An Experimental Approach to the Design of Systems for Alleviating Fish Impingement at Existing and Proposed Power Plant Intake Structures

E. P. Taft, P. Hofmann, P. J. Eisele, and T. Horst

Stone & Webster Engineering Corporation
Boston, Massachusetts 02107

INTRODUCTION

Impingement of fish in cooling water intakes can create both biologic and operational problems at power plants. There are basically two approaches to alleviating potential fish impingement at either existing or proposed power plants. The first approach is to install a device that is known to alleviate impingement of fish at other water intakes. Unfortunately, because information on the applicability of specific devices under different physical and biologic conditions is generally lacking, it is often difficult to ensure that a particular device will be effective for a specific site.

A second approach involves testing a device prior to installation. Because licensing requirements necessitate a certain degree of assurance that a system will be effective, and cost commitments for installation of diversion devices may be substantial, it would appear to be prudent to evaluate the effectiveness of particular devices prior to installation. This approach could also avoid the cost of outages, redesign, and installation of a second intake system after the impact of the initial, untested system proves too great. By utilizing this alternate approach, the decision to install a particular device will be made with a reasonable degree of assurance that the device will be effective in alleviating impingement.

This paper will discuss various field and laboratory study programs that were designed to investigate the applicability of diversion devices for specific sites.

Stone & Webster Engineering Corporation (S&W) has been both conducting laboratory model studies and evaluating monitoring data on impingement for several utilities. The laboratory studies have been designed to investigate methods for alleviating potential fish entrapment at several existing and proposed Lake Ontario power plants owned by Niagara Mohawk Power Corporation (NMPC) and Rochester Gas & Electric Corporation (RG&E) and at the Indian

Point Generating Station (Indian Point) and the proposed Cornwall Pumped Storage Project (Cornwall), both located on the Hudson River and owned by Consolidated Edison Company of New York, Inc. (Con Edison).

Field studies have been designed to evaluate the effectiveness of a bottom sill in reducing the impingement of fish, mainly of the bottom-dwelling variety. A bottom sill has been installed at the Boston Edison Company (BECO) Mystic Station, unit 6 (Mystic-6), located on the Mystic River.

The following text is a description of the various devices and systems investigated in these studies, the experimental programs designed for evaluating the effectiveness of the systems, and a general discussion of the results obtained.

EXPERIMENTAL PROGRAM

Model studies for NMPC and RG&E have involved the development of methods for diverting and bypassing fish within onshore screenwells, preventing fish entrapment at offshore, submerged intake structures, and safely returning fish from both locations back to Lake Ontario. Test species were selected on the basis of their abundance in screenwashing samples at existing intakes or their commercial and sport value. The species tested were the alewife *(Alosa pseudoharengus)*, smelt *(Osmerus mordax)*, and coho salmon *(Oncorhynchus kisutch)*. Studies for NMPC began in May 1973 and were designed to evaluate the potential effectiveness of angled traveling louvers and screens for screenwell guidance application, wide-spaced louvers for offshore intake application, and various pipe and pumping elements needed to transport fish from bypasses back to the lake. Initially, the intent of these studies was to develop design criteria for fish diversion devices that could be applied to Nine Mile Point Nuclear Station, unit 2 (NMP-2). Early in 1975, the scope of the studies was expanded to include other intakes at power plants located on Lake Ontario and owned by NMPC and RG&E. The primary objectives of these studies are to further evaluate the potential for general application of an angled traveling screen for fish diversion within existing and proposed screenwell structures on the lake.

Because the existing Indian Point and proposed Cornwall generating facilities are designed with onshore intakes, laboratory model studies for Con Edison, which began in mid-1974, are designed to develop fish diversion systems for screenwell application only. On the basis of an extensive literature review and experience gained from the NMPC studies, angled traveling louvers and screens were selected for model testing. Test species include white perch *(Morone americana)*, striped bass *(Morone saxatilis)*, and tomcod *(Microgadus tomcod)*.

Regulatory concern that the operation of additional units at Mystic Station would result in additional impingement of benthic species, particularly winter flounder *(Pseudopleuronectes americanus)*, led to the development of a bottom sill for this station. A bottom sill has been installed at the Mystic Station, and a preliminary field evaluation has been conducted.

Studies conducted to develop screenwell fish diversion systems, offshore intake diversion systems, and associated transport systems are discussed individually below.

Screenwell Fish Diversion Systems

Essentially the same approach was taken in developing screenwell fish diversion systems for NMPC, RG&E, and Con Edison. The basic experimental apparatus used was the test flume. Three flumes have been utilized for evaluating the effectiveness of angled traveling louvers and screens. Table 1 presents a list of pertinent information relative to the engineering and biologic parameters evaluated in each flume.

The first flume constructed was 3 ft deep, 3 ft wide, and 70 ft long and was used to develop an acceptable louver design for application at NMP-2. Louvers were selected for evaluation on the basis of an extensive literature review. Louver systems, which create a velocity gradient along which fish will guide, have been shown to be effective in diverting a variety of fish species on the West Coast to bypasses (Bates and Jewett 1961; Bates et al. 1960; California Department of Water Resources 1967; Downs and Meddock 1974; Ducharme 1972; Hallock et al. 1968; Ruggles and Ryan 1964; Schuler 1973; Thompson and Paulik 1967; United States Fish and Wildlife Service 1960). Information obtained from past studies was utilized in establishing initial test parameters.

Variables investigated included louver array angle, louver slat spacing, approach and bypass velocity, species, temperature, and light conditions. A bypass width of 6 in. was maintained throughout the study program. In all tests, the louver slats were set at a right angle to the louver frame. Each slat was 3 ft long, 3.5 in. wide, and 0.5 in. thick.

Forty-five tests with various louver arrangements were conducted between August 1973 and October 1974. Louver angles of 90, 60, and 25^{o} to the flow and louver slat spacings of 1, 2, and 3.25 in. were tested. The approach to bypass velocity ratio was always set at approximately 1.0:1.5. Therefore, at the three different test approach velocities of 1.0, 1.5, and 2.0 ft/sec, bypass velocities were 1.5, 2.3, and 3.5 ft/sec, respectively.

Based on initial results of testing in this flume, a louver array angled 25^{o} to the flow was chosen for a more detailed analysis. An analysis of the data collected indicated that the spacing between louver slats and the approach and bypass velocity were associated with the efficiency of the system in diverting fish. Water temperature also affected the efficiency. The average

Table 1
Physical and Biologic Parameters Investigated in Each Test Flume

Test Parameters	Test Flume: NMPC 3-Foot Flume Louvers	NMPC and RG&E 6-Foot Flume Angled Screen	Con Edison 6-Foot Flume: Screen	Con Edison 6-Foot Flume: Louvers
Test species and range of water temperature (F) tested for each species	Alewife, 77-52;	Alewife, 82-39	Striped bass, 77-35; white perch, 77-52; tomcod, 35-36	Striped bass, 62-34; white perch, 63-55; tomcod; 34
Approach velocities (feet per second)	1.0, 1.5, 2.0	0.5--0.8, 1.0, 1.5, 2.0, 3.0	0.5, 1.0, 1.5, 2.0, 2.5, 3.0	1.0, 2.0, 3.0
Bypass velocities (feet per second)	1.5, 2.3, 3.5	0.5--0.8, 1.0, 1.5, 2.0, 3.0	0.5, 1.0, 1.5, 2.0, 2.5, 3.0	1.5, 3.0, 4.5
One-week mortality studies	No	Yes	Yes	No
Number of tests, light/dark	31 light/14 dark	25, Natural light cycle	18 light/14 dark	7 light/14 dark
Louver or screen angle (degrees to the flow)	90, 60, 25	25	25	25
Louver slat spacing (inches)	3.25, 2.0, 1.0	Not applicable	Not applicable	1.0
Screen mesh	Not applicable	3/8 in., 11 gauge	3/8 in., 11 gauge	Not applicable
Flume dimensions (width, depth, length in feet)	3, 3, 70	6, 6, 40	6, 7, 80	6, 7, 80
Flume flow capacity (cubic feet per second)	12	130	110	110

efficiency of the louver system for all tests conducted at a louver array angle of 25° and a louver slat spacing of 1 in. was 90%, with a standard deviation of 7.3 (31 tests with 200 fish per test). A more detailed discussion of the test design, procedures, results, and conclusions of these tests may be found in a separate report (Stone & Webster Engineering Corporation 1975).

Although results of louver testing indicated that such a system would function relatively effectively in a power plant screenwell, developments in the design of angled traveling screens, similar to the conventional type, warranted an investigation into the feasibility of utilizing such a concept for guiding fish to a bypass. An angled traveling screen offers several advantages over a louver system for power plant application. Most important is the fact that because the screen acts as both a diversion device and a screening medium, backup screens, required behind louver systems for removal of fine debris and nondiverted fish, are not necessary. Therefore, an engineering and biologic feasibility evaluation was conducted early in 1975, and, on the basis of information obtained, a test program was initiated to develop and optimize the effectiveness of an angled screen in diverting fish to a bypass.

Initial studies, conducted in the 3-ft flume previously described, showed that a screen, angled 25° to the flow and leading to a 6-in. bypass, diverted 100% of the test fish (alewives and smelt) without impingement. Due to size limitations, however, it was not possible to incorporate all of the important design features of an angled traveling screen into the 3-ft flume. Therefore, a second flume was constructed to allow a more complete evaluation of the device. This flume was 6 ft wide, 6 ft deep, and 40 ft long (Figure 1). A simulated traveling screen, structurally identical in every detail to a full-scale screen, was installed at a 25° angle to the approach flow. The screen leads to a 6-in. wide bypass with a sloping roof that directs the bypass flow into a 12-in. diameter pipe. This pipe then enters a collection area from which bypassed fish can be removed. Alternately, the pipe can be connected to a system of pipes and a jet pump, as described later, designed to evaluate a complete diversion, bypass, and return system for Lake Ontario application.

A similar flume, with an overall length of 80 ft, is being utilized to evaluate angled traveling louver and screen diversion devices for Con Edison (Figure 2). The approach section of the flume is 6 ft wide and 7 ft deep. Tests are conducted at a water depth of 6 ft. The louver and screen test devices are fabricated in sections and are interchangeable. This system permits testing with both devices under similar water quality conditions and allows for simplified alterations to the angle of the device to the approach flow.

A 6-in. bypass has been utilized in all tests. Water flows along the bypass at the full 6-ft depth to a baffle wall where the flow separates and passes around the wall before exiting through a screen. Fish collect in a quiescent area behind the wall where velocities are low.

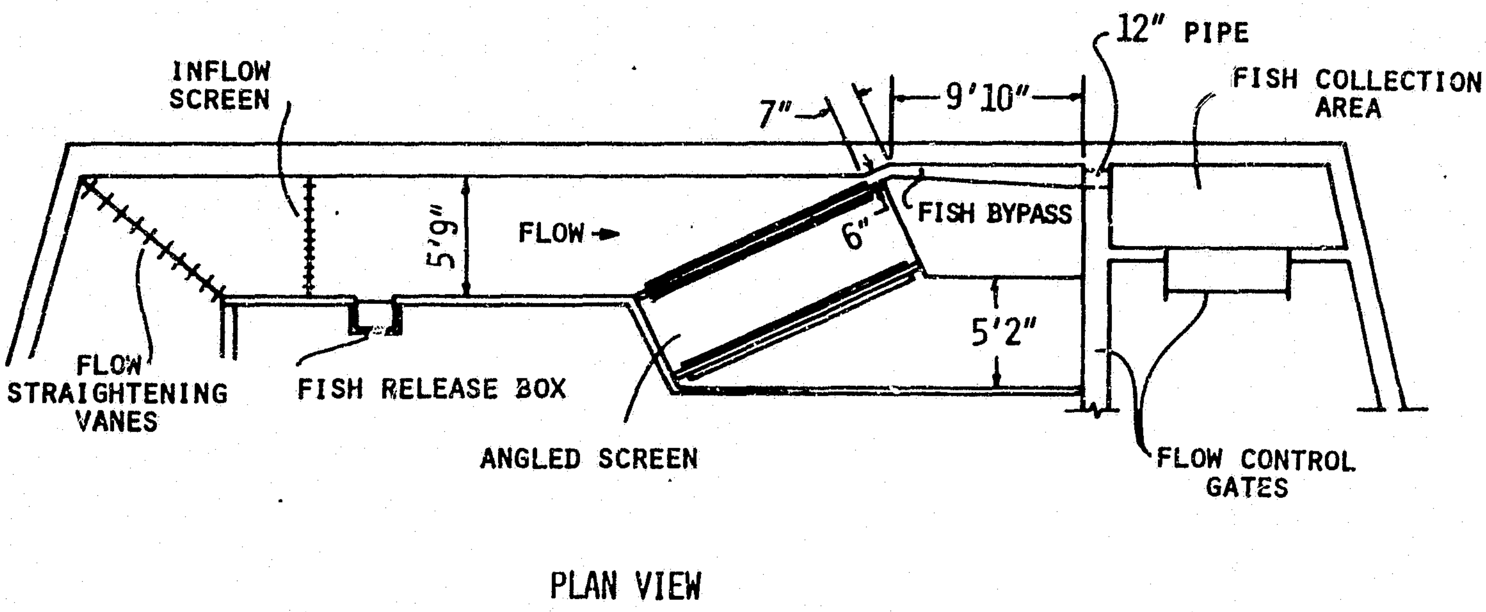


Figure 1. NMPC/RG&E test flume.

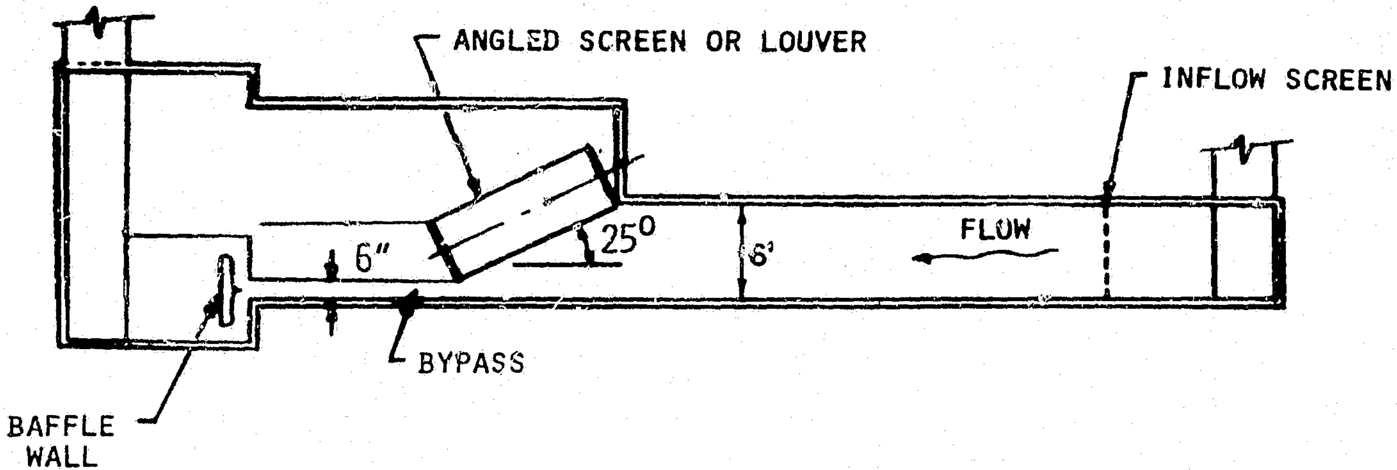


Figure 2. Con Edison test flume.

Because the test procedures and results of both the NMPC/RG&E and Con Edison flume studies were very similar, they are discussed together below.

Variables investigated include species, approach and bypass velocity, lighting condition (light or dark), water temperature (and various other water quality parameters), length of test, test and control mortality, and differential mortality (Table 1). Mortality is observed for 7 days after each test with the angled traveling screen devices. The purpose of these studies is to determine whether stress, such as contact with the screen or prolonged energy exertion, occurs as a result of testing, which may affect the survival of bypassed fish. The procedures utilized involve holding all test fish for 1 week and comparing mortality among these individuals with that of a control group of fish. In most cases, fish have been tested only once; that is, test and control fish consisted of individuals that had not previously been exposed to a test device or to the handling involved in removing controls to a holding box.

During 1-week mortality studies, all fish that die during each 24-hour period are weighed and measured to the nearest 0.1 g and 1.0 mm, respectively, for determination of condition factor, K. At the end of 1 week, a subsample of remaining live fish is sacrificed, weighed, and measured.

During louver studies for Con Edison, mortality studies are not conducted, because it is assumed that bypassed fish will not suffer any higher mortality than fish diverted by a screen and that the loss of fish through the louver structure provides an adequate basis for efficiency evaluation. However, the coefficient of condition was determined for all fish that passed through the louver device, and for an equal number of bypassed fish, to determine whether condition is a factor in louver diversion efficiency.

To date, the louver and screen angle evaluated in both flumes has been 25° to the flow. Approach and bypass velocities with the angled screen have always been equal and have ranged from 0.5 to 3.0 ft/sec. In evaluating the louver device for Con Edison, the approach to bypass velocity has always been set at a ratio of 1.0:1.5. Therefore, at test approach velocities of 1.0, 2.0, and 3.0 ft/sec, bypass velocities have been approximately 1.5, 3.0, and 4.5 ft/sec, respectively.

In most cases, the angled screen was found to be 100% effective in diverting all test species (alewife, white perch, tomcod, and striped bass) to the 6-in. bypass under all test conditions occurring in both test flumes. In addition, 1-week survival was considered to be an important criterion for determining the overall effectiveness of the device. A least-squares analysis of covariance (ANCOVA) was performed on 1-week mortality data with alewives (NMPC/RG&E). Both total and differential mortalities were analyzed with temperature, velocity, and mean coefficient of condition as independent variables. Velocity had a significant effect on total mortality ($p = 0.015$); that is, mortality increased with increased velocity. Results of an ANCOVA for differential mortality indicate that temperature was significant ($p = 0.08$), with a slight negative effect; that is, differential mortality increased with decreasing temperature. The mean differential mortality and 95% confidence limits were 35.7 ± 13.5%. The analysis was somewhat difficult to interpret due to high test mortality and variable control mortality, presumably resulting from the handling of this fragile species under laboratory conditions.

As with the NMPC/RG&E studies, angled screen diversion efficiencies with Hudson River species were almost always 100% (32 tests, 200 fish per test). One-week differential mortality was low in all cases (mean = 3.3 ± 2.5%), regardless of test velocities, species, temperature, or lighting condition. An ANCOVA showed that temperature significantly influenced mortality of both test and control fish ($p = 0.002$). However, the relationship was opposite to that found with alewives; that is, as temperature decreased, mortality decreased.

Results of louver testing in the Con Edison flume to date show that the device, angled 25° to the flow, is from 50% to 99% efficient in diverting the three test species to a bypass under all temperature, velocity, salinity, and lighting conditions evaluated. A preliminary analysis of the data obtained from 21 tests shows an average efficiency of 84.6 ± 5.4%. A detailed analysis has not been conducted.

As previously mentioned, field studies were conducted at the Mystic Station to evaluate the effectiveness of a bottom sill in alleviating the impingement of winter flounder. A screenwash monitoring program was initiated in mid-1971 to determine the numbers of fish impinged at the existing station. The results of the program were to serve as a basis for predicting potential losses of fish at a new unit. The existing station consisted of six units with six intake bays. The flow into each bay varied. The monitoring program consisted of collecting all fish that were washed into the screenwash sluiceway over a 24-hour period, 2 days each week. Fish densities were corrected for varying flows by calculating the numbers of each species collected for each unit volume of flow.

Based on the results of the monitoring program through 1973, it was determined that losses of winter flounder at the new unit could be higher than those from existing units. In an attempt to alleviate existing and potential flounder losses at the station, the decision was made to install a bottom sill at Mystic-6 to establish the effectiveness of a sill as a deterrent to flounder.

In late 1973, a bottom sill, which consisted of an 8 ft high wall, was placed upstream of the trash racks at unit 6. The fish monitoring program was continued by use of units 1-5 as the control, or unaltered, condition. The effectiveness of the bottom sill was evaluated by using the log ratio of the monthly densities of flounder from units 1-5 to the monthly densities from unit 6. The prebottom sill ratios were then compared to postbottom sill ratios by a one-tailed t test. Preliminary results indicate that there was a significant ($p = 0.01$) reduction in flounder impingement of about 50% after the installation of the bottom sill.

As a result of this evaluation, a bottom sill will be incorporated into the intake forebay of unit 7. Monitoring studies will then continue to verify the effectiveness of the device in the new unit.

Offshore Intake Diversion System

A scheme for bypassing fish at the NMP-2 submerged offshore intake and returning them to the lake was proposed by NMPC in January 1974. The concept was developed on the basis of screenwell louver studies previously discussed. However, because close spacing between louvers would be impractical at an offshore intake due to the potential for clogging by debris and frazil ice, it was proposed that wider spacings, combined with higher velocities, might act to establish the hydraulic conditions necessary to guide fish away from the main water flow and into a bypass (Figure 3). Approximately 10% of the flow entering the intake structure is drawn into the bypass.

A series of preliminary biologic tests was conducted with coho salmon in a scaled model of the concept. Results were encouraging, and 1:9- and 1:1-scale intake segment models were constructed to more fully evaluate the potential of this scheme.

Results of the 1:9-scale hydraulic model were used to develop initial design criteria for the 1:1-scale segment model. This model was constructed inside a basin approximately 60 ft wide, 70 ft long, and 6 ft deep (Figure 4). Six pumps, with a combined capacity of 130 ft^3/sec, were installed to circulate water through the model.

The test procedure involved placing fish in the model upstream of the intake structure and monitoring their passage through the system over time. The variables investigated included approach velocity, ratio of approach to bypass velocity, and water temperature.

The results of the offshore intake louver study were analyzed with an ANCOVA (41 tests, 500 fish per test). The efficiency of the system in diverting fish was increased by increasing the approach velocity and increasing the ratio of approach to bypass velocity. The range of approach velocities tested was between 1.5 and 4.0 ft/sec, while the ratios tested were 1.0-1.67. The efficiency of the louver system also depend on water temperature and the year in which the system was tested. The overall average efficiency for all tests with alewives was 49%, with a standard deviation of 21%.

Fish Transport System

Both the offshore intake diversion system and the screenwell guidance system developed for NMPC require a fish transportation system to return fish safely to

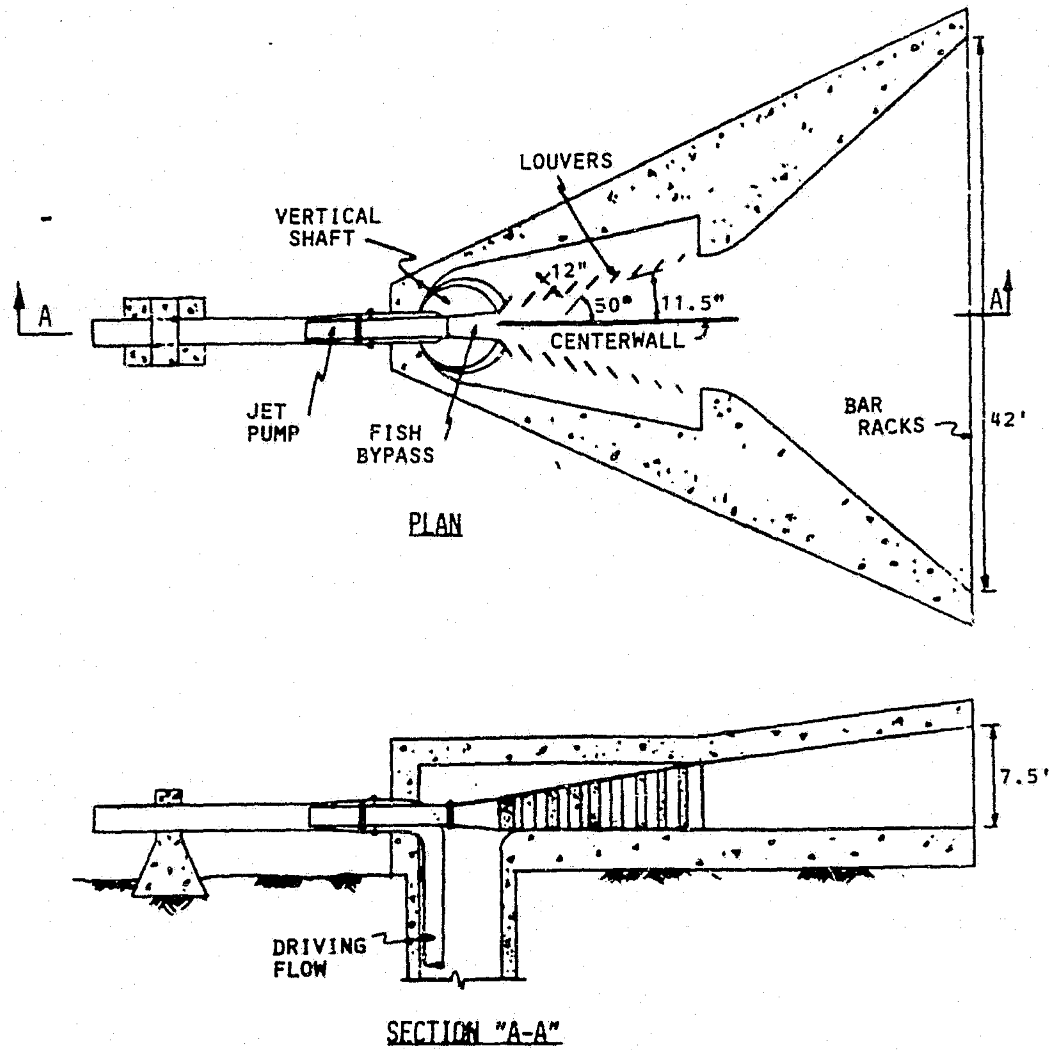


Figure 3. Concept of offshore intake louver system.

Lake Ontario. The transportation system that has been developed by S&W involves the use of a jet pump to induce flow into a bypass and to drive the flow in the pipes used to transport fish. A jet pump was selected for evaluation because it has no moving parts and is, therefore, easily maintained and has a low potential for injury to fish resulting from contact with pump components. Models were constructed to determine the effects of two different types of jet pump and the effects of passage through a pipe at various velocities on fish viability. In addition, the effects of the various pressure changes that fish would experience in passage through the entire intake system were determined by testing in a pressure chamber. A description of these studies and the results that were obtained follow.

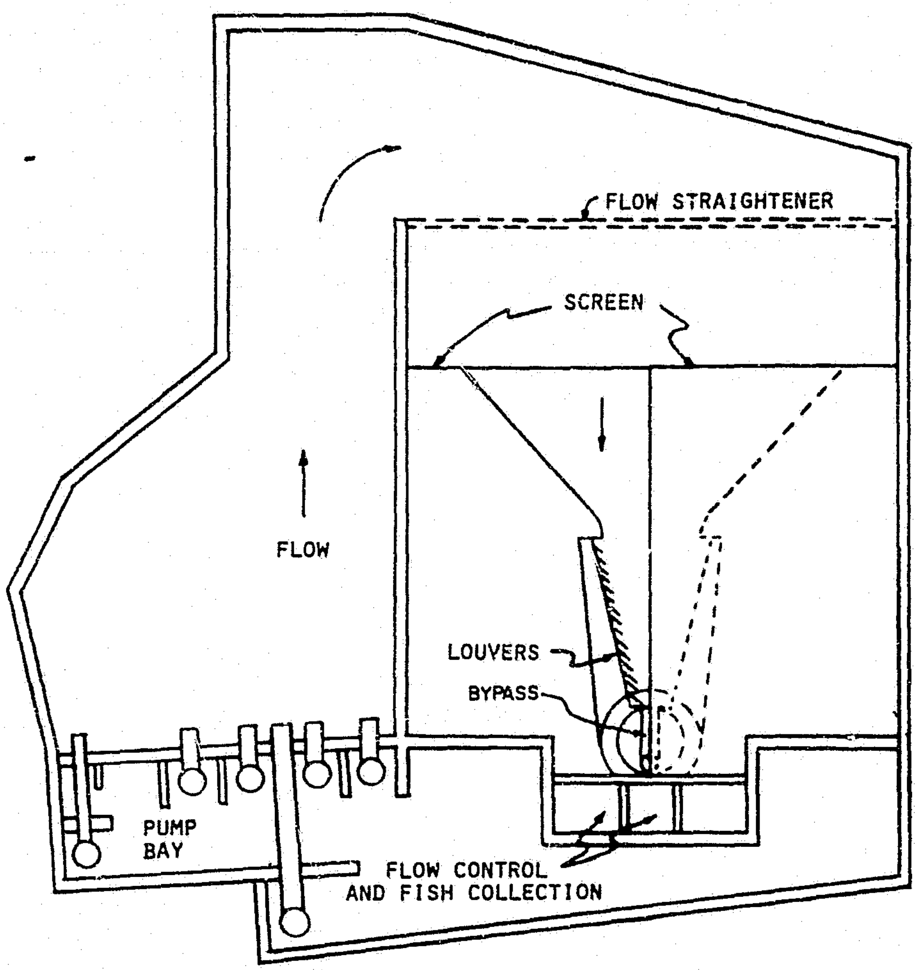


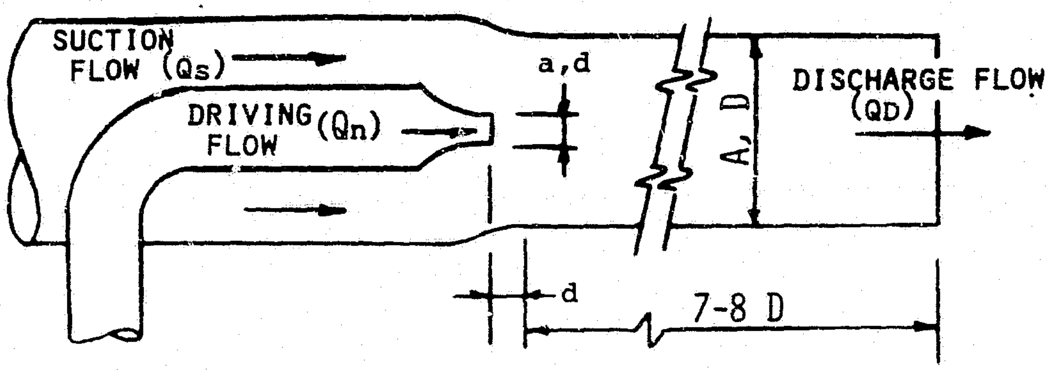
Figure 4. 1:1-scale ratio offshore intake segment model.

Jet Pump Studies

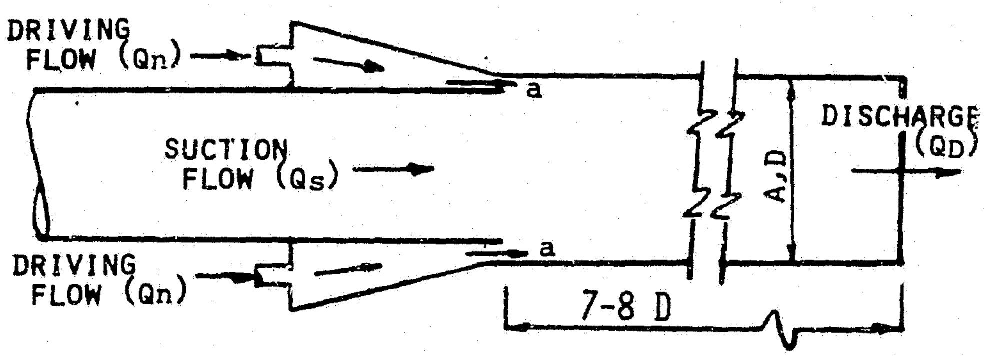
A jet pump is a unit that performs its pumping action by the transfer of energy from a high-velocity jet to one of low velocity. Two types of jet pump were evaluated: a core type, in which a concentric nozzle is placed centrally, and a peripheral type, in which the nozzle is placed around the periphery (Figure 5).

To utilize a jet pump to pass fish safely requires hydraulic design information on its performance characteristics and information on the effects of the hydraulic jet shearing forces on fish mortality.

The core-type jet pump model (Figure 6) consisted of a 2-ft diameter, 14-ft long mixing tube and an 8-in. diameter driving nozzle, resulting in an area ratio



(a.) CORE-TYPE JET PUMP



(b.) PERIPHERAL-TYPE JET PUMP

Figure 5. Types of jet pump.

of 0.12. The pump assembly was installed in a large basin approximately 10.5 ft. wide, 55 ft long, and 6.5 ft deep. Biologic testing was conducted by introducing fish directly into the jet flow via a 3-in. diameter plastic pipe. On release, fish were passed through the mixing zone and were discharged from the 2-ft diameter mixing tube into an 18-by-22-ft collecting area.

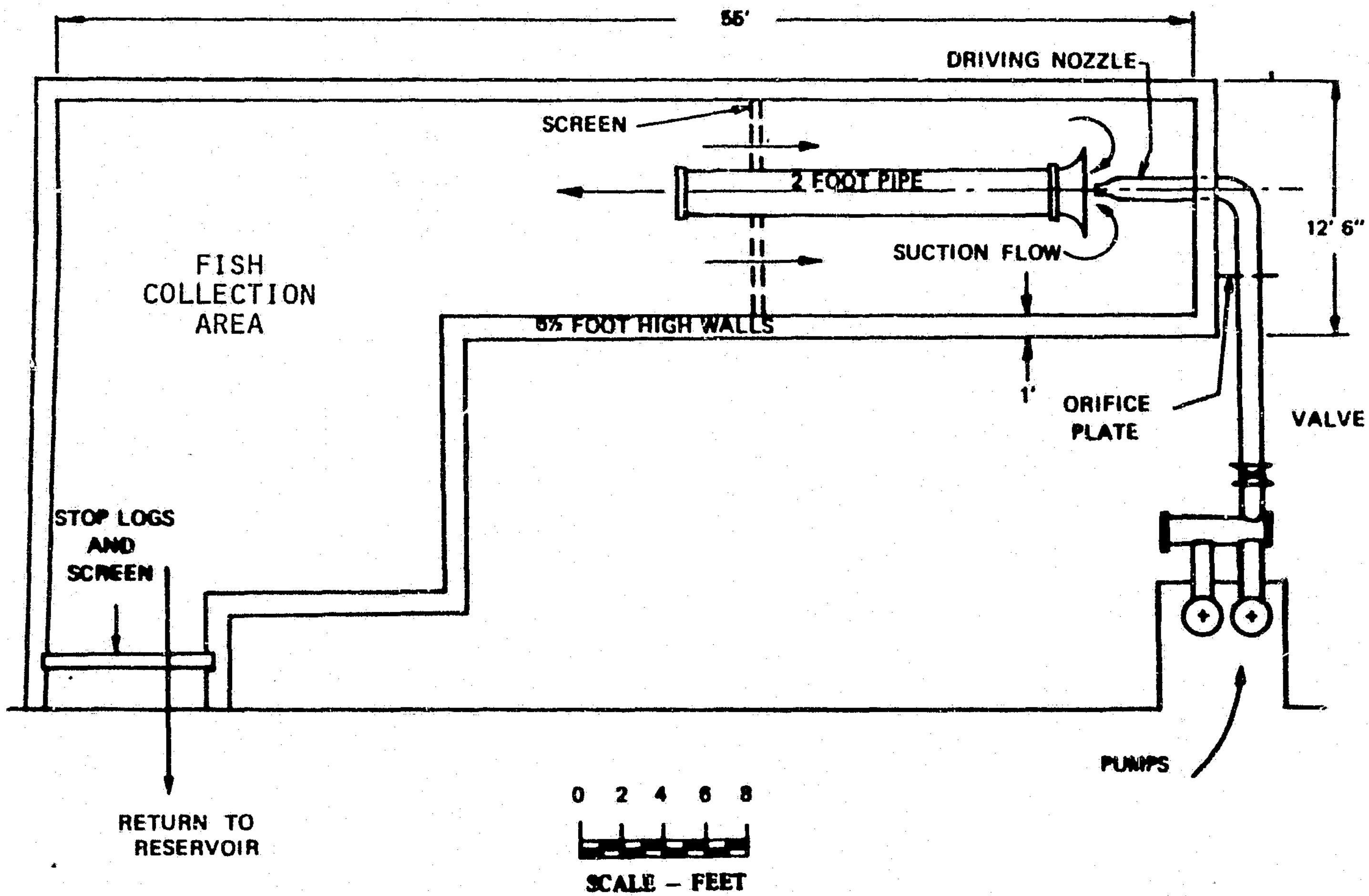


Figure 6. Layout of core jet pump test facility.

The peripheral-type jet pump (Figure 7) was evaluated in a 4-in. diameter model with a 2.5-ft mixing tube. The model was installed in a 2-by-2-ft flume approximately 30 ft long. The biologic test procedure consisted of placing test individuals directly into the suction pipe. Jet nozzle velocities of 30, 40, 50, and 60 ft/sec were evaluated.

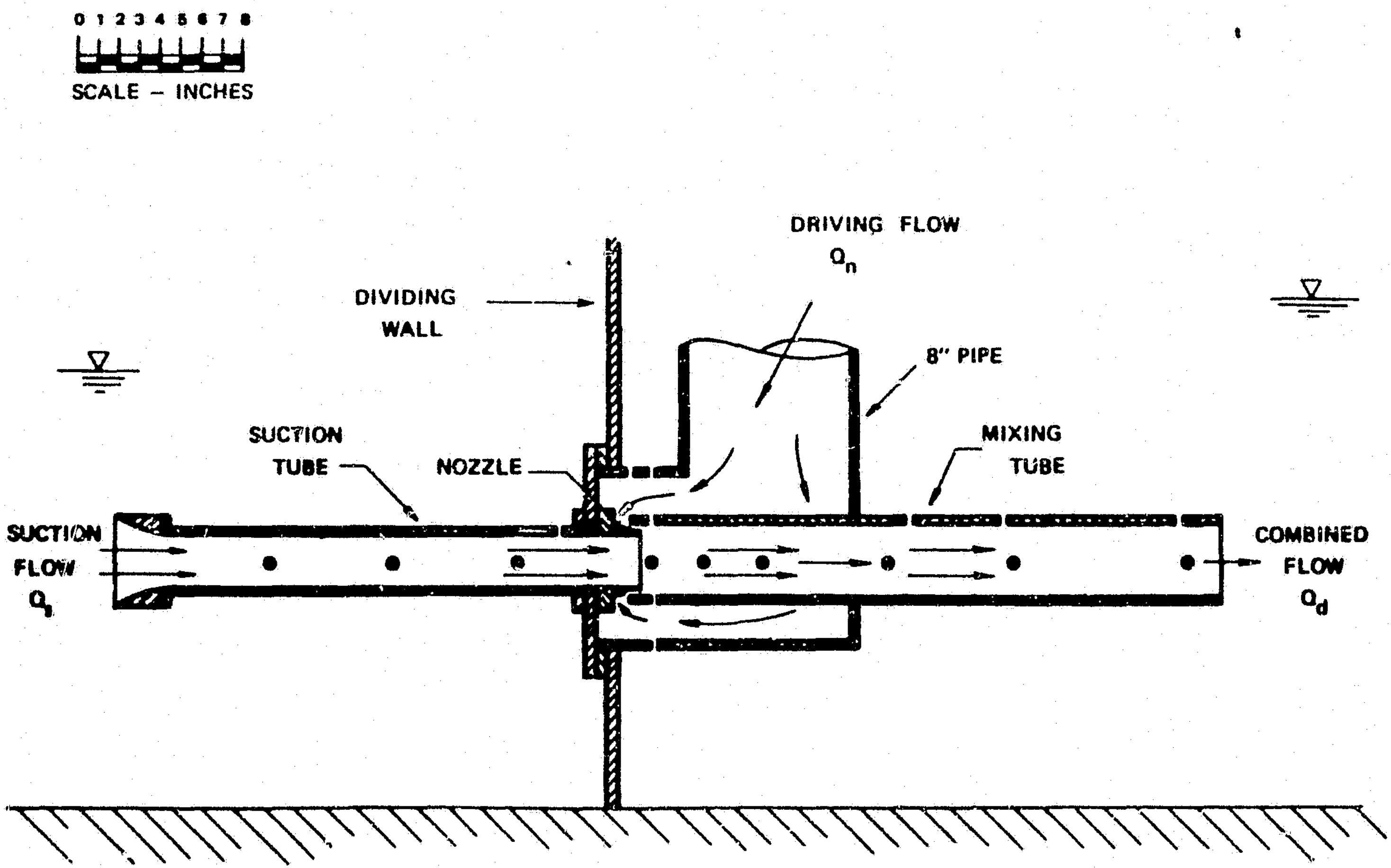
With a core jet pump, test individuals displaced normal schooling behavior in all cases and showed no signs of damage or stress after passage through the pump (seven tests with a total of 360 fish). One-week mortalities of both test and control fish were low.

Similar results were noted with the peripheral jet pump (29 tests with a total of 1,244 fish). By observing fish after passage through the pump, and by comparing 1-week test and control mortalities, differential mortality was found to be low for all three test species (less than 10%) at a jet nozzle velocity of 30 ft/sec. Because physical damage (scaling, loss of orientation) was more evident as jet nozzle velocity was increased to 40, 50, and 60 ft/sec, the potential for mortality appeared to be higher at these higher test velocities. However, an analysis of the data showed no significant relationship between velocity and mortality due to a limited number of tests and large variability in test and control mortalities.

Although the core jet pump proved to be a safe and effective means of transporting fish among the various components of the fish diversion system, the peripheral jet pump has been chosen for prototype application. The latter is deemed more practical because it has a lower potential for damaging fish (Figure 8). The nozzle piping of a core jet presents an obstacle to approaching fish that could cause a loss of orientation and physical damage due to abrasion. Comparison of the prototype pump with the model shows that this condition was not accounted for in the test procedure. Also, the nature of the core jet is such that fish entering the mixing zone would be forced toward the sides of the mixing tube and could, therefore, be further injured due to abrasion. The peripheral jet pump would present no obstacles to the fish and would tend to force them to the center of the mixing tube, thereby minimizing the possibility of abrasion of the sides.

Pipe Velocity Study

Operation of both the offshore intake diversion system and the screenwell louver system at NMP-2 involves the passage of fish through pipes. To determine the velocities needed to induce fish to move through a pipe with a minimum of physical damage and stress, tests were conducted in which fish were introduced into a pipe at various velocities.



COURTESY OF ALDEN RESEARCH LABORATIES

Figure 7. Peripheral jet pump.

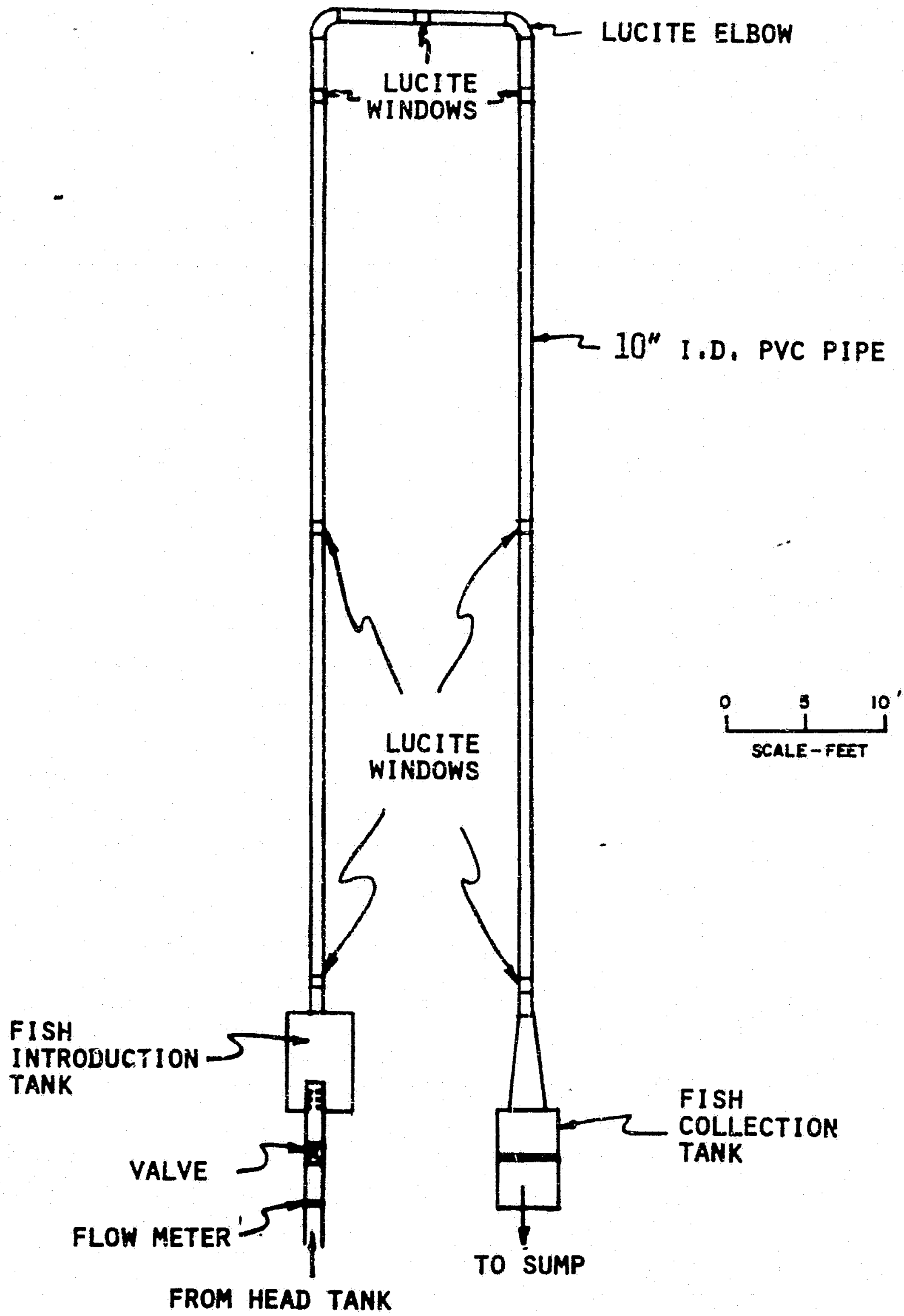


Figure 9. Plan view of pipe loop model.

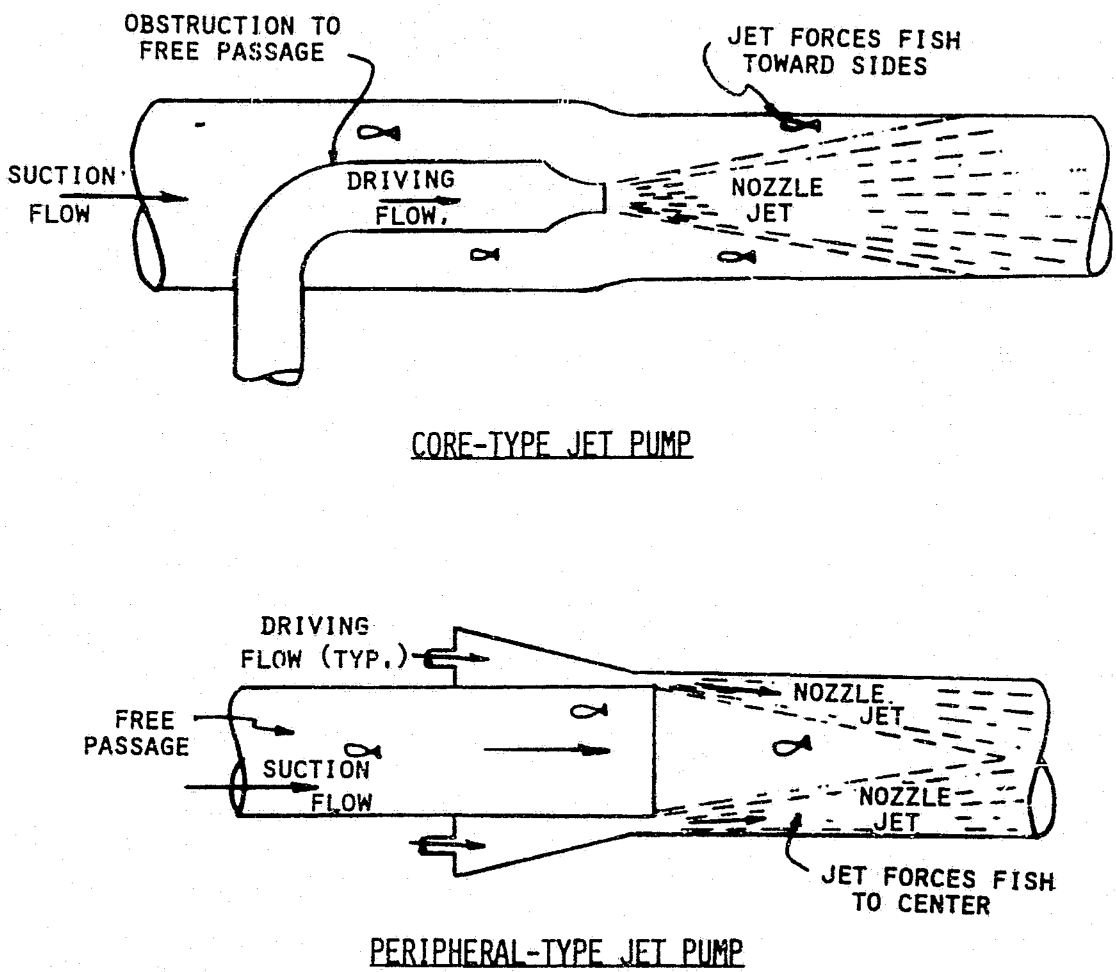


Figure 8. Comparison of core-type and peripheral-type jet pumps in relation to potential injury to fish.

Results of the study will be used in determining the acceptable velocities of the various components of the prototype piping system. These velocities will, in turn, be used for sizing the pipes of the system.

The pipe study test facility (Figure 9) consisted of a head tank and a collection tank connected by a 10-in. diameter, polyvinyl chloride pipe loop with an overall length of 147 ft. The loop had two straight sections, each 65 ft long, connected by two five-element, 90° mitered elbows and a third, 10-ft-long section.

Tests were conducted by introducing test individuals to the pipe, observing their behavior during passage through the system, and then removing the fish to a holding tank for determination of 1-week survival. An equal number of control fish was subjected to the same procedure, except for passage through the pipe, and then was placed in a separate tank for comparison of mortality.

Tests were conducted at velocities up to 9.5 ft/sec. In every case, the test fish showed no visible signs of damage or stress when collected. The mean differential 1-week mortality and 95% confidence limits at all velocities tested were -2.8 ± 7.5 for alewives (eight tests with a total of 187 fish) and $+7.6 \pm 11.9$ for smelt (8 tests with a total of 645 fish). Higher mortalities in both test and control fish correspond to outbreaks of bacterial infection.

Results of these studies will be utilized to design pipe dimensions and velocities in the prototype system. At this time, it appears that velocities up to 8 ft/sec are safe for transporting fish.

Pressure Study

Fish entering the NMP-2 submerged offshore intake will be subjected to pressure changes during their passage to the screenwell. Fish that are bypassed in the screenwell will be exposed to further changes as they are transported back to Lake Ontario. Very little information is available in the literature on the possible effects that these pressure changes may have on fish. Therefore, a test pressure chamber was constructed in which the pressures experienced by fish over time could be simulated.

The chamber was a square metal box, 1 ft on each side. One-inch-thick Plexiglas® windows on the front and back of the chamber allowed observation of the fish during testing. Pressure was supplied by a compressor capable of producing 85 $lb/in.^2$ within the chamber. Two valves were used to regulate the pressure in the chamber over a given time.

For the purpose of this study, calculations were made of the degree and time of exposure of fish to positive and negative pressures as they passed through the NMP-2 circulating water system, including the bypass and return facilities.

During testing, fish were placed in the pressure chamber and subjected to the positive and negative pressure changes that they would experience in the prototype intake. After testing, the fish were removed from the chamber and placed in a holding tank. One-week mortality was recorded and compared with that of control fish.

Pressure chamber testing resulted in mean differential mortality values and 95% confidence limits of -20.83 ± 21.1 for alewives (six tests with a total of 68 fish) and -11.3 ± 16.0 for smelt (eight tests with a total of 160 fish). High mortality was experienced in both test and control fish at certain times due to a bacterial infection. This finding would indicate that the mortality was not attributable to pressure stress, but rather to natural stress that resulted from the fungal infection. Therefore, it appears that pressure changes in the prototype intake system would not adversely effect the condition of fish entering it.

Prototype System Demonstration

To evaluate the cumulative effects of all of the components of a prototype screenwell fish diversion and return system for NMP-2, a large model was constructed that consisted of an angled screen, bypass, piping, jet pump, and collection area (Figure 10). The model was also used to verify the system's hydraulic characteristics, which had been calculated through a computer analysis under a wide variety of operating conditions.

The angled screen and model basins previously utilized for NMPC/RG&E flume testing were incorporated into the system demonstration model. At the end of the sloping angled screen bypass, a 10-in. inside diameter polyvinyl chloride pipe was fitted to the 12-in. diameter pipe previously described. This pipe, which contained six horizontal and vertical 90° bends, then carried the bypass flow to a jet pump that acted as the driving force. Two pumps supplied the driving flow to the jet pump. Exiting from the jet pump, a mixing tube carried the flow to a secondary fish bypass area that contained an angled screen. Fish entering the secondary bypass guided along the screen into a holding area from which they could be removed in a netted box without further handling.

As previously discussed, testing of the angled screen device for NMPC/RG&E resulted in a mean differential 5-day mortality and 95% confidence limits of 35.7 ± 13.5%. Results of system demonstration testing indicate that these values may be conservatively high.

It would be expected that mortality in the system demonstration would be higher than mortality with the angled screen alone due to cumulative stresses that result from passage through a pipe and jet pump at high velocities and guidance along a second screen to a collection area. However, this expected higher mortality was not observed. In three tests (500 fish per test) with screen approach and bypass velocities that ranged from 1.0 to 2.0 ft/sec, pipe velocities from 5 to 9 ft/sec, and jet nozzle velocities from 30 to 50 ft/sec, the mean differential mortality and 95% confidence limits in the system were 7.6 ± 9.8%. The results of a simple t test of the mean mortalities of angled screen and system demonstration tests indicate that the differential mortality was significantly lower ($\alpha = 0.05$) in the system demonstration than in tests with the angled screen alone.

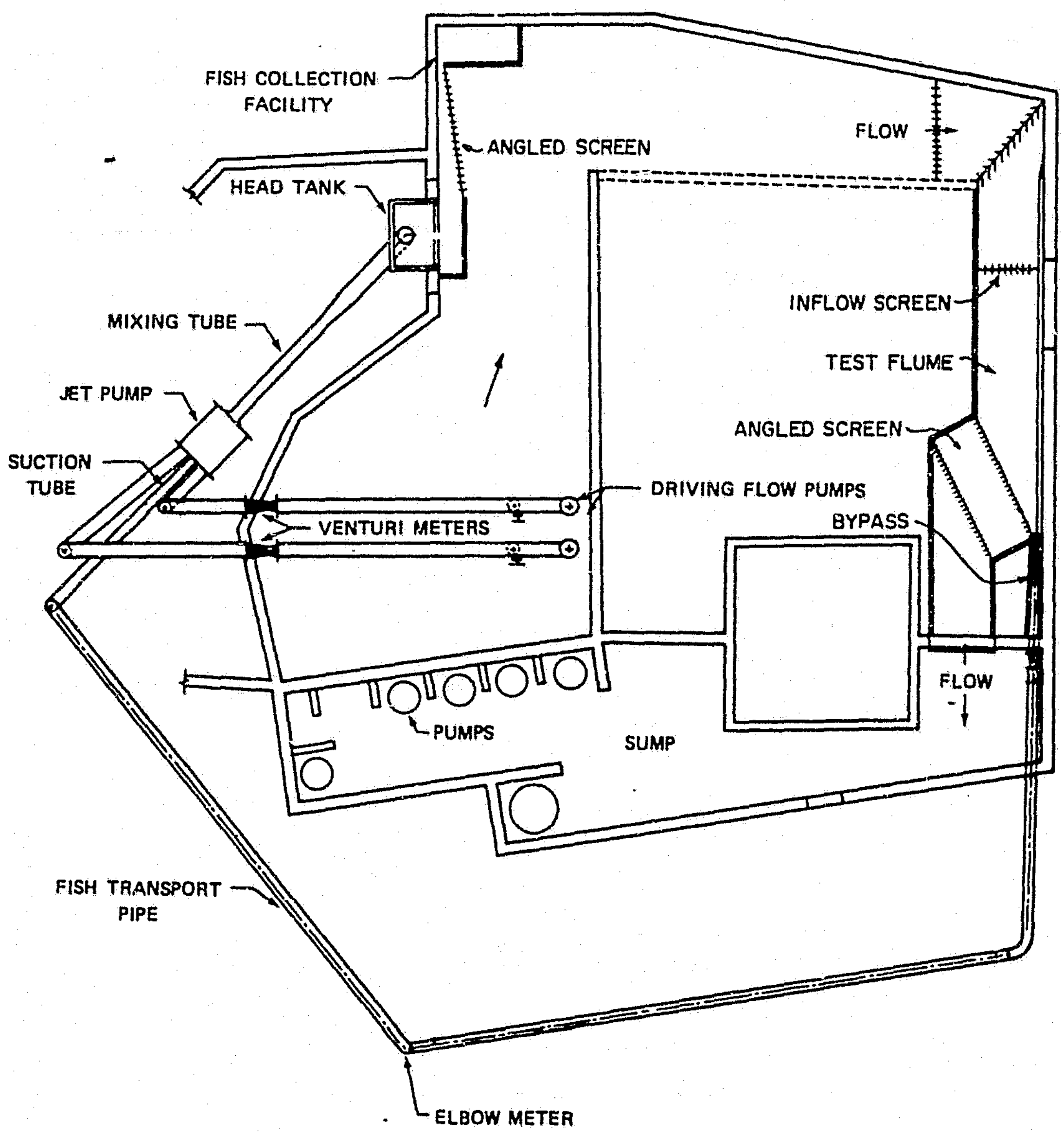


Figure 10. NMP unit-2 system demonstration model.

A possible explanation for this observed difference in mortality is that additional handling of test fish, as required for their removal from the angled screen bypass collection area, resulted in greater stress and, therefore, mortality in these fish, whereas fish tested in the system demonstration model were not handled subsequently to their introduction to the test flume. Therefore, because it appears that high mortalities in tests with the angled screen alone are partially a result of fish handling as part of the test procedure, the results of the system demonstration tests may be more indicative of the latent mortality that might occur in such a system constructed on Lake Ontario.

CONCLUSIONS

In instances where operating experience indicates a high potential for fish impingement, the use of hydraulic models and/or evaluation in the field of various techniques to minimize impingement can provide valuable design criteria for water intakes. This experimental approach provides two major advantages. First, the information obtained by observing the reaction of fish under various simulated design conditions allows for an evaluation of potential effectiveness over a wide range of design criteria. Models can be constructed so that design changes can be readily accommodated in a short period of time, whereas changes to an actual intake without some assurance of effectiveness would be time consuming and expensive. The second major advantage of these types of studies is that the information obtained can serve as evidence, to various regulatory agencies, that the proposed facility intake represents a reasonable design for the protection of species that are indigenous to the area.

The studies described in this paper are ongoing, and the results given are, therefore, preliminary. A detailed description of results will be published on completion of the various study programs.

ACKNOWLEDGMENTS

We express our appreciation to Messrs. J.L. Hilke and J.M. Toennies of Niagara Mohawk Power Corporation, Mr. R.W. Gilkinson of Rochester Gas and Electric Corporation, Messrs. L.A. Rodriguez and L.R. Tuttle of Consolidated Edison Company of New York, and Mr. F. Gottlich of Boston Edison Company for their technical assistance in conducting these studies and for their critical review of the manuscript. We also thank Messrs. G.E. Hecker, J. Larsen, and J.W. Leavitt of the Alden Research Laboratories for their input into the design, construction, and operation of the various biologic and hydraulic models and their aid in the interpretation of hydraulic data.

In addition, we gratefully acknowledge Messrs. Y.G. Mussalli and J.M. Polefka of Stone & Webster Engineering Corporation for their direction in the engineering aspects of the study program.

BIBLIOGRAPHY

Bates, D.W., and S.G. Jewett. 1961. Louver efficiency in deflecting downstream migrant steelhead. Trans. Eng. Fish. Soc. 90(3):336-337.

Bates, D.W., O. Logan, and E. Pesonen. 1960. Efficiency evaluation, Tracy Fish Collecting Facility, Central Valley Project.

California Department of Water Resources. 1967. Fish collection facilities bypass intake passage spacing tests at Tracy Fish Collecting Facility 1963, 1964. The Resources Agency of California.

Downs, D.I., and K.R. Meddock. 1974. Design of fish conserving intake system. J. Power Div. ASCE 100(P02).

Ducharme, L.J.A. 1972. An application of louver deflectors for guiding Atlantic salmon *(Salmo salar)* smolts from power turbines. J. Fish Res. Board Can. 29:1397-1404.

Hallock, R.J., R.A. Iselin, and D.H. Fry, Jr. 1968. Efficiency tests of the primary louver system. Tracy Fish Screen, 1966-1967, Marine Resources Branch, California Department of Fish and Game.

Ruggles, C.P., and P. Ryan. 1964. Louvers for guiding Pacific salmon. Can. Fish Cult. 33: 1-68.

Schuler, V. 1973. Experimental studies in guiding marine fishes of Southern California with screens and louvers. Ichthyol. Ass. Bull. 8.

Thompson, J.S., and G.J. Paulik. 1967. An evaluation of louvers and bypass facilities for guiding seaward migrant salmonid past Mayfield Dam in West Washington. Washington Department of Fisheries, Olympia, Washington.

United States Fish and Wildlife Service. 1960. Efficiency evaluation, Tracy Fish Collecting Facility, Bureau of Reclamation, Region 2.

Stone & Webster Engineering Corporation. 1975. Studies to alleviate potential fish entrapment problems-summary report, 1973-1974. Niagara Mohawk Power Corporation.