resources and a list of technical references containing more detailed analyses of the problems and mitigation alternatives are included.

INTRODUCTION

There is growing recognition that mortality of aquatic biota due to entrainment or impingement at power plant intakes produce substantial impacts on estuarine, riverine, lacustrine, and coastal ecosystems. In some power plants water withdrawal may produce greater losses to fishery resources than thermal pollution. For example, up to 165.5 million menhaden larvae were killed per day by entrainment at the Brayton Point Plant in Massachusetts during the summer of 1971 (U.S. Environmental Protection Agency 1972). The ecological implications of this mortality are not yet known.

POWER PLANT	ENTRAINMENT EVENT	DATE	COMMENT
Brayton Point, Mt. Hope Bay, Mass.	7.0 to 165.5 million menhaden (some river herring) killed per day	Summer, 1971	Estimated from EPA's sampling techniques. 164.5 million kill on July 2; fish mangled.
	50 million fish killed in 11 days	August 10-21, 1971	Estimated from net tons at discharge; menhaden and blueback herring; tests showed all fish died.
Millstone, Niantic Bay, Conn.	36 million fish killed in 16 days (probably menhaden blueback herring)	Nov. 2-18, 1971	Estimated by sampling of vertebrae of dead fish in discharge channel.
	2.5 million flounder entrained	Apr.-June 1972	Death rate not estimated
Connecticut Yankee, Conn. River, Conn	179 million fish larvae killed per year	1969&1970	Estimated by B. Marcy.
Indian Point, Hudson Estuary, N.Y.	Predicted 7.3 million striped bass killed per year, larvae and juveniles	Future	For Units 1&2; estimated from estuary sampling in 1966 and 1967.
Seabrook, Hampton-Seabrook Estuary, N.H.	Predicted kill of 74 million clam larvae per day	Future	Estimate for proposed plant; 74 million is initial kill at plant startup, lower rate after equilibrium reached.

Table 1. Reports and Predictions of Power Plant Entrainment (U.S. Environmental Protection Agency 1976*a*)

POWER PLANT	IMPINGEMENT EVENT	DATE	COMMENT
Millstone, Niantic Bay Conn.	Massive kill of small menhaden (more than 2.0 million), screens clogged.	1971	Occurring late summer, early fall; plant shut down on 8/21/71; persistent low kill of 10 other species.
P. H. Robinson, Galveston Bay, Tex.	7,191,785 fish impinged in one year.	1969-70	Projected from sampling of operating plant; principal species were menhaden, anchovy, croaker; highest in March.
Indian Point, No. 1	Yearly kill of 1.0 to 1.5 million fish.	1965-72	Primarily white perch with 4-10% striped bass.
Hudson River, N.Y.	Kill of 1.3 million in 9 1/2 weeks	1969-70	10% striped bass; plant closed Feb. 8.
Indian Point, No. 2	Massive kills; maximum per day 120,000	Jan. 71	Testing cooling system of new plant (no heat); white perch & other species
	175,000 fish killed in 5 days.	Feb. 72	Testing again (no heat) Con. Ed. fined $1.6 million by N.Y. for kills.
Indian Point, No. 1,2	Predicted total kill 6.5 million fish per year		With both plants in full operation
Port Jefferson Long Island, N.Y.	2 truckloads (at least) of fish killed on screens in 3 days.	Jan. 26-28 1966	Mostly small menhaden; also white perch.
Crystal River (near) Cedar Key, Fla.	Predicted annual kill of 400,000 fish and 100,000 shellfish.	1969	Based upon operation of 3 units (2 units now destroy 1.2 this amount).
Brayton Point Mt. Hope Bay, Mass.	350,000 fish impinged in one year; mostly menhaden	1971-72	Heaviest from Nov-March; flounder, silverside, & other also impinged.
Oyster Creek, Barnegat Bay, N.J.	10,000 fish, 5,000 crabs, destroyed per month in spring and summer.	1971	Estimated from 19 days of sampling; screen kill in cold season unknown.
Surry Power Station James River, Va.	6 million river herring destroyed in 2-3 months	Oct.-Dec. 1972	Estimated by AEC from screen samplings during partial power runs.

Table 2. Reports and Predictions of Power Plant Impingement (U.S. Environmental Protection Agency 1976*a*)

STATEMENT OF THE PROBLEM

Rates of entrainment and impingement of aquatic resources are directly related to intake velocities at and around the intake structures, and also to numerous other physical and biological phenomena. An understanding of these phenomena is necessary to make effective recommendations concerning intake velocities.

Hydrodynamic conditions in the water body are the principal physical phenomena controlling entrainment and impingement. Three types of hydrodynamic conditions may exist (with associated site-specific modifications): a stagnant pool system, such as a lake or pond with no prevailing currents; an uni-directional system, such as a stream, river, or coastal system with one prevailing current in the vicinity of the intake; and a multi-directional flow system, such as in an estuary.

Relative location and construction details of the intake structure are also important, because they control flow conditions in the immediate vicinity of the intake. The location of the structure in relation to the shoreline, bottom, and water surface influences the abundance, variety, and extent of withdrawal of aquatic organisms. Construction of skimmer walls, submerged weirs, velocity caps, etc., can limit the zone of power plant water withdrawal, and screens set at an angle to the direction of inflow may reduce the impingement of small fish considerably (Stone & Webster Engineering Corporation 1976).

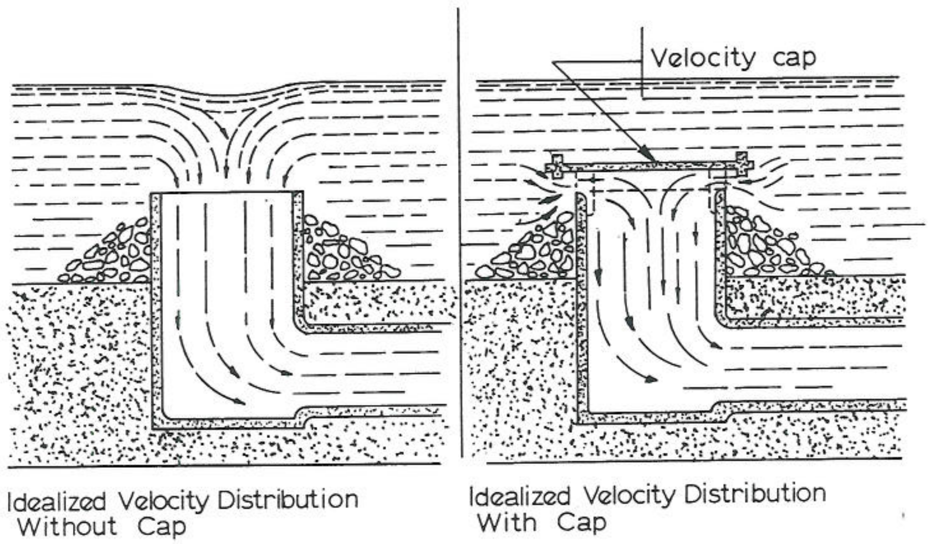


Figure 1. Operation of the Velocity Cap
(U.S. Environmental Protection Agency 1976*a*)

Biological phenomena that influence the magnitude of entrainment and impingement of aquatic organisms include their: (1) motility; (2) physiological and behavioral responses to factors such as temperature, salinity, oxygen concentration, currents, etc.; (3) vertical and horizontal distribution in the vicinity of the power plant intake; and (4) growth rate which governs the period of vulnerability to entrainment or impingement during each life stage.

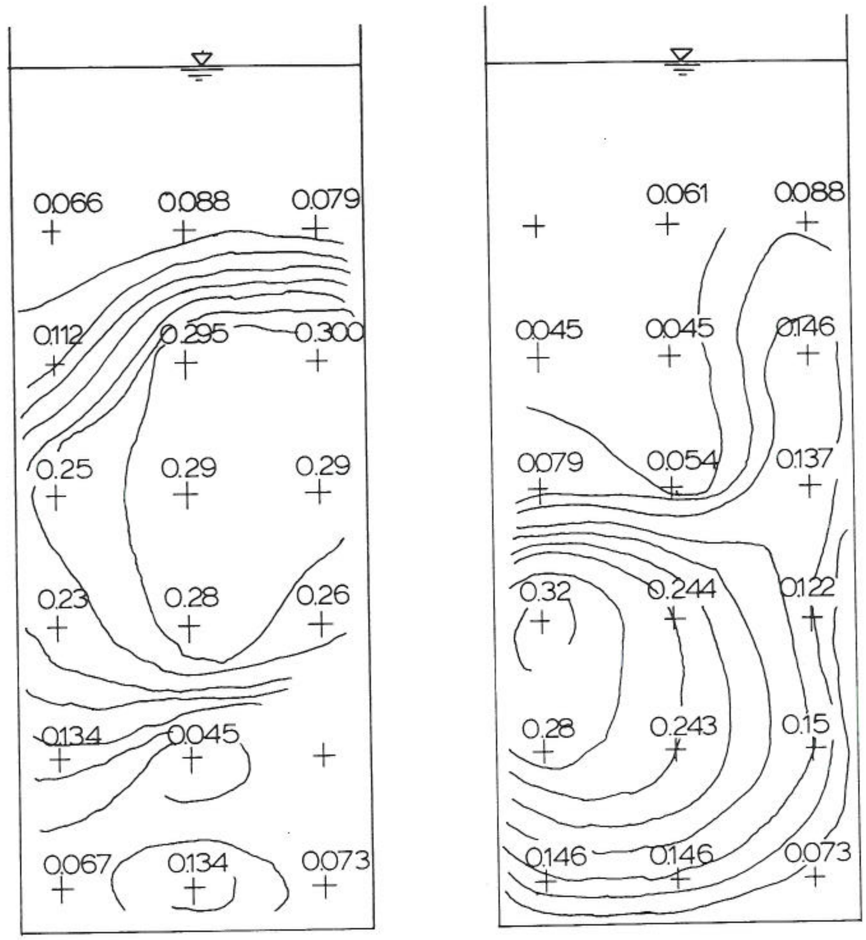
The biologist should be aware of the following problems inherent in discussions of entrainment and impingement impacts on critical fishery resources that appear in environmental reports, environmental impact statements, 316(b) demonstrations and other such reports. The biologist should also consider these problems when providing power plant comments during the design stage.

Prediction of the zone of water withdrawal. No universally accepted method has yet been established for predicting the zone of influence on aquatic organisms around power plant intake. Three-dimensional velocity profile models superimposed on movement patterns of aquatic species are one approach to this problem. However, these models are still in the formulative stage. Simplistic mathematical models neglect important hydrodynamic phenomena necessary for predicting flow conditions in the vicinities of power plant intakes. Field verifications by dye or drogue studies do not reflect the reaction of aquatic organisms to the higher velocities in the immediate vicinity of intakes and, therefore, are unreliable for predictive purposes.

Relating swimming speeds of fishes to intake vulnerability. Impingement and entrainment rates of fishes are dependent on much more than simply their ability to maintain position in a given velocity for a given period of time. For example, available data indicates that impingement rates of fishes are strongly influenced by temperature and salinity conditions in the vicinities of estuarine power plant intakes. Rheotaxis (response of an organism to current), phototaxis (response to light), and tactile responses also are important in determining the vulnerability of a species. Furthermore, fish may hold a position immediately in front of the intake structure and become susceptible to entrainment or impingement upon exhaustion.

Reports may also mention an organism's capacity to exert a burst of speed to support arguments for reduced vulnerability to intakes. However, such arguments are seldom supportable because initial orientation, distance and direction travelled, and the types of stimuli that elicit a sudden burst of speed all are variables that can not be sufficiently documented.

Measurements of intake velocities. The report should state exactly where measurements or estimates of intake velocities have been made with respect to the intake structure, water surface and bottom, tide, river stage, and other pertinent variables. Often an average intake velocity is reported with no indication of the range of velocities across the intake structure; some parts of the intake may have close to zero velocity, while others may have velocities much higher than the "average". Furthermore, low velocities are extremely difficult to measure, and the accuracy of these measurements may be questionable.



NOTES:
1. VELOCITIES SHOWN IN METERS / SEC
2. MEASUREMENTS MADE BETWEEN DEICING LOOP PIPE AND BAR RACKS IN MARCH 1970
3. MEASUREMENTS MADE AT A WATER FLOW RATE 60% OF FULL CAPABILITY

Figure 2. Undesirable Intake Well Velocity Profiles (U.S. Environmental Protection Agency 1976*a*)

Stagnant pool areas around the intake. All intakes are designed to prevent the pumps from running dry. To keep them from running dry some companies construct a reservoir. In such cases, a stagnant water area usually occurs in the vicinity of intakes, which allows material such as sand and silt to settle out and concentrations of aquatic organisms to increase. Vulnerability of the aquatic organisms to the intakes is also increased. These areas can be created by breakwaters in combination with a dredged-out area, sheet pile walls, ponds dredged adjacent to the river, intake canals, etc.

Relation of intake location to plant discharge. Fish and shellfish often are attracted to the discharge, and more of them may be subjected to entrainment or impingement if the intake is located too near the discharge.

SUGGESTED STRATEGY

Entrainment: Eggs and early larval stages of aquatic organisms are particularly vulnerable to entrainment. Volume of intake flow is often more important than intake velocity in determining degree of impact. If important fishery resources are likely to be entrained at a power plant, the project report should include the following:

- Accurate delineation of vertical and horizontal distribution of eggs and larvae by species in the expected zone of withdrawal.
- Information on the period of vulnerability of the resource to entrainment, including data on duration of the egg and larval stages, length of spawning season, and relationship of developmental periods to environmental factors (e.g., temperature) that are likely to affect them.
- Description of the physical and biological phenomena that could increase vulnerability, such as tidal cycles, current patterns, location of intake, behavior, etc.
- Indication of the volume of water withdrawal in relation to the net flow of the water body.
- Estimates of the egg and larvae population sizes.
- Evaluation of significance of entrainment losses to recreational and commercial fisheries.

Reduction of entrainment losses can be accomplished by several methods, including use of skimmer walls, velocity caps, and submerged weirs to control the zone of withdrawal; relocation of the intake in areas of less critical habitat; or construction of a closed-cycle cooling system to reduce the volume of water withdrawal. Seasonal mode operation of once-through cooling during periods of low potential impact may also be recommended. It cannot be overemphasized that the best way to minimize the impact of a power plant on important aquatic resources is to site the plant in a location where such resources are very scarce.

<u>Impingement</u>. Juvenile (post-larval) stages of fish are much more vulnerable to impingement losses than any other life stage. In some instances, however, substantial impingement of adult fish can occur.

If critical fishery resources are likely to be impinged at power plant intakes, the project report should contain the following:

- Accurate delineation movement patterns of the critical fishery resource through the zone of withdrawal.

- Description of the physical and biological phenomena that may increase the vulnerability of a species to impingement, such as temperature, salinity, currents, behavior, etc.

- If fish by-pass systems are utilized, evidence that fish returned to the water body will survive, grow, and reproduce successfully.

- Estimation of the numbers and sizes of impinged species in relation to the quantity of water passing through the plant, intake current velocities, season, water temperatures, stage of tide, illumination, and other environmental conditions.

- Population estimates of the impingeable stocks of aquatic organisms.

- Evaluation of the degree to which impingement losses will reduce recreational and commercial fisheries.

Reduction of impingement can be accomplished by use of methods such as travelling screens, fish bypass systems, louvers, relocation of the intake, etc. Air bubbler screens and sound waves have not been shown to be effective measures.

More detailed analyses of alternate intakes that will reduce entrainment and impingement are found in the Atomic Industrial Forum source book on cooling water intakes (Battelle 1975) and the U.S. Environmental Protection Agency's cooling water intake development document (1976*a*). Guidelines for studies related to power plant intake velocity impacts on aquatic resources are presented in the U.S. Environmental Protection Agency's 316(b) technical guidance manual (1976*b*).

It is important to keep in mind that closed-cycle cooling is not the best available technology in all cases. Minor alterations in existing open-cycle systems to minimize impact should be recommended whenever possible. Each system must be judged on a case-by-case basis.

CURRENT POLICY

The U.S. Environmental Protection Agency (1973) recommends reducing intake velocities to below 0.5 ft/sec(fps) at the trash rack to enable fish to escape the screenwell. The U.S. Nuclear Regulatory Commission (1975) recommends that "...the site should have characteristics that allow placement of intake structures where the relative abundance of important species is small and where low approach velocities can be attained." Also "...approach velocity and screen face velocity are the principal design criteria for controlling the impingement of larger organisms, principally fish, on intake screens. Acceptable approach and screen face velocities are based on fish swim speeds which will thus vary with the species, site and season. Maximum acceptable approach velocities are on the order of 0.5 fps."

Fish and Wildlife Service concerns on intake velocities appeared in Dr. Willis King's Instructional Memorandum RB-44, dated February 5, 1973, and in the Navigable Waters Handbook (U.S. Fish and Wildlife Service 1974). The memorandum reads: "The maximum velocity protecting most small fish is 0.5 fps but even lower velocities will entrain larvae and plankton and even small fish where intake channels are not provided with an effective escape bypass."

REFERENCES CITED

Battelle. 1975. Environmental impact monitoring of nuclear power plants -- source book of monitoring methods. Atomic Industrial Forum, Inc., New York. 2 vols.

Stone & Webster Engineering Corporation. 1976. Studies to alleviate fish entrapment at power plant cooling water intakes: final report. Boston, Mass. 1 vol.

U.S. Environmental Protection Agency. 1972. Proceedings in the matter of pollution of Mount Hope Bay and its tributaries. Washington, D.C. 643 pp.

U.S. Environmental Protection Agency. 1973. Reviewing environmental impact statements - power plant cooling systems, engineering aspects. Environmental Protection Technology Series EPA-660/2-73-016. Corvallis, Oregon. 93 pp.

U.S. Environmental Protection Agency. 1976a. Development document for best technology available for the location design, construction and capacity of cooling water intake structure for minimizing adverse environmental impact. EPA 440/1-76/015-a. Washington, D.C. 263 pp.

U.S. Environmental Protection Agency. 1976b. Guidance for determining best technology available for the location, design, construction and capacity of cooling water intake structures for minimizing adverse environmental impact. Section 316(b) P. L. 92-500. (draft 2) Washington, D.C. 50 pp.

U.S. Fish and Wildlife Service. 1974. Navigable waters handbook. Loose-leaf pub. n.p.

U.S. Nuclear Regulatory Commission. 1975. Regulatory guide 4.7. General site suitability criteria for nuclear power stations. Washington, D.C. 30 pp.

ADDITIONAL USEFUL REFERENCES

Clark, J. and W. Brownell. 1973. Electric power plants in the coastal zone: environmental issues. American Littoral Society Special Publication No. 7. 80 pp.

Edsall, T. A. 1976. Electric power generation and its influence on Great Lakes fish. Pages 453-462 *in* Proceedings of the Second Conference on the Great Lakes. Great Lakes Basin Commission, Ann Arbor, Mich.

Huber, E. E. 1974. Fish protection at intake structures and dams: guidance screens and collection devices. ORNL-EIS-74-67. Oak Ridge National Laboratory, Oak Ridge, Tenn. 75 pp.

Lake Michigan Cooling Water Intake Technical Committee. 1973. Lake Michigan intakes: report on the best technology available. U.S. Environmental Protection Agency, Chicago, Ill. 1 vol.

Lake Michigan Cooling Water Studies Panel. 1975. Statement of concerns and suggested environmental research: report no. 1 of the Lake Michgan Cooling Water Studies Panel. U.S. Environmental Protection Agency, Chicago, Ill. 382 pp.

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