TVA | Tennessee Valley Authority | Office of Power
Power Research Staff
Chattanooga, Tennessee 37401 | PRS-16

EPA | United States Environmental Protection Agencv | Office of Research and Development
Office of Energy, Minerals, and Industry
IERL, Research Triangle Park, NC 27711 | EPA-600/7-76-020

October 1976

A STATE-OF-THE-ART REPORT ON INTAKE TECHNOLOGIES

Interagency Energy-Environment Research and Development Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into seven series. These seven broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The seven series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally--compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

PRS-16
EPA-600/7-76-020
October 1976

A STATE-OF-THE-ART REPORT ON INTAKE TECHNOLOGIES

by

S. S. Ray and R. L. Snipes (TVA/Chattanooga)
and D. A. Tomljanovich (TVA/Norris)

Tennessee Valley Authority
Power Research Staff
Chattanooga, Tennessee 37401

and

Division of Forestry, Fisheries, and Wildlife Development
Norris, Tennessee 37828

EPA Interagency Agreement No. D5-E-721
Program Element No. EHB531

EPA Project Officer: James P. Chasse (EPA/Corvallis)
TVA Project Officer: H. B. Flora (TVA/Chattanooga)

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

This study was conducted
as part of the Federal
Interagency Energy/Environment
Research and Development Program.

Prepared for

OFFICE OF ENERGY, MINERALS, AND INDUSTRY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

DISCLAIMER

ABSTRACT

The purpose of this report is to present an updated evaluation of mechanisms and intake designs for reducing the numbers of fish entrained and impinged at water intake facilities. These mechanisms consist of intake configurations, behavioral barriers to guide fish past intake entrances, screening devices to remove or divert fish from cooling water intakes, and fish removal systems to evacuate fish already within the intake area.

This report summarizes evaluations of available intake technologies and, more importantly, presents results of recent tests and studies. Where promising mechanisms are identified, recommendations are made with regard to tests needed to demonstrate the applicability of a mechanism for protecting fish in site-specific situations.

This report also addresses the problem of reducing fish losses at both large-volume, once-through cooling water intakes and lower-volume intakes at plants requiring only makeup water to replace losses due to cooling tower blowdown and evaporation. For the evaluations of devices for reducing impingement and entrainment, due consideration was given to devices and designs that are capable of protecting very small fish and eggs.

This report was submitted by the Tennessee Valley Authority Power Research Staff in partial fulfillment of Energy Accomplishment Plan No. 77BBE under terms of Interagency Energy Agreement No. D5-E-721 with the Environmental Protection Agency.

CONTENTS

FIGURES

TABLES

SECTION 1

INTRODUCTION

The purpose of this report is to present an updated presentation of mechanisms and intake designs that are currently available for reducing the numbers of fish lost due to entrainment and impingement at cooling water intake facilities. Several reports on available technologies pertaining to fish protection at cooling water intake structures were prepared prior to or during 1973.[1-6] These documents contained descriptions and evaluations of types of intake locations and configurations, behavioral barriers for guiding fish past intake entrances, and mechanical devices to screen or otherwise divert fish from cooling water intakes. This report briefly summarizes the descriptions of available intake technologies described in those documents and presents the results of tests and studies not found in those reports as well as an update of studies conducted subsequent to the 1973 reports. During the preparation of this report, an additional summary document was distributed by the Energy Research and Development Administration (ERDA) on fish protective devices.[7] The ERDA report, a compilation of recent designs, concepts, and operating experience of water intakes used in the United States , is also summarized herein.

The scope of this report is to address the problem of reducing fish losses at both large-volume, once-through cooling water intakes and lower-volume intakes at plants requiring only makeup water to replace losses due to cooling tower blowdown and evaporation. Discussions are included on plant siting, intake design, behavioral barriers to guide fish past water intakes, physical barriers to prevent fish from entering intakes, and fish removal systems.

An important consideration in the evaluation of an intake screen system or mitigative device is the smallest fish that these mechanisms and devices are capable of protecting. Most conventional vertical traveling screens in use throughout the country utilize 9.5 mm opening square mesh screens. These screens have effectively divided the fish community into two sizes: impingeable size (those that are retained by the screen) and entrainable sizes (those that pass through the 9.5 mm opening mesh screen). Depending upon the body shape of the species, velocity through the screen, and position of the fish when it contacts the screen, the impingeable and entrainable size may vary. Impingement sampling at 13 Tennessee Valley Authority (TVA) electric power plants has indicated that fish less than 26 to 30 mm in total length pass through the screens, and that those larger are impinged against the screens.[8] In the past, efforts have been focused on devices to reduce impingement, while the entrainment problem has been regarded as largely unsolvable except where plant siting can minimize larval fish losses. However, increased attention is currently being directed at the feasibility of protecting larval fish at water intakes.

SECTION 2

CONCLUSIONS

1. The protection of fish at water diversions has a long history in the United States, but the enactment of recent legislation has resulted in an intensified nationwide examination of entrainment and impingement effects at power plant cooling water intakes.

2. Because of the requirement in Public Law 92-500, as amended in 1972, for "best technology available for minimizing adverse environmental impact"regarding the cooling water intake, comparisons of impact based on type of intakes are desirable. However, the many variables that affect the number of fish entrapped at an intake, ranging from hydraulic and structural differences to fish density and species differences in the source water body, render these comparisons difficult.

3. Plant siting in least productive areas is important in terms of mitigation of fish loss. However, in the case of existing plants, siting for fish protection may not have been a consideration.

4. Many types of behavioral barriers have been tested for their capability of guiding fish away from water intakes. To date, most have limited applicability to power plant intakes although several successful applications of electrical, air, and louver barriers have been reported.

5. Several fish pumping or collecting devices have been proposed or installed to remove fish trapped in intake wells. To date, test results of recent prototypes have not been reported.

6. One modification to an existing vertical traveling screen has shown high savings of impingeable-size fish. Water-carrying troughs attached to each screen panel lift live fish from the screen well as the screen rotates continuously.

7. Most power plant intake screens are incapable of providing protection for larval fish. An exception may be a single-entry, double-exit (center flow) continuous traveling screen with semi-circular shaped screen panels. The screens consist of 0.5 mm opening polyester screen. This screen has the potential for pre-

venting larval fish entrainment and diverting live fish back to the source of water but may require several modifications. To date, field studies on larval fish survival have not been completed.

8. Other possible intakes capable of larval fish protection include low-velocity, filtration-type structures (infiltration beds and slotted or perforated conduit) and the horizontal traveling screen with fine mesh screen.

SECTION 3

RECOMMENDATIONS

Much effort has been expended in recent years toward development and evaluation of fish protection systems at water diversions and power plant intakes. To date, however, there exists no one screening system that has been deemed "best technology available." Several concepts and prototypes have been introduced that show promise for fish protection but too often these same designs present major operating problems. Site specificity may require unique designs for each site to satisfy the "best technology" requirement. However, several proposed concepts, if sufficiently developed and evaluated, may be widely applicable at water intakes.

Areas in need of further study and development are suggested by the current state-of-the-art of fish protection at water intakes. Several of these areas are listed below:

1. Assessment of impact of entrainment and impingement losses at existing intakes on the source water populations.
2. Prediction of fish losses and impact at proposed water intake sites.
3. Development of methods to crowd, guide, and otherwise control the movement of fish past water intakes, including control and laboratory study of fish response to velocity and temperature gradients, as well as other stimuli.
4. Protection of larval fish and eggs at water intakes using fine mesh screening, filtration devices, and low velocity slotted and perforated conduit.
5. Development of prototype structures from results of the laboratory tests suggested above.
6. Establishment of a nationwide task force on intake structure, research, and development. To preclude duplication of effort, a need exists for a timely and efficient means of coordinating proposed studies, status reports, and results of studies.

SECTION 4

PLANT SITING AND INTAKE DESIGN

GENERAL

The importance of plant siting and intake location in reducing adult and larval fish loss is recognized. In some river systems, however, spawning migration of many species and transport of eggs and larvae with river currents may preclude "favorable" siting. Egg and larval forms of many species of fish are subject to transport with the currents for at least a short period of time. Consequently, the protection of adequate numbers of larval fish near power plant intakes is in part dependent upon the amount of water withdrawn. Therefore, it is desirable to avoid withdrawing large percentages of the body of water unless larval fish protection is provided for or unless it has been determined that the amount of entrainment is an acceptable loss.

INTAKE CONFIGURATION AND DESIGN

There are three basic orientations of cooling water intakes with respect to the shoreline: offshore conduit, shoreline (bankside), and the intake approach channel. Descriptions of these designs have been well documented.[2] Selection of a design in the past has been based primarily on factors unrelated to protection of fish. Subsequent evaluations of fish entrapment have provided some comparative information on the magnitude of fish losses at the different types of intakes. However, because of the many variables associated with impingement at each site, comparison of intakes among plants is difficult.

Offshore Intake

Minimization of fish losses, including larval fish, may be achieved by siting intakes offshore in areas of low densities of fish. On the other hand, if these intakes are located in areas of high concentrations of fish, offshore intakes can result in adverse impacts to adult and larval fish because of their usually high entrance velocities. After the fish enter the conduit and are pulled toward the intake pumping structure, their chances of escape are greatly diminished.

An additional problem exists with some offshore intake configurations which result in a vertical withdrawal as the water enters the conduit. Fish are much less sensitive to water flowing vertically than horizontally. Since fish can better detect the horizontal flow, a velocity cap placed horizontally above the end of the intake pipe to convert vertical flow to horizontal flow has been successful[1] in reducing the numbers of entrapped fish. Southern California Edison Company, which installed the first velocity cap in 1956 at the El Segundo Generating Station, reported 90 percent reductions in fish entrapment.[9] This company has also undertaken testing at Los Angeles, California, to determine the most efficient design of the velocity cap.

Shoreline or Bankside Intake

The orientation of the intake screen housing flush with the shoreline offers some potential for lateral movement of fish to escape entrapment. However, most shoreline intakes contain separate suction pits for each screen with openings only on the front side. These openings are usually covered by trashrack bars spaced approximately 9 cm apart and located below a concrete curtain wall. Once inside the screen well, the fish have no lateral escape route and must pass back through the trashracks to avoid impingement. In California, one version of the shoreline design (termed the "Pacific Gas and Electric Intake Design"[3]) has the screens placed flush with the shoreline with no divider walls, allowing free direct and lateral passage of fish. One large cage-like trashrack located out from the screens excludes large debris. The approach velocity (velocity of flow through the trashrack) is designed to be less than the sustained swimming speed of the indigenous fishes. If the fish passes through the trashracks, it does not become trapped in a well but may swim laterally along the face of the screens to avoid impingement.

Approach Channel Intake

The location of the intake screen housing structure at the end of an approach channel is usually considered less effective for fish protection than a shoreline orientation because of the entrapment effect created by the channel.[2-5] If the fish follows the intake shoreline, it eventually encounters the end screen of the pumping structure. A combination of eddy currents, turbulence and turbidity in the corners where the end screens meet the channel banks is probably responsible for the higher impingement usually associated with end screens at many approach channel intakes.

Biologists at Duke Power Company attribute low numbers of impinged fish at Buck Steam Station to an intake located flush with the riverbank and lacking eddy currents.[10,11] Conversely, higher numbers of impinged fish at Duke Power Company's Marshall Plant and Allen Plant were attributed in part to the location of these intakes at the end of a cove (Marshall) and a shoreline depression (Allen).

The Tennessee Valley Authority has compared impingement monitoring results at its nine channel intakes and five shoreline intakes.[8] Of the former nine channel intakes, five showed very low numbers of impinged fish while the remaining four produced much higher numbers. Of the five shoreline intakes, four produced low numbers of impinged fish, and one produced high numbers. In these cases, the numbers of impinged fish were not directly related to type of intake. Differences in impingement among plants may have been caused by differences in fish densities near the intake; species common to the area; severity of winter cold shock on threadfin shad; and intake velocities through the skimmer opening, channel, trashrack openings, and screen. In addition, impingement at a plant is probably affected by several other often subtle factors including the following: water elevation, temperature changes, turbidity, fish migration, schooling behavior, light conditions, fish condition, etc.

A skimmer wall at the entrance of the approach channel, if deep enough, may reduce entrainment of larval fish. However, a skimmer wall may also be selective for bottom dwelling fish and could create a trap for fish that swim under the wall. In addition, high approach velocity through the skimmer wall opening, through the channel, or through the trashracks and screens may seriously reduce the ability of fish to escape from approach channel intakes and intakes with skimmer walls. Where constrictions occur in an approach channel intake, intake velocities may surpass the sustained swimming speed of many species and sizes of fish and result in a high rate of fish entrapment.

Except by their possible location away from high concentrations of larval fish, none of the three intake orientations offers any mitigation in entrainment of larval or young juvenile fish.

SECTION 5

BEHAVIORAL BARRIERS

GENERAL

To minimize the problem of fish entrapment at cooling water intakes, several behavioral screening methods have been evaluated for safely diverting fish. It is emphasized here, as in several of the reports on this subject, that, before any device of this type can be fully evaluated from a biological standpoint, a thorough understanding of several pertinent biological characteristics of the fish to be protected is required. Particularly important are the species of concern, their sizes and swimming ability, the effect of water temperature on their swimming ability, and behavioral characteristics such as schooling and preference for specific zones or strata of the water column. The remainder of this section is a summary of available fish-protective behavioral barriers.

ELECTRICAL BARRIER

Description and evaluation of the feasibility of guiding fish with electricity is well documented.[1-3] Typically, an electric barrier (Figure 1) consists of an array of electrodes suspended across the intake which, when energized, prevents fish passage. The first patent for this type of barrier was taken in 1910.

The results from studies on guiding fish by electric barrier have been varied. Electric barriers have been successfully used to stop upstream-migrating salmon. If a fish swims too far into the electric field, it is stunned and carried downstream. Upon recovery, an upstream-migrating fish swims back toward the electrode and eventually is guided to one side of the river where the bypass is usually located. On the other hand, downstream-migrating fish (or fish approaching an intake channel or structure) which are stunned by an electric field are likely to be carried by the current toward the intake screens. The effects of electric fields on fish are discussed by Maxfield.[12]

Holmes[13] discussed the experience of electrical fish diversion systems in California and the Pacific Northwest up until 1948. Results of his research indicated that some of the first systems were successful, but ultimately all the electric barriers were removed and evaluated as failures.

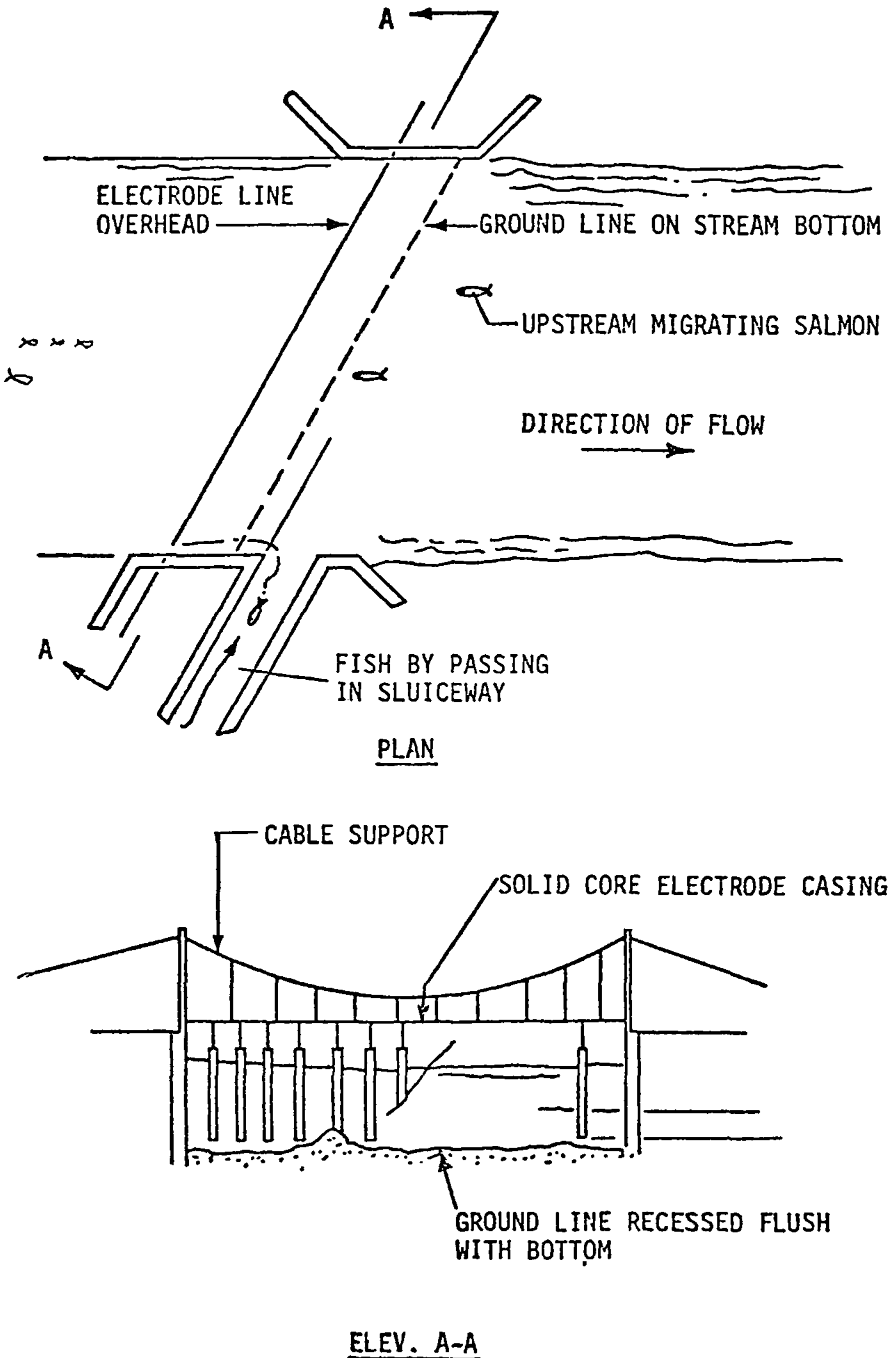


FIGURE 1. TYPICAL FEATURES OF AN ELECTRIC SCREEN USED IN U.S. (2,7)

Recent work in electrical systems has been concerned with guiding techniques. Laboratory experiments discussed by Maxfield[12] and Trefethen[14] give some results on the configuration of the electrode array and its angle to the flow. Maxfield's work on the potential pulse frequency and pulse duration of his system showed that, when using an array of several rows of electrodes 45.7 cm apart, the optimum potential was 60 volts and the most effective pulse frequency was two pulses per second. Trefethen found that positioning the electrodes at an angle of 40 degrees to the flow and spacing them 30.5 cm apart was the most efficient and practical arrangement. Trefethen achieved a diversion efficiency of 68 percent of salmon fingerlings with an electric screen using a voltage gradient of one volt per centimeter and pulse frequency of 8 pulses per second with a pulse duration of 40 milliseconds. Maxfield discussed a full-scale experiment at the Cascade Reservoir in Idaho. The electrodes were arranged in parallel rows to allow for a sequence of pulses which were designed to guide the fish toward the bypass. This laboratory test gave diversion efficiencies up to 80 percent for adult squawfish.

Recent research conducted at the Connecticut Yankee Atomic Power Plant[15] showed the use of an electric barrier to exclude fish from a 24.9 m^3/sec intake mounted flush with the shoreline. Results showed some reduction in numbers impinged, but size and species selectivity was apparent. Problems were encountered because of the excessive time that fish remained in the area between the electric barrier and the traveling screens between tests. Additionally, ice formation necessitated removal of the floating electrode booms during winter months. However, project biologists believed the results of these tests were encouraging enough to warrant further testing of additional designs and modifications of the electric barrier.[16]

At a few plants, electric barriers were installed with no preoperational baseline data describing the extent of the fish impingement problem. Furthermore, too often little or no postoperational biological testing of barriers has been conducted to evaluate the effectiveness of the mechanism. For example, in the 1940's Northern Indiana Public Service Company (NIPSCO) installed an electric fish screen at their 215 megawatt Michigan City plant because migrating minnows and perch had previously threatened plant operation each spring and fall. The electrodes were spaced 30.5 cm apart in two rows spaced 45.7 cm apart. Voltages varied from 300 to 600 volts, pulse rate varied from 1 to 5 per second, and the water approach velocity was 20.7 cm/sec. This electric barrier is currently being used in conjunction with an air curtain. The barrier was labeled a success[1] since it has been in operation for more than 27 years, but there has never been any controlled biological testing of the system.[17] Too often the only criterion for the success of these devices is whether or not plant operation is interrupted by fish impingement. The installation's satisfactory operation for 27 years led to the installation of an additional electric barrier at another NIPSCO 414 megawatt plant.

The successful use of the electric fish barrier for prevention of impingement and entrainment at water intake systems appears doubtful at this time for several reasons.

1. Approach velocities at most water intakes may be too high for most guidance devices or barriers.

2. Most studies have shown low or marginal reductions in impingement losses following installation of electric barriers at large intakes.

3. The electric barrier requires much trial-and-error fine-tuning to provide optimal operation.

4. The effect of an electric gradient is dependent on the fish species and size of the organism.

5. Since they operate as a behavioral device for juvenile or adult fish, the electric guidance devices are not designed to reduce entrainment of larval fish or small, weak-swimming post-larval fish.

6. If a fish is stunned by the electric field, it may be carried into the intake.

7. An electric barrier has not been developed for use in estuarine or ocean waters.

8. The electric barrier may present a danger to humans and animals.

Electric barriers appear to have the most promising application at intakes where one or few species of a limited size range are to be protected. The electric screen, with all its published theory and application, is sometimes summed up as follows: "so little is known about how an electric field stimulates a fish that it is difficult to design a successful electrical guiding device."[1]

SOUND BARRIER

Attempts have been made to use sound barriers for diversion of fish around power plant intakes. Fish have been shown to respond to various intensities and frequencies of sound. A sound barrier typically uses underwater speakers located at various depths and locations to broadcast the frequencies desired. The fish trying to avoid the sound outputs are guided to an area where a bypass or safe fish removal system is located. A wide variety of sound-generating devices has been investigated, but none has been very successful. The problems associated with varying intensities and frequencies for different species seem to be the main reasons for lack of success.

After an extensive research effort to guide fingerling Chinook salmon in the late 1940's, Burner and Moore[18] concluded that certain fishes may be frightened momentarily by any noise but adjust to disregard it (become conditioned) almost instantaneously and that at no time did a sound frequency or intensity influence the action of the fish enough to be utilized in guiding young salmon into safe passages around dams and diversions.

Vanderwalker [19] indicated that fish respond to selected frequencies and concluded that repeated exposures did not affect the sensitivity and acclimation of the fish to the frequencies.

The use of sound barriers proved to be unsatisfactory for repelling fish at Indian Point[7] and Surry[20] Power Plants. The Surry sound barrier was designed and installed by Virginia Electric and Power Company (VEPCO) for the purpose of reducing impingement. VEPCO recognized at Surry that fish became acclimated to repetitive sound. Rock-and-roll music, which produced ultimate discordance with varying frequencies and amplitudes, was subsequently used. This sound barrier was partially successful and did reduce the fish impingement problem but the company concluded that this concept was not the solution to their particular situation. The sound barrier was subsequently replaced by a mechanical device to reduce the fish problem.

Based on the results obtained by VEPCO, Schuler and Larson[21] conducted sound avoidance experiments in California to test the reaction of black perch, shiner perch, kelp surfperch, greenfish, and northern anchovy. Rock music, a killer whale tape, and a range of frequencies from 20 c/s to 15,000 c/s resulted in no observable fear reaction when played through the underwater speakers. Experiments suggested that the fish did not respond to the tape replay of a live sound with the same reaction they would have given to the live sound because of the absence of a shock wave which would have been associated with the live sound.

In addition to the music experiments, Schuler and Larson performed experiments with an underwater pneumatic impact device which produced a shock wave ("popper"). It was found that most fishes avoided the immediate area of the "popper" by at least 3 m when it was cycled continuously at rates of 2 to 15 cycles per minute. Further, the "popper" appeared to be more effective in open water as opposed to a confined forebay. Fishes toward the upper part of the water column showed a greater response to the "popper".

LIGHT BARRIER

The use of light to guide fish has been investigated as a possible fish barrier for water intakes. It has been shown that under certain conditions some fish can be repelled by lights while others are attracted. In general, it appears that the use of light as a barrier screen is not considered reliable.

Fields[22] has done extensive work on guiding migrant salmon with artificial light and concluded that "under some conditions artificial light can repel migrants and divert them from certain areas. In such situations, the problem is one of balancing various environmental stimuli so that light intensity overrides velocity, turbidity, depth, and temperature. Under other conditions artificial light can attract migrants and concentrate them in particular areas. Some degree of light adaptation is necessary before attraction will occur."

Fields[22] stated that all dark-adapted downstream-migrant salmon and steelhead trout can be guided by light repulsion when they are in relatively clear water flowing at more than 30 cm/sec. Any light perceivably brighter than the adaptation light will elicit the avoidance response under controlled conditions. For example, in areas of current velocity of 1.2 m/sec or greater, unshaded lights placed along the stream banks will move the downstream migrants away from the bank. For silver salmon, a constant light is more effective than an interrupted or flashing light because the fish float into or through the light barrier during the dark phase of the cycle. It is more difficult to guide fry by repulsion because of their lesser swimming ability and their choice of lower-velocity waters. It also appears that fry are more likely to adapt to the light.

Fields found guidance by light attraction inevitably involved a certain degree of light adaptation. Fields expected that under normal conditions dark-adapted fish would not be guided by light attraction. Attraction guidance is more effective when the original adaptation illumination is then followed by a reduction in illumination. For example, a light barrier constructed at a 90° angle may block all downstream migrants. The length of time that the fish can remain stationary against the flow while resisting the light is the fish adaptation time to the higher-intensity light. When a fatigued condition is reached by the migrants, they are pulled by the water current into the higher illumination area. After the migrants leave the higher-illumination area, they are attracted to a downstream light area of the same or lesser illumination. The brighter the initial adapting area and the longer the adaptation period, the better the movements of migrants can be controlled. Fields also found that as the light-adapted fish are subjected to sudden darkness, they are unable to maintain a visual orientation and are swept downstream at the mercy of the water currents.[22] Striped bass were found to quickly adapt to and pass through an intense illumination barrier.[23]

The unpredictability of individual fish species' reactions to lights precludes a general recommendation for use of lights at water intakes. However, it has been suggested[5] that lights may serve to improve fish guidance when used to complement other barriers or removal systems which rely on the visual responses of the fish. The use of lights in conjunction with the Detroit Edison Monroe Power Plant fish pump increased the pumping efficiency by 1.5 to 2.0 percent. Prior to installation of the lights, efficiency was 80 to 90 percent. Additionally, the use of lights apparently resulted in an increase in the removal of smaller-size fish than had previously been pumped.[24]

AIR BUBBLE BARRIER

The air curtain (Figure 2) has been summarized in several references.[1,2] Impingement of alewife, a schooling shad species similar in size and appearance to threadfin shad, has reportedly been reduced due to the presence of air bubblers at Wisconsin Public Service Company's Pulliam Plant and Kewaunee Nuclear Plant on Lake Michigan.[1,25]

The Kewaunee air bubbler, located at an offshore intake structure, is shown in Figure 3. Although no controlled tests have ever been conducted, the company believes the bubblers are effectively excluding the alewife.[25] Prior to the installation of the air bubble barrier, there had been several shutdowns of the plant caused by schools of alewives blocking the screens. Since the air screen installation, there have been only one or two shutdowns. Occasional outages of the air bubbler compressor have been accompanied by heavy impingement of alewife on the screens. However, operation of the bubblers did not eliminate impingement. Occasionally, schools of alewife break through the air curtain, but these occurrences are not of the magnitude and frequency experienced without the barrier.

The Northern Indiana Public Service Company's (NIPSCO) Michigan City plant bubbler is believed to effectively divert alewife while larger fish are diverted by the electric screens at the same intake.[17]

Brett and MacKinnon[26] reported that a bubble barrier failed to guide young spring salmon during their nighttime migration. When the bubble barrier is accompanied by continuous or flashing light, the number of fish deflected by the air screen appeared to increase.

Bates and Vanderwalker,[27] testing spring Chinook salmon, also found high deflection rates with air screens during daylight conditions but poor results during dark conditions. Best results were obtained during daylight hours with an approach velocity of 58 cm/sec. They stated that "the effectiveness of an air bubbler screen in deflecting downstream migrants is a function of the fish's ability to see it." The visual ability of fish is limited during nighttime hours or when the fish are located in highly turbid waters. They tried the use of artificial lights to solve the nighttime problem but found that the lights did not improve the diversion efficiency. They concluded that additional studies with various lighting techniques might improve the nighttime effectiveness.

Smith[28] reported a successful use of a 200-fathom long air curtain to guide herring into a weir for commercial harvest. Guiding was successful if the fish were not overcrowded or pushed too fast.

Imamura and Ogura[29] reported the air curtain to be effective for driving *Trachurous japonicus* in Japan but that long-term crowding could not be accomplished.

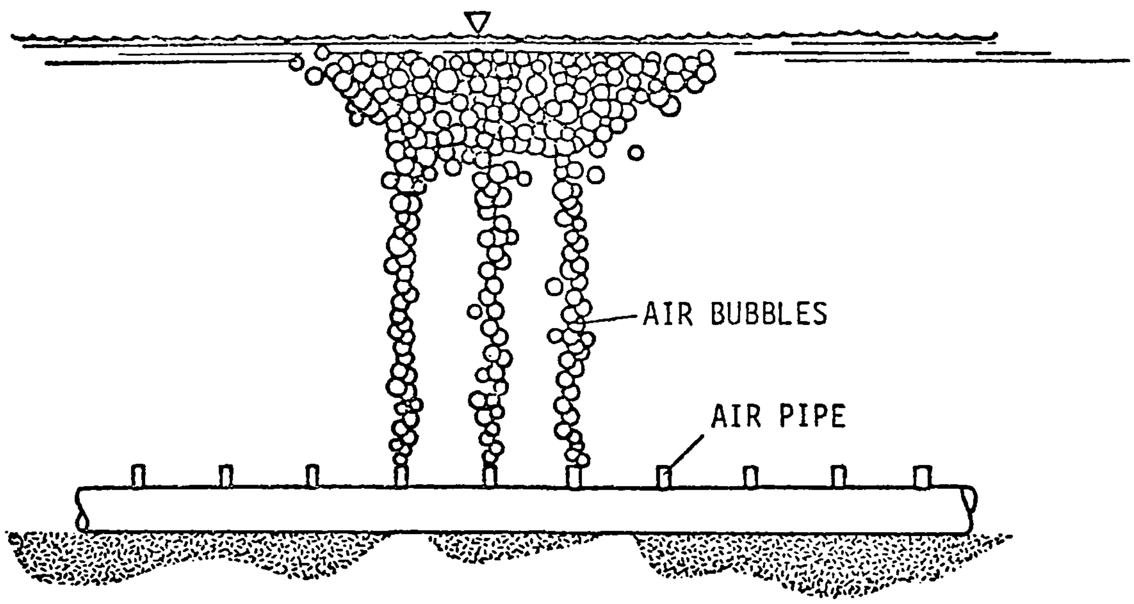


FIGURE 2. AIR BUBBLE SCREEN (ELEVATION VIEW) (2,7)

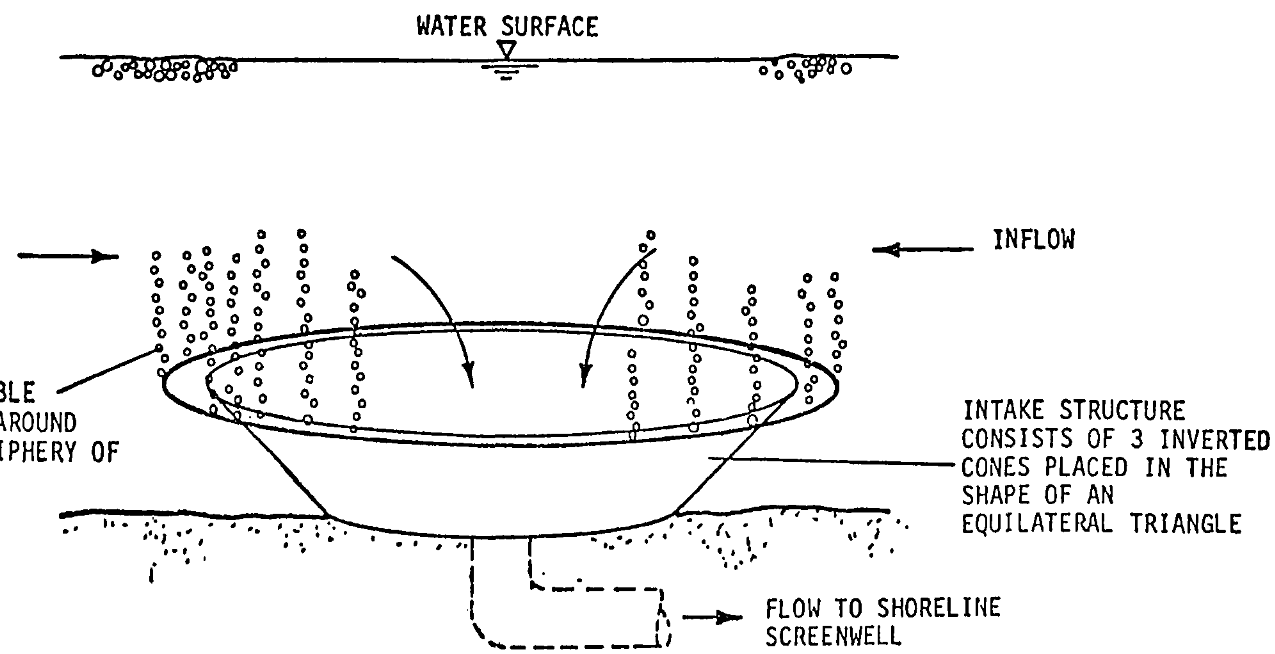


FIGURE 3. AN OFFSHORE AIR BUBBLE INTAKE STRUCTURE.(7)

Bell[30] stated that fish show an immediate response (probably a fright response) to a bubble barrier. However, he concluded that "experiments with salmonid fish indicate that bubble screens are not effective in either stopping or guiding."

A recent laboratory study by Bibko, Wirtenan, and Kueser[23] showed that an air curtain effectively blocked the movement of young-of-the-year striped bass even during darkness. Results of this study showed that young striped bass would not cross an air-bubble screen at temperatures of 4.5 C or 11.1 C, but they would drift passively through the air screen when the water temperature was 0.8 C. Gizzard shad did not cross the established air screen at 11.1 C but continually passed through at ambient water temperatures of 0.8 C and 4.5 C. It was also found that the passage of young striped bass is not restricted at any water temperature if an opening of 5 cm or more was allowed in the bubble barrier.

Schuler and Larson[21] found little diversion of fish into a flume bypass using a screen placed at a 30° angle to the flow. When air bubbles were tried in conjunction with the screen, results were not substantially increased. However, they believe that the failure was primarily due to the breakdown of the air curtain due to high water velocity and insufficient air pressure. Nearly 100 percent diversion was obtained in the intact lower part of the air curtain.

Alevras[31] has discussed Consolidated Edison's use of an air bubble installation at the Indian Point Power Plant on the Hudson River estuary. This system, shown in Figure 4, consists of two vertical rows of horizontal bubbler pipes which release air at 1.2 m intervals directly in front of the intake screens. Since installation the number of impinged fish has been lower, but the reduction varies by species. The air bubble screen appeared to repel some fish species but not others.[32]

Kupfer and Gordon[33] stated that the city officials of Milwaukee initiated a study for a permanent bubbler system across the Milwaukee River after reviewing the work of the United States Bureau of Commercial Fisheries on their successful guidance of Atlantic herring in clear water using bubble barriers. The purpose of the air curtain was to prevent alewife from migrating upriver where they die in large numbers and cause sanitation problems.

The bubbler system contained 152 m of plastic pipe traversing the river on a 45° angle to the flow. A chain was attached to the pipe to hold it on the bed of the river. Clogging of holes 0.3 mm in diameter spaced 15.2 cm apart resulted in a change to 0.5 mm diameter holes spaced 5 cm apart. During a six weeks evaluation in spring 1964, the operation of the curtain appeared overall to retard the upstream alewife migration. Initial results were inconsistent and statistical analyses were not reported.[33]

Field and laboratory tests were conducted in 1966-67 by the Tennessee

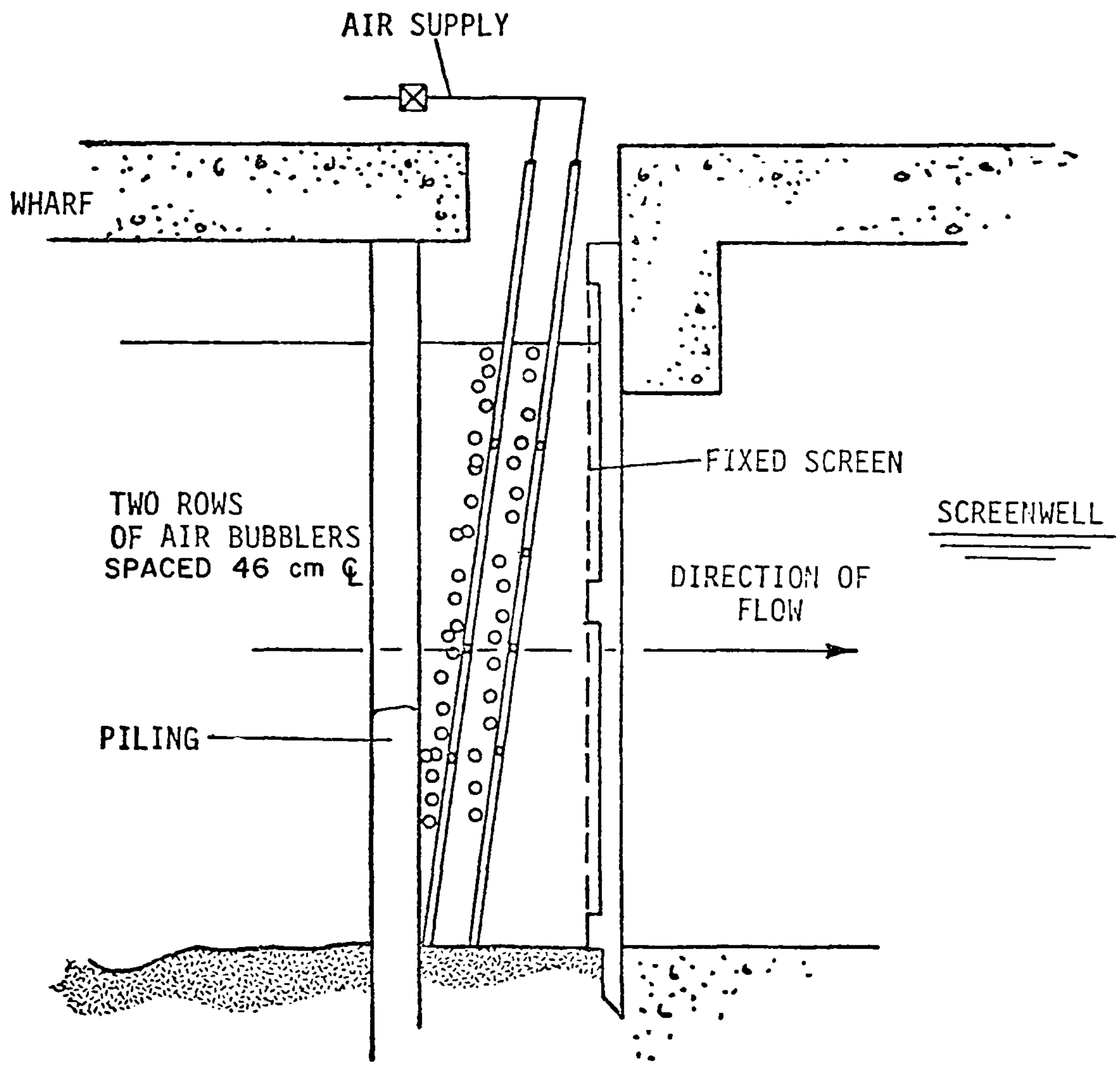


FIGURE 4. INDIAN POINT AIR BUBBLE SYSTEM. (7)

Valley Authority to evaluate the effectiveness of an air curtain for "leading, holding, and herding fish."[34] The objective of the study was to evaluate the potential use of an air curtain in the harvest of commercial fish species. Laboratory tests were performed on gizzard shad, smallmouth buffalo, carp, and largemouth bass in a 18.3 m x 2.4 m x 2.4 m flume using an air curtain produced from holes on 1.9 cm centers in an air base.

Results of the tests included the following:

1. Carp and gizzard shad could be contained significantly longer than largemouth bass and smallmouth buffalo.

2. Carp could be crowded into a small space before breaking through the curtain. Crowding of gizzard shad was less successful.

3. Tests designed to evaluate the effectiveness of the curtain in guiding fish to a bypass were unsuccessful. All species except gizzard shad passed through the bubbles rather than being guided along the air curtain. When a current of 21.3 cm/sec was created in the flume, these species readily passed through the curtain. In both stagnant and flowing water all gizzard shad were retained by the curtain, but none was guided the full length of the curtain to the bypass.

Results of field tests comparing the bubble curtain with a conventional lead net in guiding fish showed higher guiding rate with the conventional net, but the difference was not significant.

In several of the studies on air curtains, it was emphasized that the bubbler must extend all the way to the bottom of the flume or water column. Fish were able to find gaps between the hose and the flume floor and would readily circumvent the barrier by passing through this bubble-free zone.

Evaluations on two prototype air curtains have recently been completed. Arkansas Power and Light Company (AP&L) installed a 122 m long air curtain across the entrance of the cooling water intake canal at the Arkansas Nuclear Plant - Unit One, located on the Dardanelle Reservoir.[35] Water depth in the location of the curtain was approximately 4.6 m and air holes were spaced at 25 mm intervals. Testing was performed between fall 1974 through summer 1975. Results of the one year of testing showed the air curtain to be ineffective in repelling impingeable-size fish of 38 species. During the test periods approximately 9.5 million fish were impinged on the intake screens, approximately 5 million of which were impinged during air curtain operation. Difference in impingement while the curtain was in the "on" and "off" modes were not significant during the fall, winter, and summer. In the spring, numbers of impinged fish were significantly higher with the operation of the air curtain. Threadfin shad contributed 91 percent of the total number of fish impinged during this study.

In 1973 a 49 m long air curtain was installed at the entrance to the cooling water intake at Northern States Power's (NSP) Prairie Island Nuclear Plant in Minnesota. A one-year evaluation beginning September 1974 indicated that the air curtain was largely ineffective at deterring most fish species.[36] Crappie and freshwater drum were deterred 19 percent and 9.8 percent, respectively, but the operation of the curtain increased the numbers of carp (5.3 percent), silver chub (40 percent), and white bass (31.7 percent). Overall, the operation of the air curtain resulted in a 7.1 percent increase in fish entering the intake channel. However, during the months of April, May, and July significant deterrence (65.5 percent, 30.8 percent, 30.0 percent, respectively) was found for total number of fish, resulting in a recommendation that the air curtain be operated only during these months.

WATER JET VELOCITY

Bates and Vanderwalker [27] studied the guidance of spring Chinook salmon with water jet barriers. Fish diversion ranged from 60 to 80 percent under varied water pressures, array angle, and approach velocities. These preliminary studies indicated some promise in diverting fish with a water jet system. Limitations include the large volume of water that would be required at a large installation and extensive maintenance on the jet orifices because of rusting and clogging. There has not been any research or development done on a water jet system in the last few years.

CABLE AND CHAIN SCREENS

The Department of Fisheries of Canada[37] experimented with a traveling cable screen to guide downstream-migrating fry. The system was designed to take advantage of the fish's tendency to avoid objects moving through the water. Cables hanging at close intervals were positioned diagonally across the river to form a screen. In this experiment the hanging cables were not very effective, as the fish tended to swim through the cable screen.

Fields et al.[38] tested the effectiveness of a stationary chain barrier using three age groups and four salmonid species. The laboratory tests were performed in still water during daytime and nighttime periods. Fish were forced to enter one of two channels, identical except that one of them included a chain barrier at its entrance. A chain barrier with spacings of 2.5 cm produced a daytime deflection of 66 percent. Although this result was statistically significant, it was not large enough to be of practical importance; the deflection expected by chance alone was 50 percent. The chain barrier was even less effective in the dark, producing a nighttime deflection of only 56 percent. Unequal illumination in the channels during the daytime was more effective than the chain barrier in controlling behavior of the fish. For example, 89 percent of the fish avoided entering the brighter channel, while only 66 percent avoided entering the channel blocked by the chain barrier.

Fields et al.[39] also investigated the use of chain barriers in flowing water by using two angles, two densities of chain spacing, two velocities of water, and three species of hatchery-reared fish. They found that the overall average deflection of fish by the chain barriers was 53.6 percent as compared to a 50 percent deflection which might be expected by chance alone. The greater influence of unequal illumination over the chain barrier effect on fish behavior was indicated again in this study. The researchers concluded from these two studies that chain barriers were of "no practical value in guiding young salmon..." in either still or moving water.

Brett and Olderdice,[37] working with migrating sockeye salmon, also experimented with chain barriers. Studies were conducted with a maximum water velocity of 45 cm/sec; chains spaced at intervals of 5, 10, and 15 cm; and chain placed 45° to the flow. Maximum average deflections of 94 and 71 percent were obtained in daytime and nighttime, respectively, using 5 cm spacing of chains.

LOUVERS

The concept of the louver for the protection of fish at water intakes arose from earlier attempts to prevent moss growth in California irrigation canals.[40] The earliest attempts to guide fish with louvers were in 1952 at the U. S. Fish and Wildlife Service Coleman Fish Hatchery.

The success of the louver barrier depends on the ability of the fish to detect and avoid abrupt changes in velocities and flow directions. A typical louver barrier (Figure 5) consists of a series of narrowly spaced vanes placed 90° to the flow and a bypass. Flow straighteners (Figure 5) often are placed downstream of the louvers. The most efficient diversion of fish is achieved by optimizing at each site the approach velocity, louver slat spacing, louver array angle to flow, and the bypass velocity and shape. The most effective louver slat spacing and array angle to flow depend to some extent upon species, size, and ability of the fish to be diverted. Bates and Logan[41] and Bates and Vinsonhaler[42] discussed in detail the relationships of fish swimming speed, louver angle, and approach velocity as they affect the ability of the fish to avoid entrainment through a louver barrier.

In 1957 the U. S. Bureau of Reclamation and the U. S. Fish and Wildlife Service developed and tested the Tracy Fish Collecting Facility, a louver system designed to protect fish at the entrance to the Delta-Mendota Canal in California.[41] This system (Figure 6) consists of a primary and secondary array of louvers, bypasses, tanks to hold fish, and transport trucks to return fish to the natural water. Water depth in the 25.6 m wide pumping canal varies from 6.6 m to 7.9 m, and volume through the canal ranges from 22 m^3/sec to 144 m^3/sec depending on number of pumps operating and tidal conditions. Critical parameters in the louver system include fish

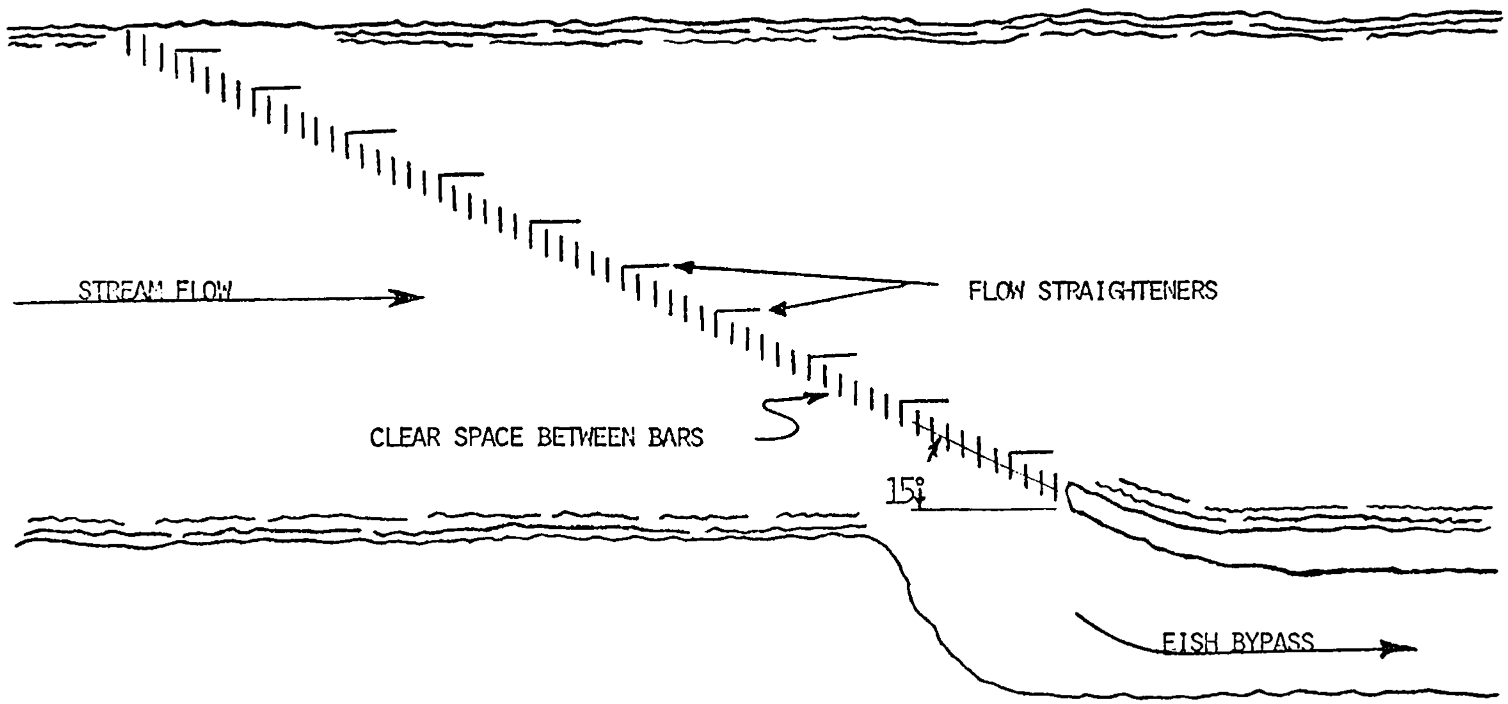


FIGURE 5. LOUVER DIVERSION SYSTEM-SCHEMATIC (2)

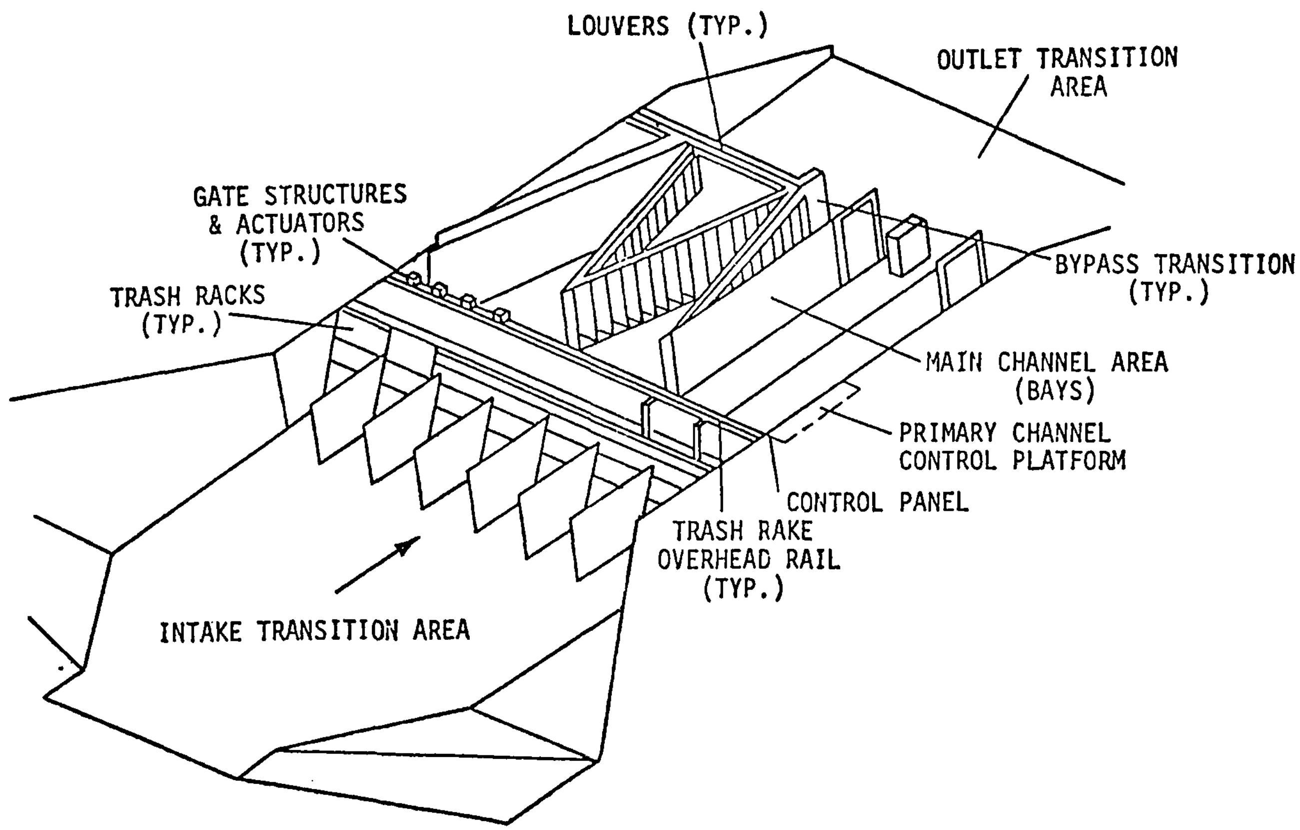


FIGURE 6. DELTA FISH DIVERSION-LOUVER SYSTEM (2,3,7)

species, fish size, approach water velocity, bypass to channel velocity ratio, louver array angle, slat spacing, time of day, and debris level. The 97.5 m long primary louver is placed 15 degrees to direction of flow. Four evenly spaced bypasses are provided along the length of the primary louvers. Louver slats are placed 90° to direction of flow and spaced 25 mm apart. Results obtained from tests on the primary louver array in 1957 showed an overall guiding efficiency of approximately 97 percent.

In 1958, tests of the secondary louver system showed a 76 to 86 percent guiding efficiency of all fish less than 25 cm in length when approach velocities did not exceed 91 cm/sec. Nearly all (95 to 99 percent) of those fish 3.7 to 10 cm long were guided to the bypass. A bypass to approach water velocity ratio of 1.4:1 improved guiding efficiency over a 1 to 1 ratio. The increased efficiency was fish species and size dependent.

In 1964 a series of tests was conducted by the California Water Resources Agency and the Bureau of Reclamation to determine the effect of louver slat spacing and guiding efficiency of several fish species at the Tracy Fish Collecting Facility.[40] Tests of four slat spacings (2.5 cm, 3.7 cm, 6.4 cm, and 10 cm) were performed on the secondary louver array. The original 2.5 cm louver slat spacing was found to be superior for all sizes of those species (striped bass, white catfish, shad, and smelt) which appeared in sufficient numbers to permit an evaluation.

Bates and Jewett[43] found a 98 percent deflection of immature migrating steelhead with a louver barrier at the Maxwell Irrigation Canal, Umatilla River, Oregon. Louver slat spacing was 5.0 cm. Efficiencies remained above 90 percent when the slat spacing was increased to 10.8 cm.

Ducharme[44] reported a five-year evaluation of a louver barrier at Ruth Falls Power Plant in Nova Scotia. Guiding efficiency of 2-year-old Atlantic salmon smolts, 35.2 to 37.7 cm in length, increased from 57 percent during the first test year to 80 percent after 5 years and several modifications. Louver slats were placed 5.1, 10.2, 15.2, and 30.5 cm apart and 90 degrees to direction of flow. Optimum bypass to approach velocity ratio was determined to be 1.0 : 1.5. Approach velocities ranged from 0.24 to 1.06 m/sec. An increase in guiding efficiency occurred at the higher approach velocities after completion of modifications to the bypass. Comparison of slat spacing tests led to the conclusion that the optimum spacing for guiding efficiency as well as "economy of bypass water" might be a "wide bar spacing at the widest part of the louvers, with gradual reduction in bar spacing leading towards the bypass."

Schuler and Larson[21] found for several coastal species in California that the highest degree of guidance was obtained with slats placed 2.5 cm apart, louver array 20 degrees to flow, bypass velocity 1.5 times that of approach velocity, approach velocity 0.6 cm/sec, and bypass design curved with no abrupt changes in direction.

A louver barrier (Figure 7) has been proposed for the offshore intake of the Nine-Mile Point Nuclear Power Station No. 2 to be located on Lake Erie.[7] An extensive experimental testing program has been undertaken to design the facilities. Five to 13 cm long alewives were tested on a 24 m long hexagonal-shaped louver. Water flows into the structure along its periphery and fish are guided to the center of the structure where they are then induced to enter a bypass.

Most studies on louvers indicate a decreased guiding efficiency with increase in debris load. To assist in cleaning, one variation's design (Figure 8) includes a vertical traveling louver similar to the conventional vertical traveling screen.[3] Several vertical louver screens are placed side-by-side to form a continuous line of louvers for guiding fish to a bypass.

A 5-year cooperative study by the California Department of Fish and Game, California Department of Water Resources, U. S. Fish and Wildlife Service, and the U. S. Bureau of Reclamation was initiated in 1970 to develop fish screens to divert fish past the proposed large volume Peripheral Canal.[45,46] It was expected that 80 percent of the anadromous fish resources in the Central Valley could be affected by the Peripheral Canal diversion. The screen would have to be capable of protecting eggs and larvae as well as juvenile and adult fish to be satisfactory. In 1973 it was recommended that the louver concept be dropped from further consideration as a screening alternative. Satisfactory guiding efficiencies were not expected for eggs or fish smaller than 37 mm.[46]

A disadvantage of the fixed louver system is that the shallow angle of louvers with respect to the channel flow requires a rather long line of louvers, which increases the cost of the intake relative to other intake designs. Additionally, since the louver system does not remove trash, conventional screens downstream of the louvers may be required.

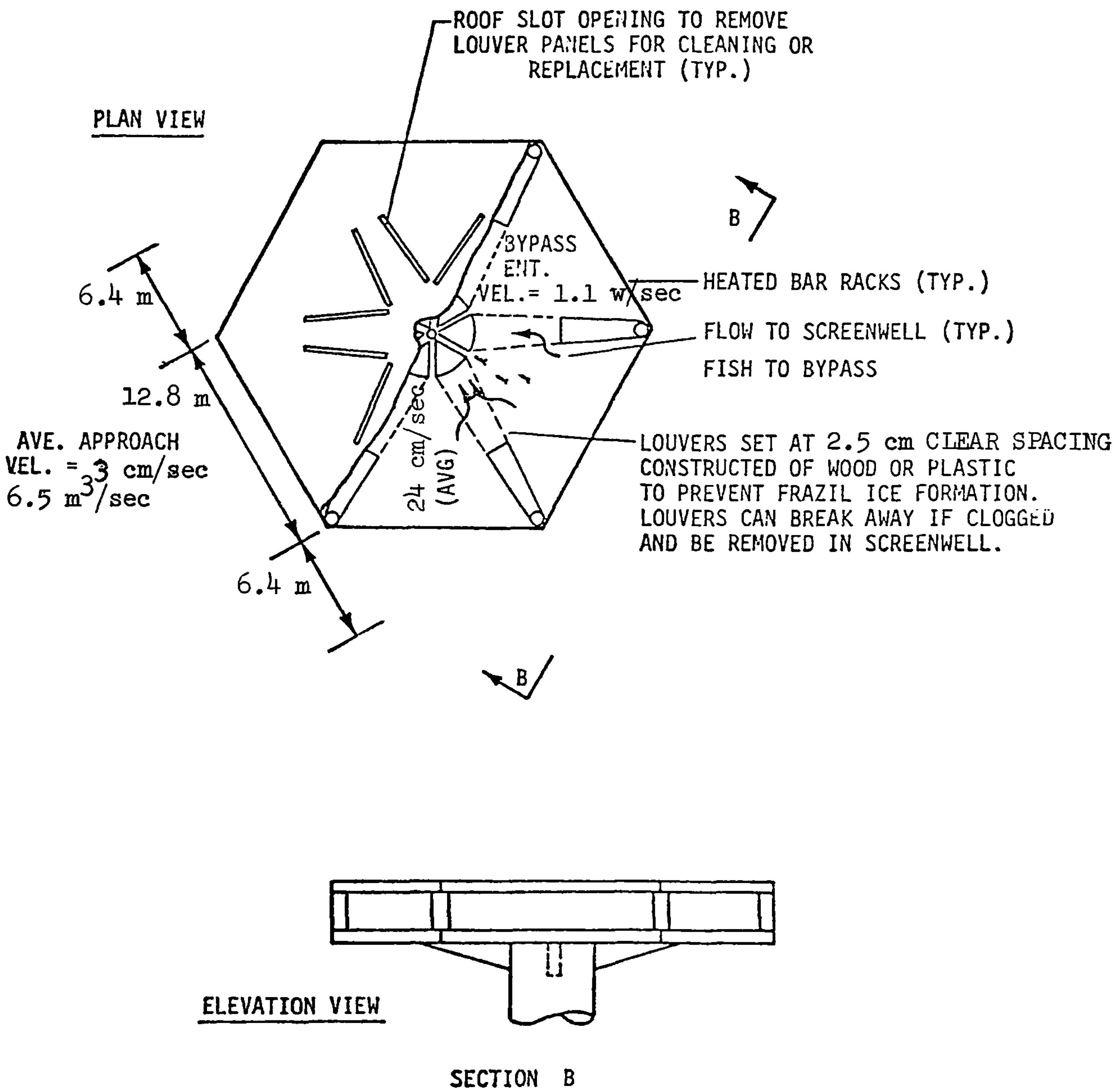


FIGURE 7. LOUVER SYSTEM AT NINE MILE POINT NUCLEAR POWER STATION. (7)

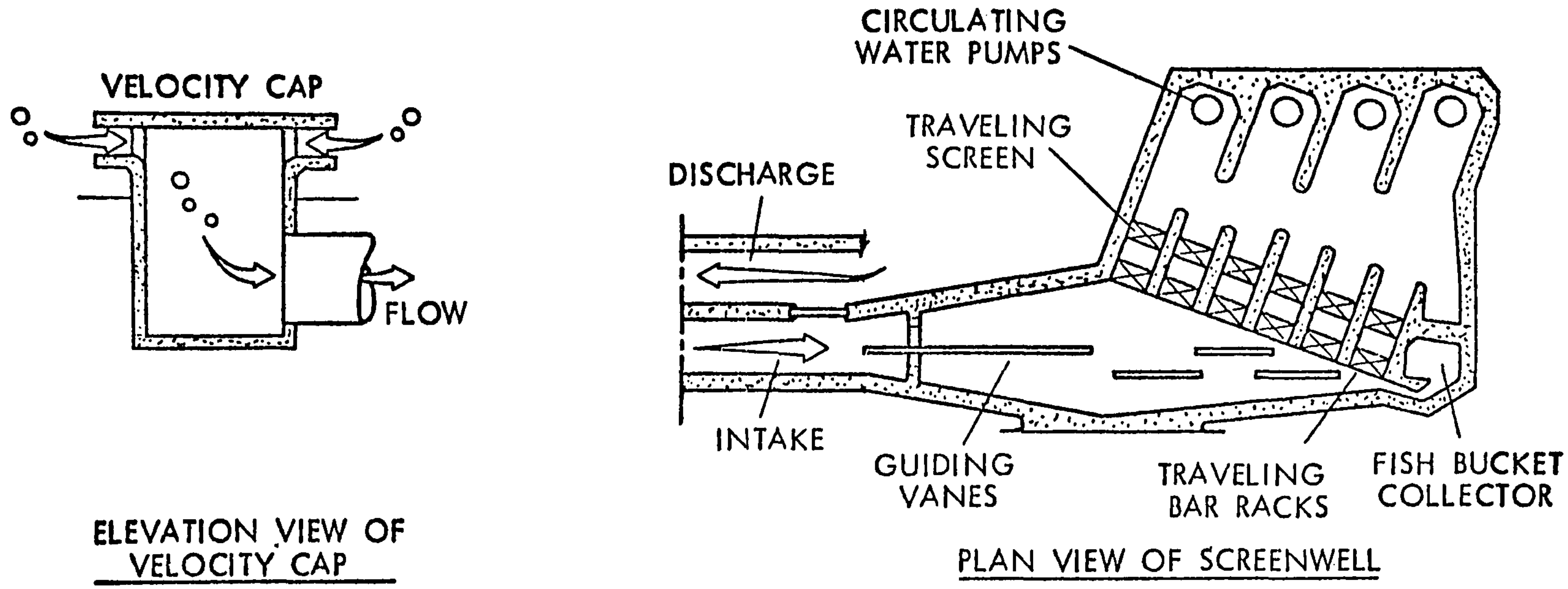


FIGURE 8. TRAVELING LOUVERS AT THE SAN ONOFRE NUCLEAR POWER PLANT, (7)

SECTION 6

PHYSICAL BARRIERS

GENERAL

Because of debris and fish present in the raw cooling water and the need for continuous plant operation, power plants require fool-proof screening devices to prevent clogging of the condenser tubes. By far the most common screen system in use today is the vertical traveling screen (Figure 9). This screen consists of an endless belt of removable screen panels drawn over sets of top and bottom sprockets. Screen panels are usually 2.4 m to 4.3 m wide and 0.6 m high with 9.5 mm square opening screen. A narrow lip, or ledge, is provided at the bottom of each screen panel to lift debris and objects that do not adhere to the screen. The vertical traveling screen is usually not rotated and cleaned until a specified pressure differential resulting from clogging exists across the screen. This varies from a few hours to several days depending on debris load. In some cases the breakup of aquatic vegetation causes such a rapid buildup on the screens as to necessitate continuous rotating and washing.

The number of screens located at a plant ranges from a few to 20 or more. They are typically installed side-by-side in a single concrete housing with each screen, or set of screens, separated completely by partitions. The distance from the screens to the front side of the intake structure curtain wall varies from less than a meter to several meters. Water enters through an opening located below the curtain wall. The opening contains vertical steel bars (trashracks) typically spaced approximately 8 cm apart which are designed to screen any debris large enough to damage the traveling screens.

Advantages of the conventional vertical traveling screen include the following:

1. Commercial availability.
2. History of reliable performance, long service life, and minimal maintenance.
3. Application to sites with fluctuating water levels.
4. Standardization and availability of components.

A serious drawback to these screens is the harm done to fish impinged on and entrained through them. The design creates a trapping effect

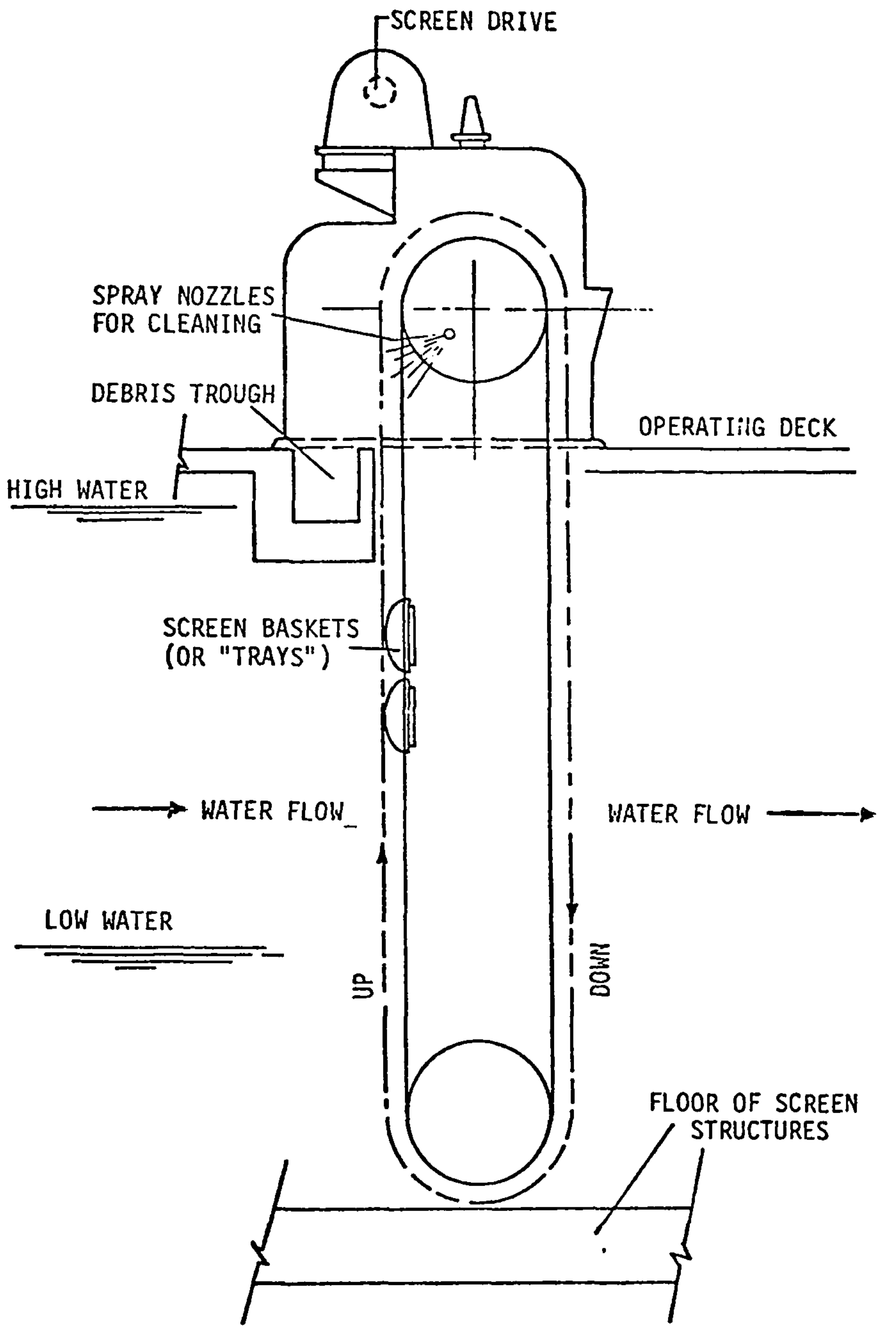


FIGURE 9. CONVENTIONAL VERTICAL TRAVELING SCREEN. (2,7)

for fish by virtue of its single opening to the screen well. Once inside the well the fish are surrounded by concrete walls and traveling screens with the only route of escape back through the trashracks. Since this is also the area of greatest velocity, the chance of escaping the well, especially for smaller fish with less swimming capability, becomes minimal. Since most vertical traveling screens are operated intermittently rather than continuously, fish can be impinged against the screen for long periods of time. In addition, the screens are not designed to remove live fish from the well. The narrow lip, or ledge, on the bottom of the screen panels is inadequate to retain active fish. As the screen panel lip clears the water, the fish may flip off and become reimpinged. Repeated impingement may continue until the fish become exhausted and die trying to avoid contact with the screens. Any live fish that are carried on the ledge are exposed to the high-pressure system screen wash used to clean the screen as it rotates.

Recent concern with protecting fish at power plant intakes has resulted in a search for alternative screening devices capable of minimizing fish losses while insuring continuous plant operation. This review briefly discusses those screens which appear to be viable alternatives or adjuncts to the use of vertical traveling screens.

MODIFICATION OF EXISTING VERTICAL TRAVELING SCREEN DESIGN

Provision for Escape Routes Inside Intake Suction Pit or Screen Well

Increasing the distance between the vertical traveling screen and the trashracks and providing escape routes through the side walls has been investigated by Washington Public Power Supply System (WPPSS).[47] A design has been proposed based upon modifications to the existing water intake system for the WPPSS Nuclear Project No. 1 located on the Columbia River (Figure 10). The intake structure would consist of two vertical traveling screens having 6 mm screen mesh openings. Fish-escape slots through the side walls would be provided to the left and right of the screens. Since shoreline indentations or dead-water areas tend to attract fish, the structure would be located on the low-water bank of the river, with access to the structure provided by a trestle from the high-water bank.

Conventional Vertical Traveling Screens Equipped With Fish Troughs

A modification to the intake screens at Virginia Electric Power Company's (VEPCO) Surry Power Station has resulted in substantial reductions in mortality of impinged fish.[48,49] The Surry Station is a 1,560 megawatt nuclear power plant with once-through cooling located in an area on the James River where saline concentrations range from zero to 15 parts per thousand. As a result, both freshwater and marine species are abundant around the plant site.

Modification to the intake screens included continuous rotation (3 m/min) to reduce the impingement time for a fish to two minutes or less. In addition, compartmented metal troughs were attached to each screen

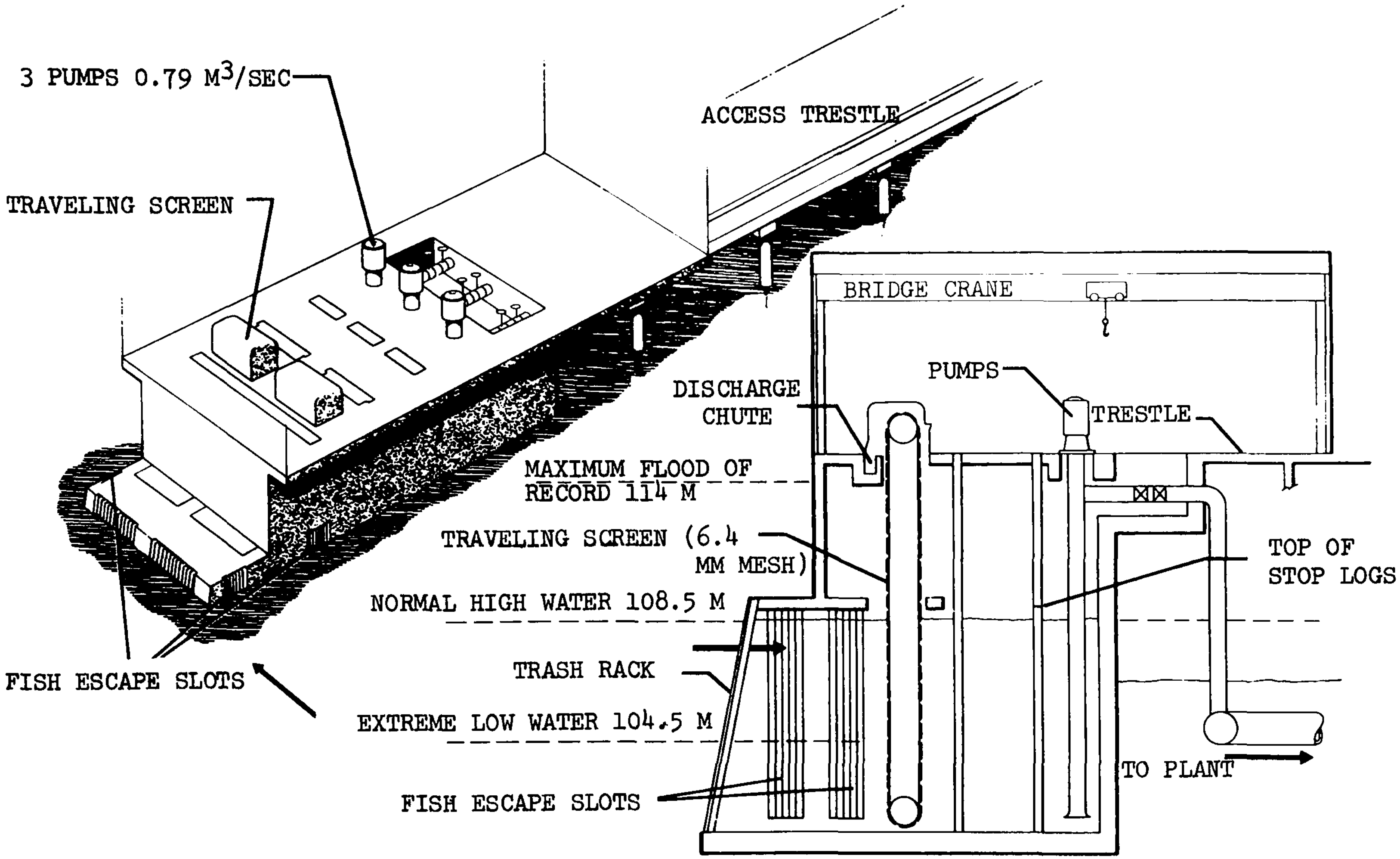


FIGURE 10. VERTICAL TRAVELING SCREEN INSTALLATION OF WPPSS (46)

panel frame to increase the efficiency of removing fish. These troughs maintain a minimum 5 cm of water depth as the screen rotates out of the water. As the trough rotates around the head sprocket, the fish and water are spilled into a common return trough which empties back into the river downstream of the intake. The high pressure (63,000 to 84,000 kg/m^2 or 90 to 120 psi) screen wash was also replaced with a low pressure (7,000 to 10,500 kg/m^2 or 10 to 15 psi) wash system to assist in safe removal of fish from the screens to the river.

Data collected during the first two years of operation (1974 to 1976) showed a 93.8 percent immediate survival of total number of fish sampled. For 26 species survival was 100 percent and for anchovies, a sensitive group of fish, overall survival was 83 percent.

Because of the continuous operation of these screens, increased maintenance is required over conventional intermittent operation. The Surry screen panels are 4.3 meters wide and carry 9 mm opening wire mesh screen. It is now believed that maintenance could have been reduced substantially by increasing the number and decreasing the width of the screens. Narrower screens would reduce the weight of the overall structure and consequently the wear on the moving parts. Reducing the screen speed from 3 m/min to 1.5 m/min is being considered and is expected to reduce maintenance costs considerably. In addition, the use of currently available light-weight polyester and Nitex screens would reduce the weight of the screen panels and would also be expected to reduce maintenance costs. This material is currently being used or considered for use on at least a few power plant intake screens in the United States.

INCLINED TRAVELING SCREENS

Two types of inclined traveling screens exist. The first type is very similar to the conventional vertical traveling screen with the exception that it is inclined at a small angle (generally between 10° and 15°) with the vertical. On this screen, fish, as well as debris, can be retained more easily than on the conventional vertical traveling screens because of the angle of screen and lip.[2]

This type of inclined screen is used by a small number of installations and has basically the same advantages and disadvantages as the conventional traveling screen. The installation cost of this type of screen is slightly higher than for the conventional screen because of the longer screen well and other modifications needed.[2]

The second type of inclined screen is an inclined downstream screen positioned at an extreme angle with the vertical (Figure 11). Although it is still in its experimental stage, it has been used in Canada. Fish protection was the basis for design of this screen. The screen panel lips are made of pliable brush material rather than the conventional metal plate. The combination of a screen with a small angle to the horizontal and the pliable brush assembly provide a safe

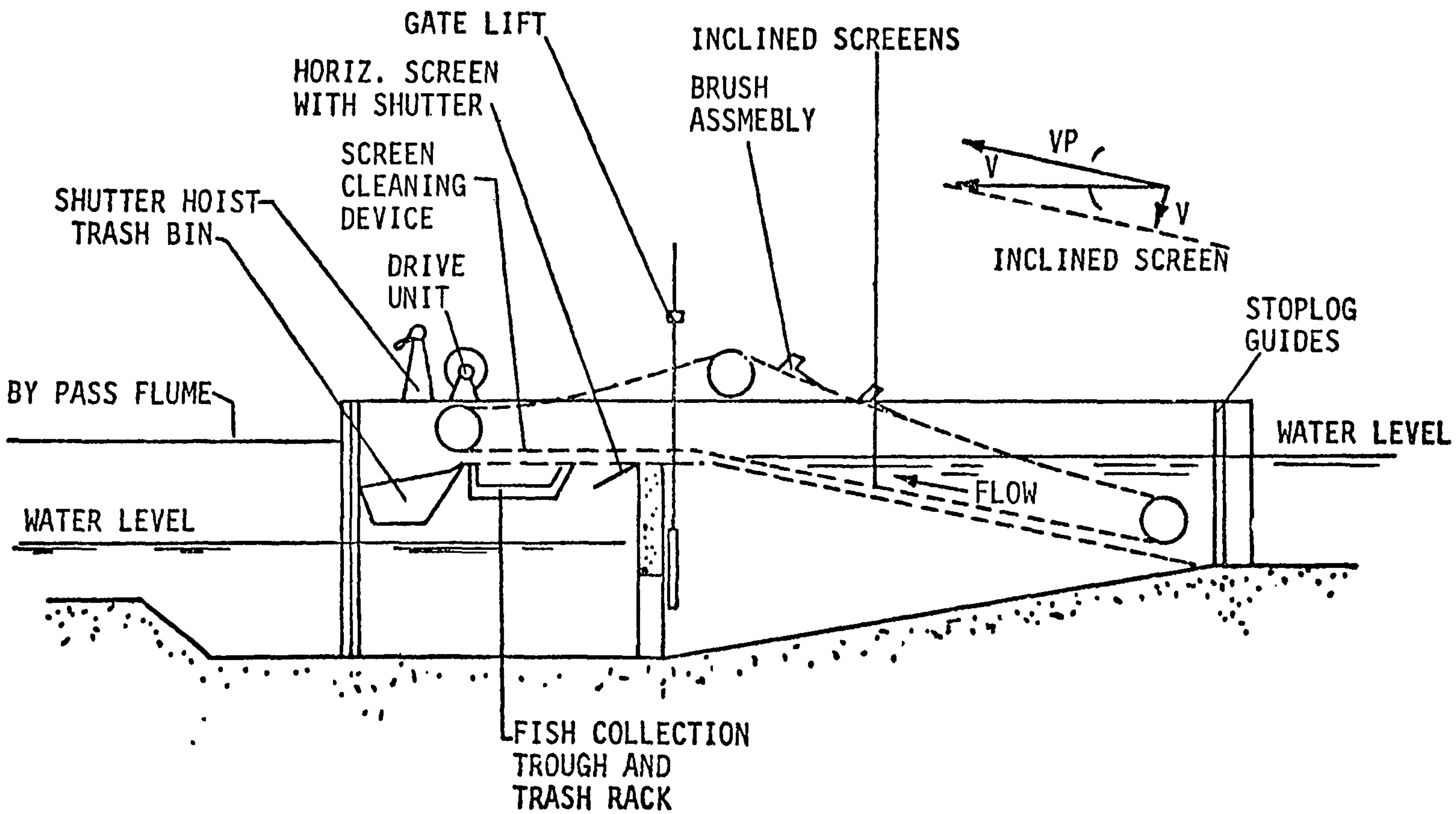


FIGURE 11. INCLINED TRAVELING SCREEN. (2,7)

passage for fish. The fish are moved up the screen, while remaining immersed in water, and are safely deposited in the debris trough. The screen return runs horizontally over the sluice trough. The cleaning system is similar to the system used by the conventional traveling screen but with lower spray pressure. This system design avoids some of the undesirable features of the conventional vertical traveling screen, e.g., fish are guided instead of being impinged, fish remain in water, and the fish are not subjected to as high pressure in cleaning.[2,5] Limitations to the use of this system include higher cost than with the conventional vertical traveling screen and need for stable water elevation.

FIXED SCREENS

Fixed screen intakes are the second most common physical screening device used by power plants with most of them installed at smaller and older plants. Fixed screening devices are usually considered for intakes where suspended debris is negligible, resulting in minimal cleaning requirement.[2]

The most common type of fixed screen is the vertical installed device located in front of the intake pumps. The mesh size, as for any other screen, is determined by the size of debris or fish which must be screened. The screens, generally mounted in a frame, are installed in vertical tracks on the intake channel walls and are usually lifted out of the water for cleaning. A fixed screen system generally consists of two sets of screens with at least one set of back-up screens in position at all times.

An irrigation pumping station of Universal Land Company of Pasco, Washington, contains five vertical fixed screens, each 2.7 m wide with 3.2 cm opening mesh.[47] Most large debris is excluded from the intake by a chain-link fence. The pumping capacity of the station is 4.5 m^3/sec with maximum velocity of 15 cm/sec. The intake device has been in use since 1969 and no fish impingement problems have been observed. With increased wave action, maintenance problems result from debris and slime which clog the screens.

A variation of the fixed screen system is a vertically inclined fixed screen. The screen may be used to guide the fish into safe areas or bypasses. Schuler and Larson[21] in 1974 tested 16 mm opening mesh stainless steel screens installed at angles of 90, 45, and 30 degrees to flow in a test flume. Mean velocity was 60 cm/sec. Results with screens were generally poor. With a relatively steep angle of 30 degrees, impingement of small fish was approximately 80 percent and other fish were guided with only marginal success.

Simple fixed screens are an economical method of screening where suspended debris is negligible. However, if debris-free, low velocity water is not available, operating and maintenance costs for cleaning and handling these screens may become excessive.

Several undesirable features of the fixed screen system include the following:

1. Operators must be available at all times to maintain the screens.
2. There is the possibility that a heavy load of debris or fish could completely clog the intake and perhaps cause plant shutdown and/or screen collapse.
3. Long impingement times between cleaning periods result in total mortality of fish.[2]

REVOLVING DRUM SCREENS

A drum screen installation consists of a large perforated drum which may be installed with either a vertical or a horizontal axis of rotation (Figure 12). The horizontal drum, extended across the stream flow, rotates slowly with its slightly exposed upper surface moving downstream. Debris is not efficiently removed and is washed off into the downstream side of the screen by the flow through the screen. A spray cleaning system, similar to that of the conventional traveling screen, can be installed to transport all fish and debris into a sluice trough. Drum screens may be designed as impinging or nonimpinging, depending upon the size of the fish to be separated, the velocity of the screen, and the rate of flow in the channel.[2]

Although revolving drum screens are used widely to screen water in irrigation screening devices, they are seldom used at power plants in the United States. At an irrigation intake, debris removal is not as important as at a power plant or industrial intake.[1,2,5] A major drum screening installation of an irrigation fish bypass structure exists on the Tehama-Colusa Irrigation Canal operated by the U. S. Bureau of Reclamation. In this system the drum screen is placed at an angle to guide fish to a bypass.[1,2,5]

There are generally two types of vertical axis drum systems in use with U. S. water intakes. One type (Figure 13) consists of vertical drum screens rotating in an opening in front of the pumps. This design enables removal of debris and fish by the passing water current. The performance of this type depends on a strong directional passing current. The second type involves rotation of the screens around the pump intake itself. This design has been supplied by a major manufacturer for relatively low-volume power plant intakes. High-pressure and other cleaning systems have been used, but no satisfactory method has been developed to clean the debris from either type of screen.

Although the horizontal screen is only partially submerged, the vertical revolving drum is completely submerged and could be designed to work under fluctuating water levels. One problem with the vertical drum system is the tendency for debris to accumulate around the drums. Both designs could be placed at an angle to the flow to provide for possible guiding to a bypass.

A version of the second type of vertical drum screen has been developed by Prior Land Company of Pasco, Washington.[47] The features of this irrigation pumping intake system, such as trash barriers, fish escape slots, and pumps, are similar to their vertical traveling

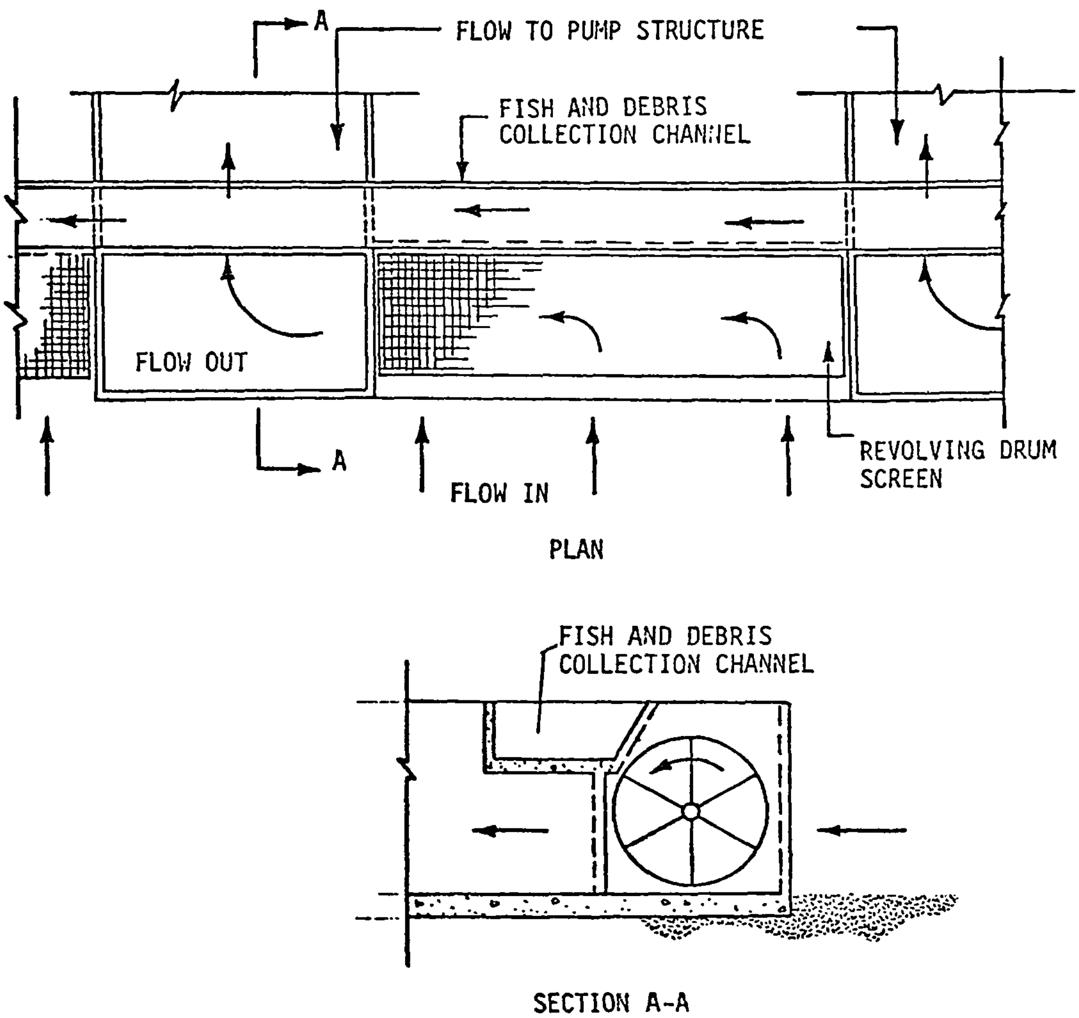


FIGURE 12. REVOLVING DRUM SCREEN WITH HORIZONTAL AXIS-SCHEMATIC. (2,7)

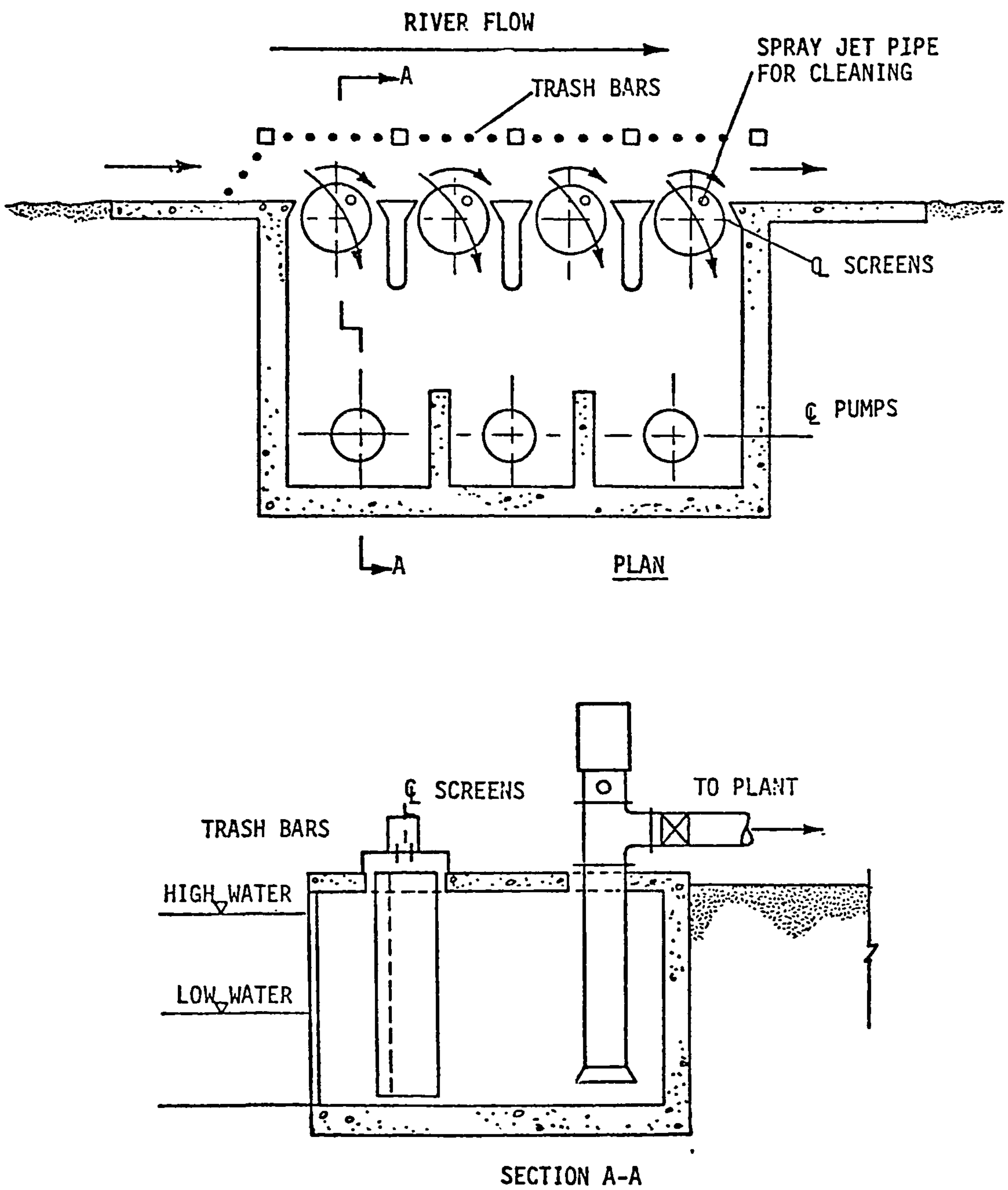


FIGURE 13. REVOLVING DRUM SCREEN WITH VERTICAL AXIS-SCHEMATIC (2,7)

screen intakes. The unique feature of this system is that the water screening function is performed by cylindrical screen cages rotating around the vertical suction intakes of the pumps at 2 r/min. A 1.2 m diameter, 6.4 mm mesh screen cage 7.3 m long surrounds the suction line of each 0.8 m^3/sec pump, equipped with an adjustable vertical sparger and brush system for cleaning. The theoretical maximum average approach velocity is 13.4 cm/sec and minimum velocity is 7.3 cm/sec.

This system has been in operation for about two years. The system had mechanical difficulties and required major overhaul during the nonirrigation season. Because of the uniqueness of screen-cage system design and lack of operating experience, operation and maintenance problems, such as excessive wear of the nylon thrust bearings of the drive mechanism and problems caused by windy conditions, have been higher than desired.[47] However, this design is better suited for a large range of water elevations than are horizontal and conventional rotating screens. The vertical drum screens described here are not sufficiently developed to provide protection for fish; and they boast only marginal effectiveness in handling debris.

A drum screening installation has the advantages of fewer moving parts than the conventional vertical traveling screen and economical operation and maintenance.[2,5] Also, more total screen mesh can be used as effective screen area.

There are also disadvantages to a drum installation:[2,5,28]

1. The drum system has a poor record of self-cleaning.
2. Side and bottom seals are often ineffective, so that fish and debris can pass through them.
3. Since the horizontal drum screen is partially out of the water, use of the entire screen is not achieved.
4. Unless the drums can be adjusted with the water level fluctuations, they would not be considered useful in waters varying more than a few inches in elevation.
5. Drum screening systems cost considerably more than the conventional intake.

Three horizontal drum screens are currently being used by the State of California in water diversion sites for fish protection.[28] The intake volumes at these plants range from 1.4 m^3/sec to 85 m^3/sec. In addition, this screen is being considered for possible use at the 623 m^3/sec Peripheral Canal diversion in California. This would require several miles of 0.35 to 0.48 cm mesh drums. Biologists working on the project believe that the use of finer screening for eggs and fish larvae is impractical at this site.[50] Essentially no testing of fish diversion has been conducted on the screens to date. However, it has been noted that salmon and steelhead larvae seem to avoid impinging on the screens while black bass larvae impinge and get carried over the revolving drum. A collection trough can be installed on the lee side of the drum to transport fish and debris back to the water body.

Drum screens are used extensively in major power plant intakes in Europe and are highly regarded there for efficiency in water screening and serviceability. Although European designs include several types, none were designed from the viewpoint of preventing fish impingement and entrainment. Types which are available and commonly used include the single-entry and double-entry cup screens.

In the single-entry cup screen, the water enters at the end (side) of the large rotating drum and passes out through screen mesh on the periphery. This screen is limited in size to about 9 m in diameter because of the cantilever design of the shaft support.

In the double-entry cup screen, the water enters the rotating drum at both ends (sides) and passes out through the screen. Maximum size is 18.3 m in diameter. Modifications are being made, e.g., installing buckets to safeguard fish. These designs require mounting the drum screens on a structure substantially larger and more costly than that required for conventional vertical traveling screens handling the same intake flows. These screens are easier to maintain, have fewer mechanical parts, and prevent carryover of debris into the screen water system.[2]

ROTATING DISC SCREENS

A typical rotating disc screen is suitable only for relatively small flows and small water level fluctuations. This screen (Figure 14), a flat disc covered with screen mesh and rotating about a horizontal axis, is set in the water channel perpendicular to the flow. As the screen rotates, debris and impinged fish are washed into a sluice trough by high-pressure sprays. The screen has low initial cost and, because of few moving parts, low maintenance cost. However, it offers no real advantage for fish protection over other screens while it incorporates most of their disadvantages (need for high pressure sprays, probability of fish impingement, need for large screen structure to limit screen approach velocities).[2]

DOUBLE-ENTRY, SINGLE-EXIT VERTICAL TRAVELING SCREENS

The double-entry, single-exit vertical screen installation appears similar to the conventional traveling screen but has several significant differences. This installation draws water in through both faces of the traveling screen and passes it out through one end of the screen, thus doubling the screening area over the conventional traveling screen.

One design has the screen faces mounted parallel to the intake flow (Figure 15). In this installation, there is no fish and debris carryover to the pump intake, since any carryover debris will be returned to the incoming water for recycling. Drawbacks to this type of double-entry, single-exit screen include possible buildup of debris resulting

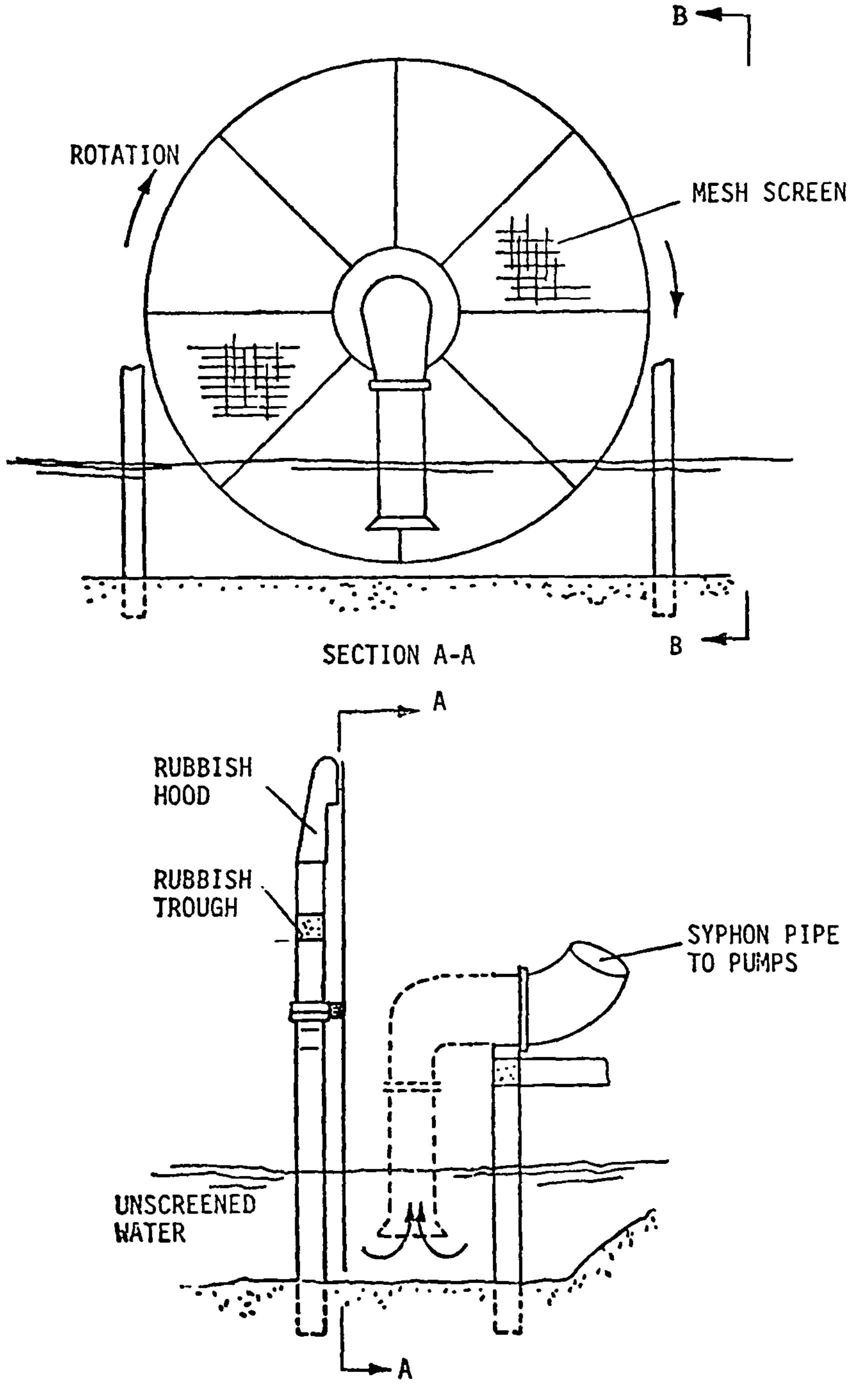


FIGURE 14. REVOLVING DISC SCREEN-SCHEMATIC.(2,7)

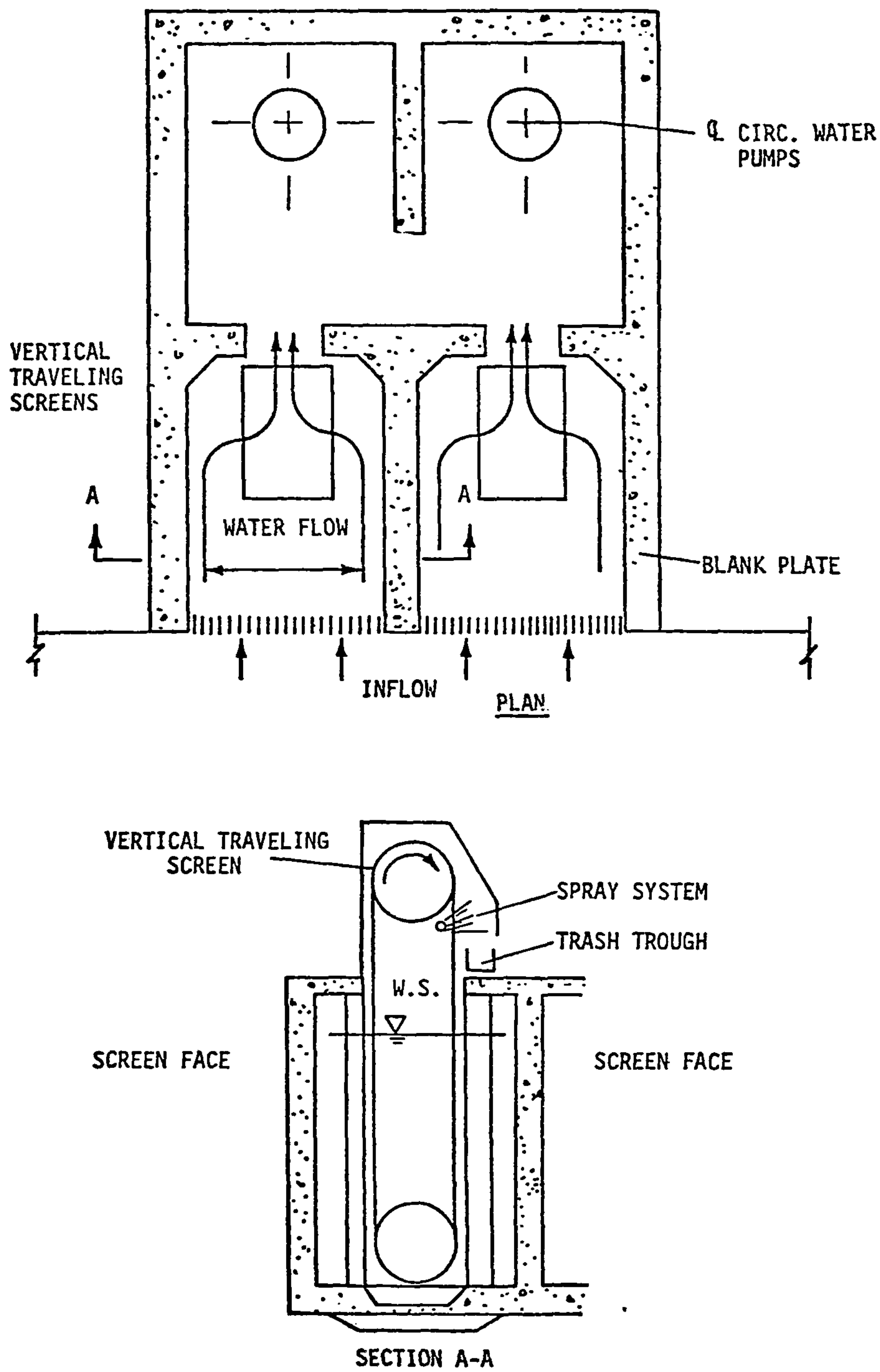


FIGURE 15. DOUBLE-ENTRY, SINGLE-EXIT VERTICAL TRAVELING SCREENS-SCHEMATIC (2,7)

in increased head losses and entrapment of fish.

A second type of double-entry screen installation is mounted on a platform (Figure 16). Since there is no confining structure surrounding the screens, fish trap areas are avoided. In addition, cost for this type of installation may be less than that for the first type of double-entry screen, as well as less than that for the conventional vertical traveling screen.[2]

SINGLE-ENTRY, DOUBLE-EXIT (CENTER FLOW) TRAVELING SCREENS

In the single-entry, double-exit (center flow) traveling screens (Figure 17) the water enters the center of the screen and passes from the inside to outside of the screening surface. The entire screen surface that is immersed is thus utilized as screening area. Since fish and debris are retained inside the screen, the possibility for debris carryover back to the intake is eliminated. The accumulated fish and debris are cleaned off the screen by gravity and a spray wash into an overhead sluice trough. The advantages and disadvantages of the single-entry screen are similar to those of the double-entry screens.

This type screen has been used in Europe for about 30 years. The European design (Figure 18) incorporates a modification which provides a potential increase in fish protection. The screen panels consist of semicircular screen mesh baskets which provide increased screening area and facilitate removal of fish. The basket panels utilize a vertical lip along the bottom to retain debris and fish in the basket until it rotates directly over the sluice trough. This lip probably increases the efficiency of retaining live fish after the panels rotate out of the water. The screening material and mesh size varies according to the fish to be protected and the type and size of debris to be screened.[51,52]

Central Power and Light Company employs this type of screen system at their 700 megawatt Barney M. Davis Steam Plant in southeast Texas.[53,54] Located on the Laguna Madre, the Davis Plant entrains and impinges species characteristic of an estuarine environment. In addition, the intake channel experiences an extremely heavy influx of vegetation for up to 10 months of the year. A 0.5 mm opening square-mesh, polyester screen was originally selected to divert this vegetation. The very fine mesh precludes any entanglement of vegetation around the screen wires and, therefore, increases the efficiency of screen cleaning. Continuous rotation of the screen (0.5 to 4 m/sec) provides for minimal head loss buildup due to clogging of the fine mesh screens. Currently, both Nitex and polyester screens are being used to compare strength and durability.

Data collected on the survival of crustacean and juvenile fish indicates high survival for the former and variable survival for the latter. An accurate evaluation of impingement survival has been hampered by the large volume of marine grass which entangles the fish.

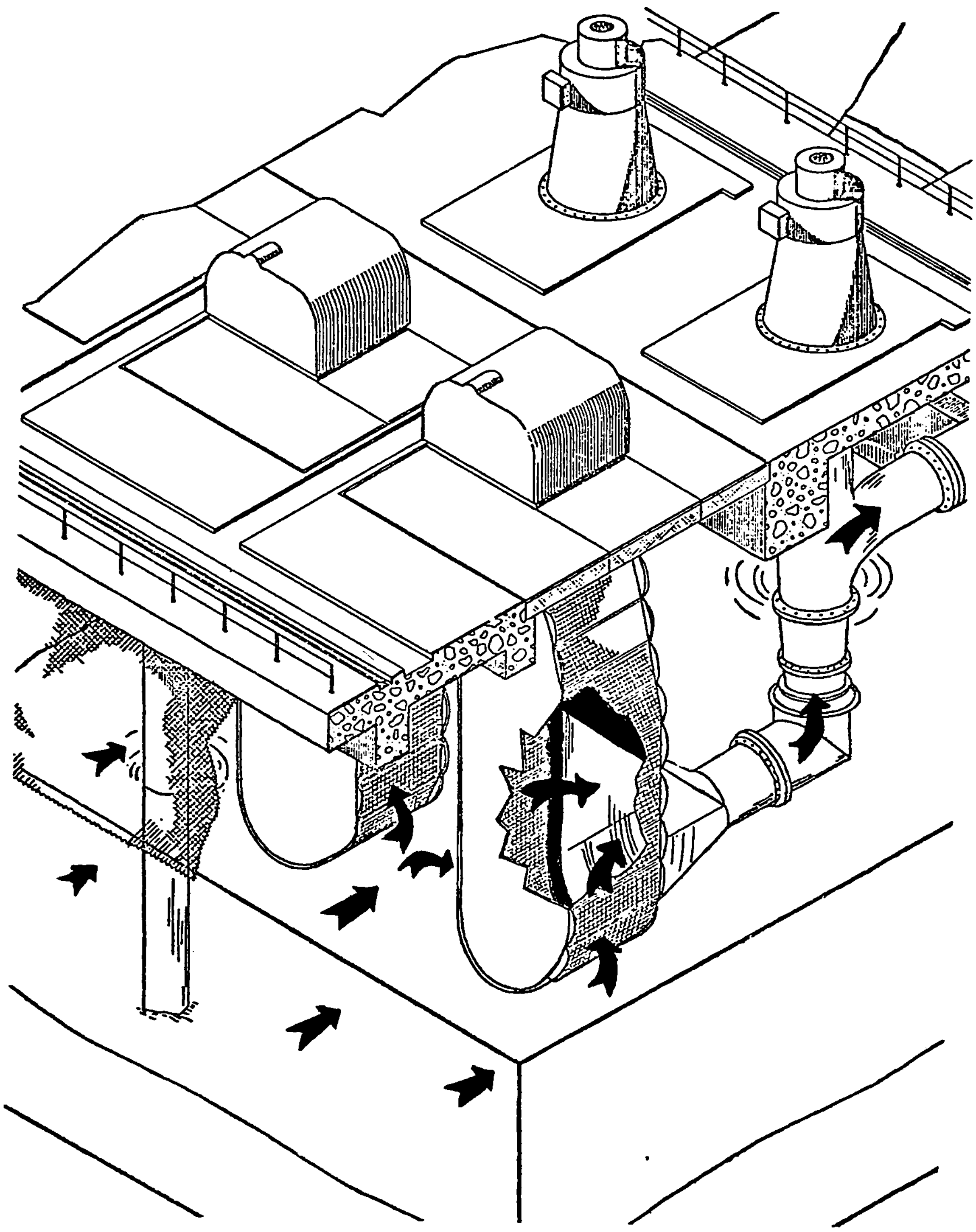


FIGURE 16. DOUBLE-ENTRY, SINGLE-EXIT INDEPENDENTLY SUPPORTED SCREEN. (83)

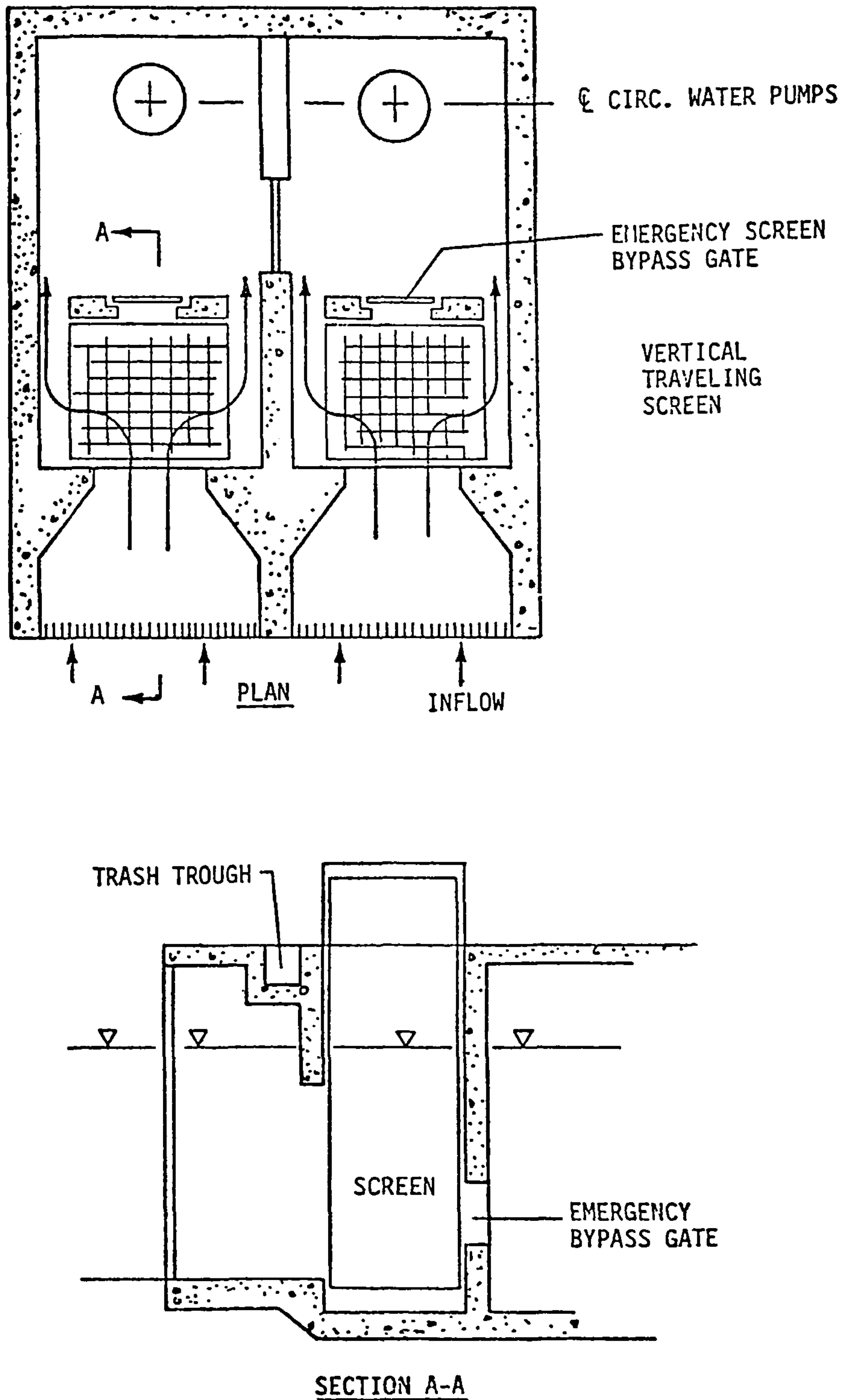


FIGURE 17. SINGLE-ENTRY, DOUBLE-EXIT VERTICAL TRAVELING SCREEN-SCHEMATIC (2,7)

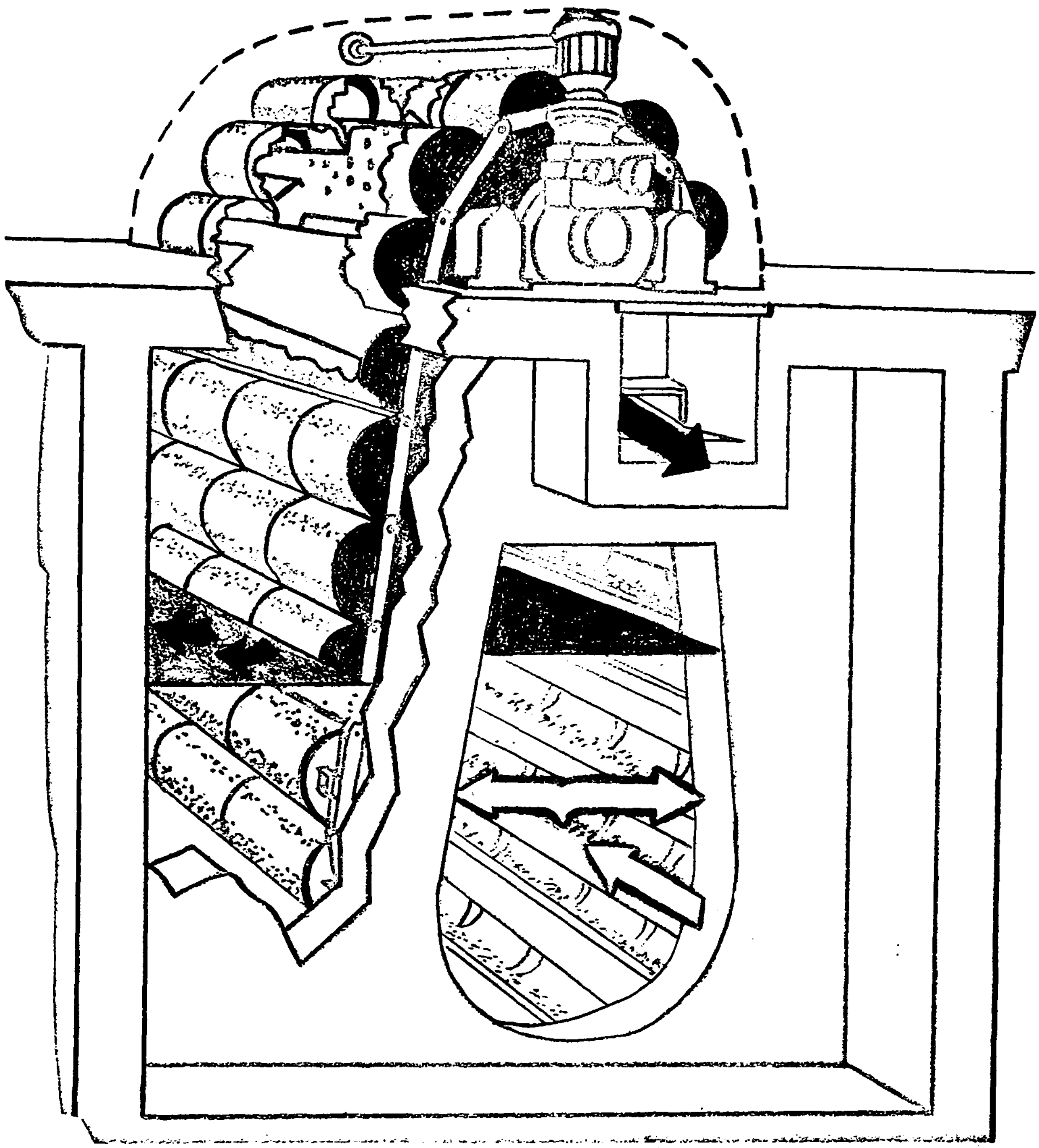


FIGURE 18. SINGLE-ENTRY, DOUBLE-EXIT SCREEN (51)

Separating the fish from the marine grass results in a higher mortality estimate than would be expected merely from the impingement. Likewise, because of the difficulty in retrieving fish apart from the vegetation, estimates of larval fish survival have not been conducted at this plant.[54]

With the following modifications, this type of screen may afford increased protection for larval through adult size fish compared to the conventional vertical traveling screen:

1. Bottom of screen panel should be modified to hold enough water to support fish during the upward rotation of the screen from the water surface to the overhead sluice trench.
2. Backup screen should be provided to support the fine mesh screen which is subject to tearing when punctured.
3. Screen wash spray velocity should be adjusted to prevent descaling and injury to fish as they are removed from the panels.
4. Intake velocity and screen speed (impingement time) should be adjusted to provide minimal injury to fish.
5. Sluice design should afford minimal stress and injury to fish being returned to the source water body.

This screen shares the advantage with the conventional vertical traveling screen of being suitable for use in waters experiencing large fluctuations in water level. In addition, the use of this screen is not limited to relatively low volume intakes since the number of screens that can be used is unlimited. For this reason, this screen may be feasible as a backfit to existing plants using large volumes of cooling water in a once-through cooling mode, although extensive pump station structure alterations may be required.

PERFORATED PLATE FISH BARRIER

The perforated plate system was designed for use as a screening device in small irrigation ditches in California. The size of the perforations vary with the minimum size of fish to be screened. The surface of the plate is kept free of debris by a wiper bar composed of a hardwood, metal, or synthetic material. The desired approach velocity can be obtained by using a variation of heights, widths, and perforation sizes. A bypass provides for diversion of fish past the intakes.

In 1947 E. W. Murphey[55] of the California Bureau of Fish Conservation designed a perforated plate system. This plate was placed at a 32° angle with the channel and included 4 mm diameter perforations. Initial tests performed by Wales and Murphey[55] in California yielded 99 percent efficiency in removal of fish, but no tests for survival of these fish were run. Besides the low operating cost and high efficiency, the initial cost of material and construction is very low in comparison to other screening devices.

The State of California currently has a vertically-positioned perforated plate which uses a wiper mechanism to clean it of fish and debris. The intake flow is 11.3 m^3/sec. It is not known to what extent safe fish diversion is attained.

PERFORATED PIPE SCREENS

The perforated pipe screen (Figure 19) is a pipe intake located in the stream and positioned so that the stream flow can wash debris downstream. The number and size of perforations in the pipe determine velocities through the perforations. In this system, low approach velocities can be attained without significantly increasing the complexity and cost of the system. Shorter pipes or larger pipe diameter tends to produce a more uniform velocity distribution. Additions of sleeves to the inside of the pipe may be used to produce a more even distribution of flow.

The B.A.S.F. Wyandotte Chemical Corporation has installed a perforated pipe intake system in the Wisconsin River at Port Edwards, Wisconsin.[47] This system was designed for a water supply of 0.22 m^3/sec but presently provides 0.19 m^3/sec. It consists of one 4.6 m long, 0.6 m diameter pipe perforated with 12.7 mm by 12.7 mm slots providing a 40 percent open area. The theoretical maximum average approach velocity at full capacity is 6.4 cm/sec. The first perforated pipe was placed in a dredged trench and silt plugged the perforations. A second perforated pipe was installed in 1968 and has required no maintenance since installation.

A design has been proposed for the Central Columbia River[47] which features a slotted perforated pipe intake at the bottom of the river (see Figure 19). The system is designed to provide a water supply of 1.58 m^3/sec through two cylindrical pipes mounted approximately 0.6 m above the river bed. The perforated pipes are 4.6 m long and 0.92 m in diameter with 9.5 mm by 38 mm rectangular slots providing an open area of 40 percent. The theoretical maximum average velocity through the perforations at full capacity is approximately 15 cm/sec. The design was based on the swimming capability of indigenous fish.

The Detroit Steel Corporation has installed a perforated pipe intake in the Ohio River at Portsmouth, Ohio.[47] Although the facility was designed to provide a continual water supply of 5.7 m^3/sec, it is presently pumping only 4.4 m^3/sec through two 12.2 m long, 1.2 m diameter pipes perforated with 6.4 mm by 100 mm slots with open area of 20 percent. The theoretical maximum average approach velocity at full capacity is about 10.4 cm/sec. Annual maintenance programs are undertaken in which divers clean the pipes by backflushing with air and water and repair them as necessary.

The perforated intake should be located at sufficient depth to prevent water cavitation and at a sufficient distance from the bottom to prevent intake of debris and mud. Based upon the operating experiences of the Wyandotte Chemical Corporation and the Detroit Steel Corporation, the system has been reliable.

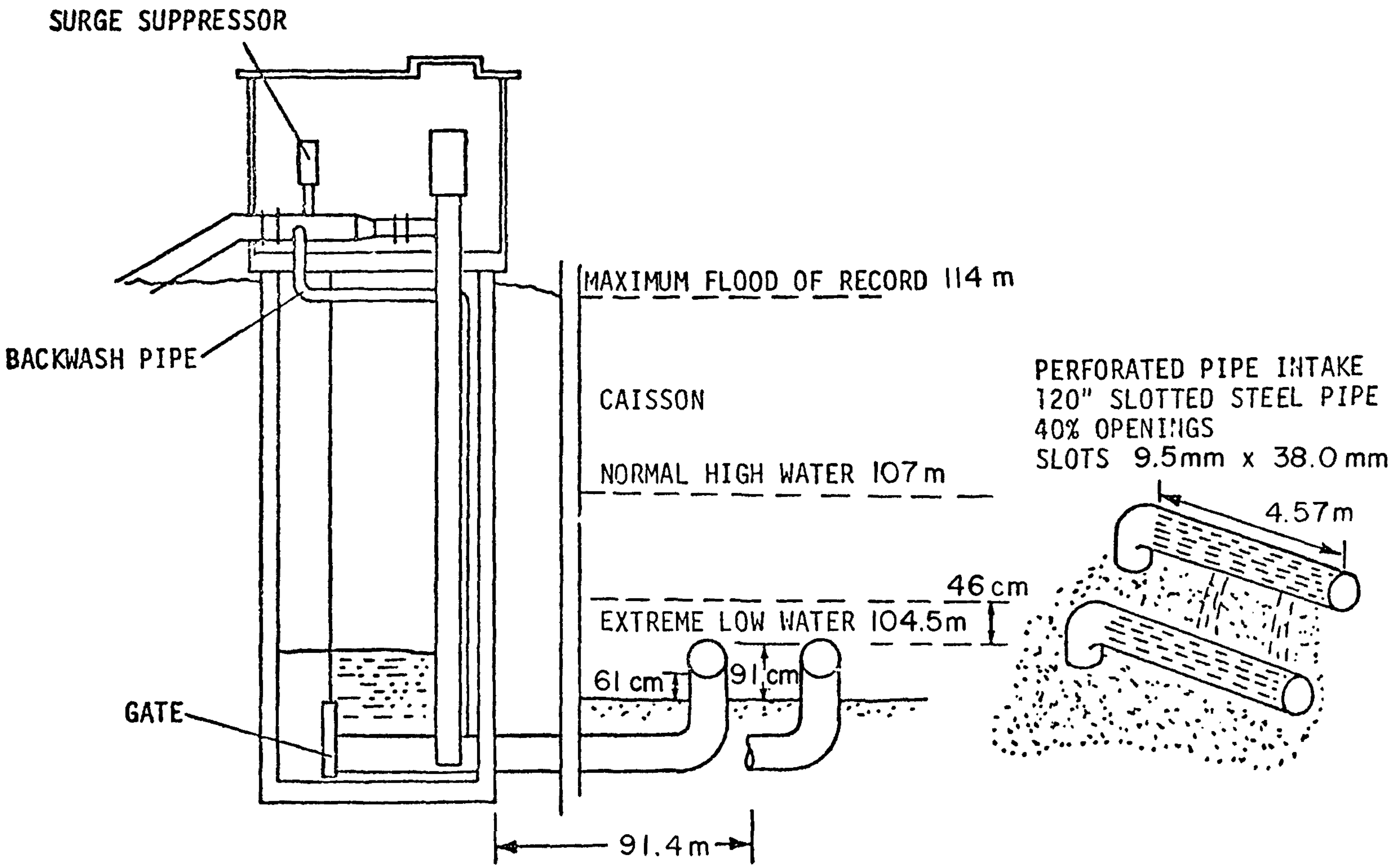


FIGURE 19. PERFORATED PIPE SYSTEM. (2,7)

The perforated pipe intake has the following advantages:

1. There is flexibility in locating the structures in the water bodies.
2. There is flexibility in size, shape, and location of perforations.
3. The intakes are relatively inexpensive.
4. Since there are no moving parts in a perforated pipe intake, operation and maintenance are not complex.[2,47]

The concept of the perforated pipe offers high potential for protecting very small fish. Depending on the velocity of the river, the velocity through the openings in the pipe, and size openings in the pipe, it appears this system could significantly reduce the numbers of larval fish entrained into a plant. A disadvantage may be possible clogging with resultant higher velocities throughout the remainder of the pipe and poor efficiency (reductions in the open area of the pipe). Provisions for backflushing the pipes can be incorporated into the design.

RADIAL WELL INTAKES

The radial well intake (Figure 20) is a type of infiltration system which uses natural, in-place, permeable material instead of artificially prepared filter beds. Slotted pipes are placed horizontally in sand or gravel beds on the bottom of the river. An installation consists of several of these radial pipe screens, each surrounded by the permeable gravel pack, and the central shaft into which the pipe screens empty. Each radial pipe screen can be back-washed separately.[3]

The feasibility of using a radial well intake depends primarily on the availability of permeable substrate and reasonably clean water. Where the appropriate geological conditions are available, operating costs for this intake are often lower than those for conventional wells because of lesser actual pumping head, lower maintenance costs, and greater pumping efficiency.[56]

For small-capacity intakes, it appears that the cost of the radial well would be competitive with that for conventional intake designs. For very large capacity intakes, however, the cost could be substantially greater than for a conventional intake because several widely scattered radial wells might be needed. Radial wells have been reliable in their service history of more than 35 years. When suitable site conditions are available, this system is attractive for minimizing the environmental impact of an intake system.[2]

CIRCULAR WELL SCREENS

A variation of the perforated pipe concept is the circular well screen, a cylindrically shaped screen having a continuous slot opening. This design provides for greater hydraulic efficiency than the perforated pipe. The slot design combines a sharp outer line of contact with a profile that abruptly widens inwardly, providing only two points of contact for debris.[57] This feature calls for potentially less clogging than a comparable size hole in a perforated pipe. The circular well

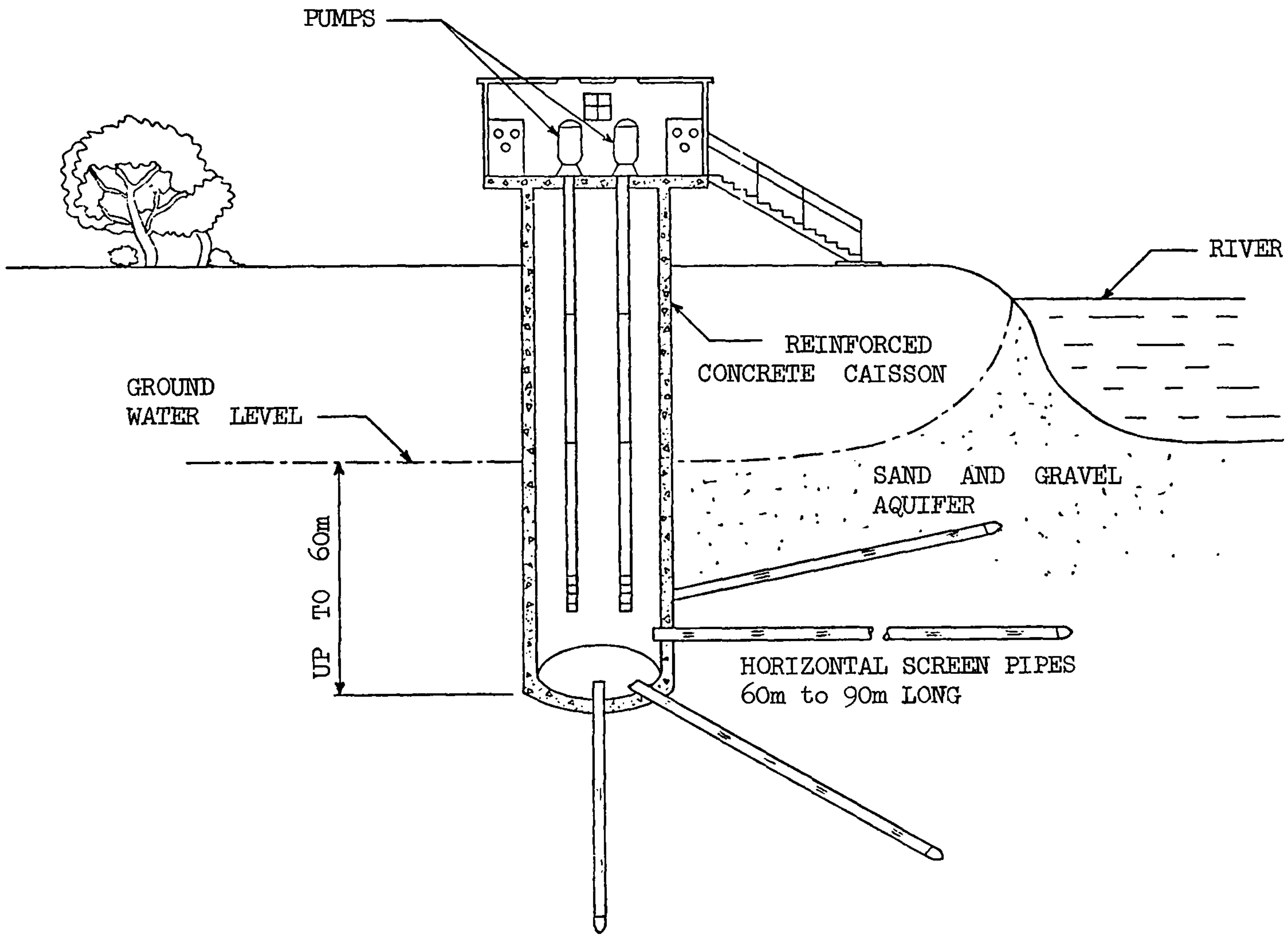


FIGURE 20. RADIAL WELL-SCHEMATIC (56)

screen can be cleaned by hydraulic backflushing and is usually found to clog at a slower rate than mesh screens.

Colorado State University in 1956 conducted extensive laboratory tests to determine the hydraulic characteristics of well screens.[58] The tests verified the criterion of 15 cm/sec as the upper limit velocity through the slot to prevent rapid clogging. The tests also indicated optimum combinations of screen diameters and lengths. According to their results, multiple screens of limited length perform more efficiently than single but longer screens. Table 1 shows the recommended flow rates for single lengths of one manufacturer's circular well screens for a range of screen diameters from 15 to 76 cm. Table 2 shows the inlet areas available for selected sizes of screen openings.

Circular well screens have been in use for many years as underground well water screens. They are also being used throughout the United States as municipal and industrial water supply intake screens located in lakes and reservoirs. At least one power plant in the United States filters raw cooling water with well screen. A circular well screen intake was installed by the Kentucky Power Company in 1963 to screen makeup cooling water at the 1,000 megawatt Big Sandy Plant in eastern Kentucky.[59] Eight 60.9 cm diameter screens, each 9.1 m long with 3.8 mm slot width, are used to screen the 0.61 to 1.23 m^3/sec makeup cooling water. The screens are cleaned by backflushing with air blasts approximately once every eight-hour shift. Clogging by coal particles initially necessitated diver cleaning. Levels of coal particles in the Big Sandy River have declined and the diver cleaning has not been required during the past two years. Minor clogging by slivers of ice during the winter months has occasionally been experienced also. The company concluded that the circular well screen intake is optimal for this plant. No data are available regarding the degree of impingement and entrainment of fish.

A laboratory study to determine the feasibility of protecting larval fish using a well screen intake at the proposed Phipps Bend Nuclear Plant on the Holston River in east Tennessee is being undertaken by the Tennessee Valley Authority.[60] The objective of the study is to determine to what extent larval and postlarval fish can avoid being impinged on or entrained through small slot (0.5 to 2.0 mm) well screen. Fish will be exposed to a range of "river" velocities and velocities through the screen. The success of this concept relies completely on the ability of the fish to detect and swim away from the screen.

Similar research was initiated by Delmarva Power and Light Company in 1976 for the purpose of developing an intake for the Summit Power Station.[61] Approximately 30 tests of several species ranging in length from 8 mm to 50 mm were conducted on 1 mm slot width circular well screen. Testing will be resumed at the beginning of the 1977 larval fish season. A preliminary report on the 1976 tests is currently being prepared.

TABLE 1. RECOMMENDED FLOW FOR CIRCULAR WELL SCREENS (58)

Intake Screen Diameter(m)	Recommended Maximum Flow per Single Length of Screen m^3/sec
.15	.010
.20	.017
.30	.038
.41	.060
.51	.088
.61	.135
.76	.211

TABLE 2. INLET AREAS FOR CIRCULAR WELL INTAKE SCREENS (58)
(Areas in square meters per lineal meter of screen for selected sizes of screen openings)

Screen Diameter, Meters	1.5 mm	2.0 mm	2.5 mm	3.8 mm	5.0 mm	6.2 mm
.15	0.21	0.25	0.28	0.26	0.30	0.32
.20	0.27	0.32	0.36	0.34	0.39	0.42
.30	0.28	0.33	0.38	0.50	0.57	0.52
.41	0.35	0.43	0.49	0.62	0.59	0.66
.51	0.33	0.42	0.48	0.62	0.73	0.82
.61	0.39	0.49	0.57	0.75	0.88	0.99
.76	0.49	0.61	0.71	0.93	1.10	1.23

HORIZONTAL TRAVELING SCREEN

The basic concept of the horizontal traveling screen is a continuously rotating screen which provides for impingement of fish for a short duration followed by release of the organism into a high velocity bypass and return to the source water body downstream of the intake. In all designs the fish are never lifted above the water surface. Larger fish may guide along the traveling screen to the bypass or swim directly upstream away from the screen rather than impinge on it. The length of time a fish is impinged depends on the length of the screen and the screen speed.

Review of intake-related literature reveals the horizontal traveling screen to be one of the few concepts that are encouraging for protection of fish eggs and larvae. A review of the biological tests conducted on these screens follows a brief description of several of these prototype screens.

Six prototype horizontal traveling screens were developed by the Bureau of Commercial Fisheries, Columbia Fisheries Program Office, at Portland, Oregon. In 1971, members of the Bureau of Reclamation and the National Marine Fisheries Service developed and tested the latest version, the Model VII. The Model VII, located in an experimental test flume near Troy, Oregon on the Grand Ronde River, underwent fairly extensive biological and mechanical testing until 1973, when it ceased operation. Descriptions of these prototype installations were presented in the Leaburg Canal feasibility study[62] and are summarized below. The results of mechanical and biological studies on the latest Model VII horizontal traveling screen at Troy, Oregon and evaluations for future use have been presented in detail in several reports.[62-68]

The first model was constructed at the Carson National Fish Hatchery, Carson, Washington, about 1965.[66] The structure consisted of a continuous screen, resembling a conveyor belt on edge, placed at an angle of 20 degrees with the direction of flow in a flume approximately 1.83 m wide and 1.22 m deep. A 0.31 m wide and 1.22 m deep bypass was constructed at the downstream end of the structure. A spiral-wound, carbon steel wire was used for the screening material. The screen itself was 90 cm wide with 8 mm openings and a 72 percent effective open area. The screen was hung on a 6.8 mm hand chain which was supported and guided by a metal track. The track was supported on each side and had a continuous slot in its center to allow passage of the screen hangers. The chain was supported at each end of the structure by a pocket sheave of 56.5 cm in diameter which was connected to the reduction gear of 10 to 170 r/min and motor assembly. Maximum speed attained by the chain was 1.5 m/sec. Eyebolts were welded to the chain to connect the screen and chain. The screen was strengthened throughout with flat metal.

The Model II screen was then designed to minimize the drag of the screen as it traveled on its return upstream. All of Model II features were similar to Model I except that the screen was lifted out of the water on its return upstream. The screen traveled downstream at an angle of 20° with the flow direction and was then raised at a 22° angle to a height of 61 cm. As the screen traveled upstream, it was lowered at an angle of 22° back to its original position.[66]

The Models I and II horizontal traveling screens were tested at the Carson National Fish Hatchery, Carson, Washington. Test fish, hatchery-reared spring Chinook salmon 9 to 15 cm long and coho salmon 5 to 8 cm long, were used to test the models at water velocities of about 1.0, 0.8, and 0.5 m/sec. Results of the tests indicated very good recovery in the bypass.

Model III was installed and tested in the Maxwell Irrigation Canal near Hermiston, Oregon, during 1966. Model III was similar to Model II in that it was lifted out of the water on its upstream return, and the screening material was similar to that of the earlier models. The screen in Model III was supported by attachment to a continuous wire rope rather than by the individually suspended hooks attached to a chain. Rollers and track similar to the trolley-conveyor type were used to support and guide the screen.[62,66]

Model IV was installed at the Bureau of Commercial Fisheries' fish testing facility near Troy, Oregon. The upstream screen travel was lifted free of the water as in previous models. The principle differences between Models IV and III were in the screen support and guidance system. The screen had to be designed for flows as great as 10 times the flows tested for Model III. The screen was attached to move along a suspended wire rope.[62,66]

Model V was constructed and tested in 1968 within an 8.5 m by 1.8 m flume at the Stanfield Irrigation Canal, Umatilla River near Echo, Oregon. Like previous models, the screen hung vertically at an angle of 20° to the flow direction and returned upstream above water. Model V represented a change from Model IV in the suspension system. Changes were from tower-supported to cable suspension support structure panels and from a continuous belt to individual panel screens. The main suspension structure consisted of a single main wire support between two end support towers on each bank of the structure. The screen was a stiff cantilevered design of individual screen panels used to eliminate any need for support and/or drive mechanism at the bottom of the screen.[34] A screen of a 13 mm stretched nylon mesh net gave a 9 mm head loss with a velocity of 73 cm/sec. The screen deflected 97 percent to 100 percent of the young steelhead and coho salmon test fish. The self-cleaning system was sufficient to keep all screen netting clean. The bypass velocity was 140 percent of the approach velocity.[66]

Model VI was installed in the previously described test facility at Troy, Oregon in 1969. Model VI was similar to Model V in that a roller and track system was used to guide and a cantilevered stiff leg to support the screen. The major difference between Models VI and V was that the screens were mounted in individual rectangular spring-tensioned panels in Model VI. The panels traveled downstream across the river with the individual panels fully closed. As the screen panels passed around the curve to the upstream track, they opened to reduce the pressure drop over the screen and any overflow. The open panel feature eliminated the need to lift the screen from the water on its upstream travel, thus allowing a low profile structure.[62]

Model VII evolved from research and development of the six previous models. This model consists of a series of continuously moving screen panels hung vertically in a 30° to 60° triangular configuration with the panels traveling diagonally downstream. The panels travel upstream parallel to the intake channel as shown in Figure 21. The individual screen panels, like those in Model VI, are spring-tensioned for overflow and reduction of drag.[63]

Several reports referencing the results of the Model VII horizontal traveling screen experiments have stated that probably reduction in entrainment of larval fish and eggs could be expected. Examination of the results of the experiments and subsequent personal communication[69] indicated that the ability to reduce entrainment of small larval fish with a horizontal traveling screen is, for the most part, speculation. Biological testing was conducted between May and December 1972, both on the Model VII horizontal traveling screen in Troy and in the laboratory on a stationary screen.[63] The screen consisted of 0.7 mm diameter galvanized wire cloth having a 2.5 mm clear opening, yielding a 60 percent total open area.

The fish tested included four size groups of spring Chinook salmon: 170 mm, 70 mm, 35 mm, and 26 mm mean total length. Diversion efficiency and survival (Tables 3 and 4) were high for all sizes of Chinook salmon tested at normal velocities of 15 cm/sec and 46 cm/sec. Fry survival ranged from 82 percent to 100 percent for impingement durations up to 30 minutes with a velocity of 46 cm/sec and up to 60 minutes with a velocity of 15 cm/sec. Survival of sac fry diverted at 15 cm/sec approach velocity was virtually 100 percent for impingement times of up to 60 minutes. Oxygen stress was not observed after 12 minutes of impingement. Survival of sac fry at 46 cm/sec was 99 percent for impingement time of 2 to 15 minutes. The major injury symptom was internal hemorrhaging in the yolk sac and caudal peduncle areas of fry tested at 46 cm/sec and greater velocities. The hemorrhaged areas showed almost complete recovery after 48 hours.

Although the results of tests at the Troy flume were encouraging, there was no testing of species other than salmon. Salmon species are larger in the egg and larval stage compared to the species indigenous to other areas of the United States.

A cooperative study by the California Department of Fish and Game, California Department of Water Resources, U. S. Bureau of Sport Fisheries and Wildlife, and the U. S. Bureau of Reclamation in 1972 and 1973[45,46] involved laboratory testing of small mesh screen for use on horizontal traveling screens. The purpose of the tests was to determine the feasibility of bypassing egg, larvae, and adult striped

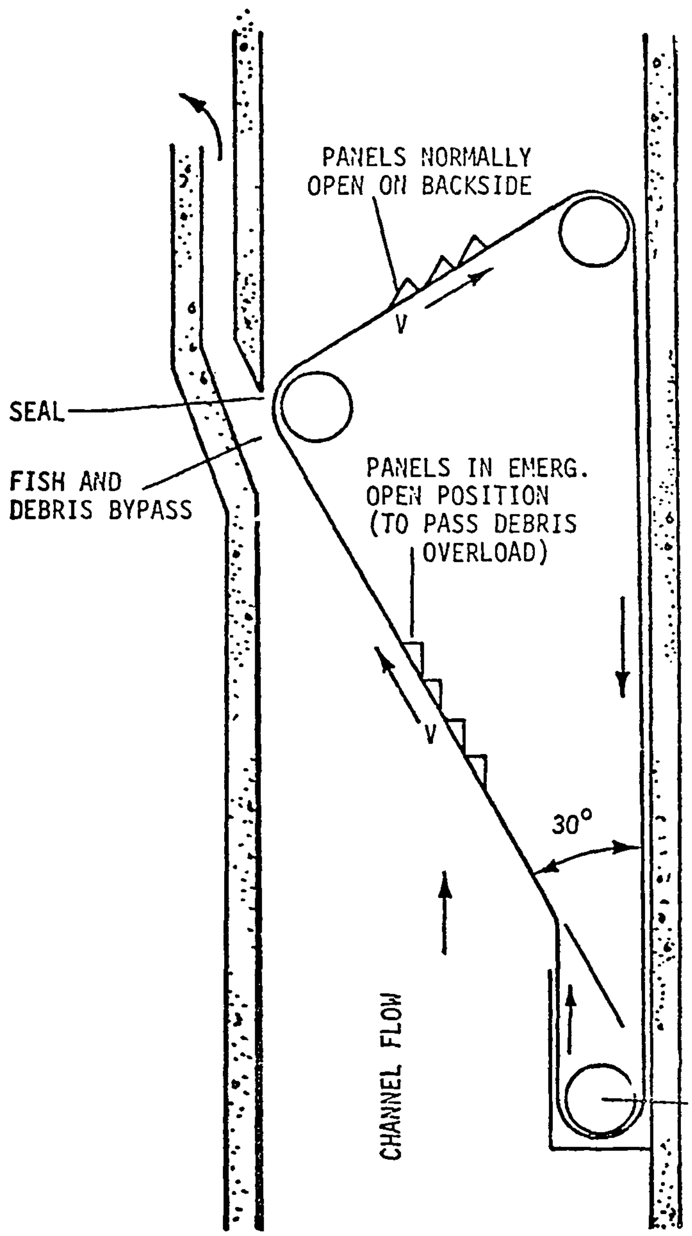


FIGURE 21. BASIC DESIGN OF HORIZONTAL TRAVELING SCREEN. (2,7)

TABLE 3. DIVERSION EFFICIENCY AND SURVIVAL OF SPRING CHINOOK IN RELATION TO APPROACH VELOCITY AND LIGHT CONDITION ON THE HORIZONTAL TRAVELING SCREEN. (63)

Normal approach velocity cm/sec	Light condition	70 mm Size Fingerling: Number of tests	Diversion efficiency (percent)	Survival (percent)	170 mm Size Fingerling: Number of tests	Diversion efficiency (percent)	Survival (percent)
15	Day				5	99.8	97.4
	Night	3	98.4	97.6	4	98.6	100.0
30	Day	5	97.9	98.5	2	99.6	99.7
	Night	6	91.5	99.7	5	99.8	99.9

TABLE 4. DIVERSION EFFICIENCY AND SURVIVAL OF SPRING CHINOOK FRY IN RELATION TO APPROACH VELOCITY AND THE DURATION OF IMPINGEMENT ON HORIZONTAL TRAVELING SCREEN MODEL VII. (63)

Normal approach velocity cm/sec	Duration of Impingement (minutes)	26 mm sac fry: Number of tests	Diversion efficiency (percent)	Survival (percent)	35 mm buttoned-up fry: Number of tests	Diversion efficiency (percent)	Survival (percent)
15	6	12	99.4	100.0	--	--	--
	30	11	99.5	100.0	--	--	--
	60	12	91.1	99.4	--	--	--
30	2	9	99.8	98.5	--	--	--
	6	14	97.8	99.7	9	98.7	100.0
	15	12	98.9	99.6	6	97.6	94.3
	30	6	96.5	90.6	2	99.8	82.1
	60	2	96.6	39.1	2	98.4	21.5

bass past the 620 to 790 m^3/sec Peripheral Canal intake located on the Sacramento River.

The Peripheral Canal project tested the survival of striped bass eggs impinged on a laboratory model horizontal traveling screen. Survival ranged from 85 percent to 95 percent at velocities less than 0.3 m/sec. At higher velocities survival was inversely related to both water velocity and impingement time. Survival and retention of striped bass larvae on 0.5 mm mesh opening screens were more variable. Nearly all larvae were recovered and survived when impinged at 7.5 cm/sec and 30 cm/sec. However, retention and survival of larvae impinged at 15 and 23 cm/sec ranged from 40 percent to 80 percent, respectively. Some of the variability was attributed to slight differences in sizes of the larvae used in the experiments. Larvae become smaller in circumference during their first four or five days of life due to absorption of the yolk sac. This allowed them to pass through the screens more easily. Larvae older than four days grow sufficiently to compensate for absorption of the yolk sac. Results of the tests conducted by the California Fish and Game personnel indicated that a screen mesh of 0.5 mm clear opening was needed to retain 100 percent of those larvae 4.5 to 5.0 mm long. Based on these results, a screen with 1 mm clear opening could be expected to retain 20 to 35 percent of this size fish.[46]

The conclusion from the tests was that the screen opening necessary to retain all striped bass larvae would have to be no greater than 0.38 mm.[46] They further concluded that "neither the technology at hand nor that expected to be developed over the next several years is likely to provide the capability to screen fish eggs and larvae from a diversion of the size contemplated. Hence, the only practical solution to protect these early development stages is to curtail diversion when eggs and larvae are passing the intake site in greatest abundance. Since the horizontal traveling screen and filter concepts would require at least several additional years of intensive research and development, with no real assurance that they could be perfected, these concepts should be dropped from further consideration." The horizontal traveling screen is, in fact, no longer being considered for use at the Peripheral Canal.[70]

Currently, the only horizontal traveling screen known to be operating is located at the Pacific Gas and Electric Company's Van Arsdale Dam on the Eel River in northern California. This 9.9 m^3/sec capacity screen (Figure 22) was installed in 1972 for the purpose of diverting migrant juvenile salmon. This screen consists of 51 panels, each 0.9 m wide by 3.4 m high. The screen length facing the incoming flow is 18.7 m with a normal water depth ranging from 1.8 m to 3.0 m. Maximum screen speed was 64 m/min. The screen has 9.5 mm diameter holes and an open area of 49 percent. The screens are suspended, guided, and driven at the top with a guide rail at the bottom. Power is provided by a 30-hp electric motor driving a variable speed hydraulic pump. Mechanical wear and maintenance problems have plagued the system, precluding continuous operation. At present, the screen is run only

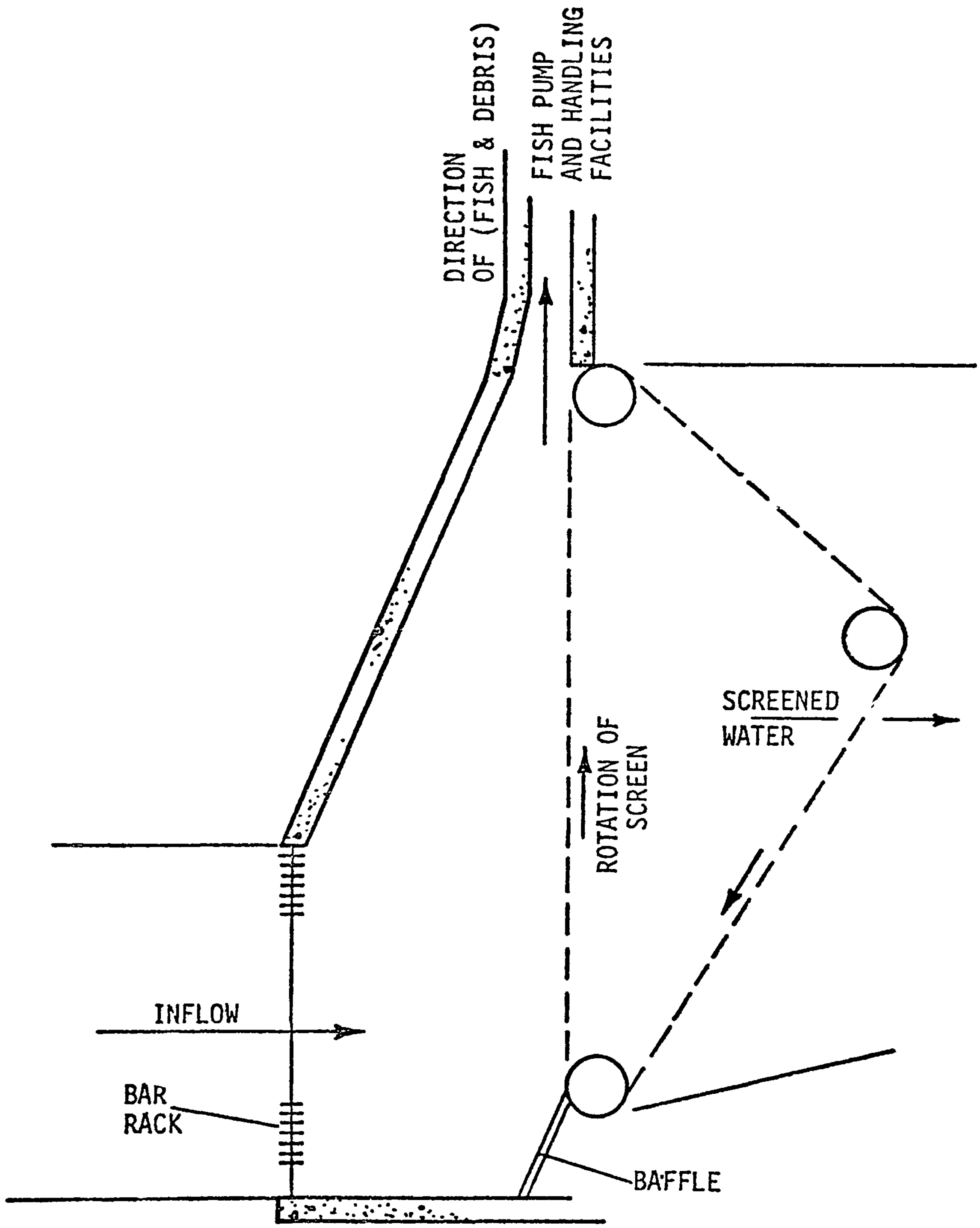


FIGURE 22. PACIFIC GAS AND ELECTRIC'S HORIZONTAL TRAVELING SCREEN INSTALLATION-SCHEMATIC. (7)

infrequently to maintain the system in working order. Very little biological testing has been possible.[71,72]

A feasibility study aimed at protecting larval fish with fine mesh screens was begun by the Tennessee Valley Authority as an outgrowth of the evaluations of the horizontal traveling screen. The objective of the laboratory flume study was to evaluate screening and mortality of larval fish based on fish species and size, velocity, impingement duration, and size of screen opening.[73] Approximately 700 tests of 10 species were conducted between April through August 1976. A preliminary report of the first three species indicated (Table 5) that the 0.5 mm square-mesh opening screen was required to retain (impinge) greater than 95 percent of striped bass 5.5 mm to 7.5 mm in total length. This retention was reduced to approximately 30 percent by the 0.97 mm opening screen. For the slightly larger (6 mm to 9 mm in total length) largemouth bass, retention by the 0.97 mm and 1.3 mm opening screens was approximately 75 and 70 percent, respectively. Seventy-five percent of the smallmouth bass 10.5 mm to 15.5 mm in total length were retained on the 1.3 mm opening screen.

Immediate and delayed mortality (Table 6) was variable for the sensitive striped bass with best survival occurring at impingement durations less than eight minutes. Survival for largemouth (Table 7) and smallmouth bass was appreciably higher (greater than 90 percent for 40 of 42 tests of smallmouth bass). Although the results of these tests can be applied to a horizontal traveling screen system, other screen support designs are being investigated for use with continuous traveling fine mesh screens. A final report on TVA's fine mesh screen study is scheduled for late 1976.

INFILTRATION BARRIER

Infiltration systems are commonly used by municipalities for water purification. Some of these filtration intakes have been used on an experimental basis for small-scale power plant intake systems. Biologically, the concept of the infiltration intake appears to offer much in the way of protection of larval, juvenile, and adult fish. Some research has been conducted in this area on the feasibility of using a high-capacity sand filter in a marine environment[74] and on fouling control techniques.[75] Two apparent drawbacks, high cost and need for clear water, are frequently mentioned concerning continued development of this method. A typical infiltration system is shown in Figure 23.

The filtration process is usually preceded by a sedimentation process to reduce the rapid clogging of the filter. A typical filter is a fine-grain layer of sand or crushed coal supported on a bed of gravel. Fine particles that cannot be removed by plain or chemical sedimentation are usually removed by the filtration bed; suspended particles and bacteria adhere to the fine grains of the filter when water is passed through the system. With the increase in particles being trapped in the filter, the pressure difference through the filtration

TABLE 5. RELATIONSHIP OF SCREEN MESH SIZE TO RETENTION OF STRIPED BASS, LARGEMOUTH, AND SMALLMOUTH BASS LARVAE (73)

Mesh Size (Clear Opening in mm)	Average percent entrained	Number of tests	Standard Deviation	Range
Striped Bass				
0.50	1.97	83	2.62	0 - 14.29
0.97	67.54	57	17.41	20 - 97.78
1.30	88.83	8	13.13	58.54-100.00
Smallmouth Bass				
1.30	6.27	13	21.28	0 - 76.92
1.80	24.15	23	30.50	0 - 90.00
2.51	63.46	9	24.66	27.78-100.00
Largemouth Bass				
0.50	1.45	17	2.11	0 - 5.71
0.97	24.00	26	27.03	0 - 78.79
1.30	29.99	27	25.01	0 - 98.77
1.80	76.32	1	0	

TABLE 6. IMMEDIATE AND DELAYED MORTALITY OF STRIPED BASS IMPINGED ON TEST SCREENS (73)

		Average Percent Mortality								
	Velocity	15 cm/sec			30 cm/sec			46 cm/sec		
	Elapsed Time	Immediate	(No. tests)	48 hrs.	Immediate	(No. tests)	48 hrs.	Immediate	(No. tests)	48 hrs.
Test Duration (minutes)										
0.5		26.93	(18)	73.72	27.53	(9)	80.09	23.43	(13)	85.22
	Range	(0-71.9)		(0-100)	(0-87.5)		(37.5-100)	(0-85.7)		(29.0-100)
1.0		14.64	(6)	73.77	15.73	(6)	76.33	19.29	(10)	76.13
	Range	(1.96-38.9)		(51.0-91.7)	(4.2-45)		(45.2-94.6)	(0-100)		(53.3-100)
2.0		23.04	(6)	68.35	14.16	(6)	73.50	33.67	(9)	79.78
	Range	(7.7 -55.7)		(6.7-100)	(0-25.0)		(39.0-100)	(0.9-100)		(49.6-100)
4.0		27.53	(5)	84.82	23.20	(6)	77.81	41.20	(10)	85.57
	Range	(7.9 -83.3)		(71.1-100)	(3.2-70.6)		(34.6-100)	(11.1-88.9)		(51.4-100)
8.0		34.64	(5)	86.97	43.78	(6)	90.84	67.97	(9)	93.28
	Range	(16.5-81.6)		(64.5-100)	(11.1-79.8)		(77.3-100)	(25.0-98.5)		(82.1-100)
16.0		70.64	(6)	97.07	85.00	(6)	100.00	96.85	(10)	100.00
	Range	(29.4-95.8)		(94.1-100)	(64.9-100)		(100-100)	(70.0-100)		(100-100)

TABLE 7. IMMEDIATE AND DELAYED MORTALITY OF LARGEMOUTH BASS IMPINGED ON TEST SCREENS (73)

Test Duration (minutes)	Velocity / Elapsed Time	15 cm/sec Immediate	(No. tests)	15 cm/sec 48 hrs.	30 cm/sec Immediate	(No. tests)	30 cm/sec 48 hrs.	46 cm/sec Immediate	(No. tests)	46 cm/sec 48 hrs.
0.5		3.27	(4)	7.57	6.50	(5)	34.35	19.80	(9)	37.80
	Range	(0-11.1)		(2.0-15.0)	(0-25)		(3.5-55.0)	(0-75.0)		(0-100)
1.0		2.86	(4)	10.44	6.74	(5)	31.67	3.25	(3)	27.32
	Range	(0-6.9)		(1.7-22.7)	(0-16.9)		(1.5-77.5)	(0-5.4)		(13.5-35.8)
2.0		1.45	(3)	4.89	11.42	(6)	31.41	4.89	(2)	11.96
	Range	(0-4.3)		(0-13.0)	(2.1-27.3)		(6.3-71.4)	(1.4-8.3)		(7.2-16.7)
4.0		2.22	(3)	13.08	4.72	(5)	40.51	8.62	(3)	82.57
	Range	(0-3.6)		(3.9-24.6)	(0-10.0)		(3.3-60.0)	(6.0-10.5)		(66.8-100)
8.0		3.22	(3)	16.17	19.70	(5)	38.94	6.48	(2)	81.48
	Range	(0-6.9)		(2.8-41.4)	(0-77.4)		(5.5-83.9)	(5.6-83.9)		(70.4-92.6)
16.0		8.90	(3)	21.49	33.34	(4)	45.70	40.86	(3)	75.04
	Range	(6.3-11.8)		(11.8-37.5)	(4.0-95.5)		(4.0-95.5)	(12.5-76.2)		(55.9-95.2)

Average Percent Mortality

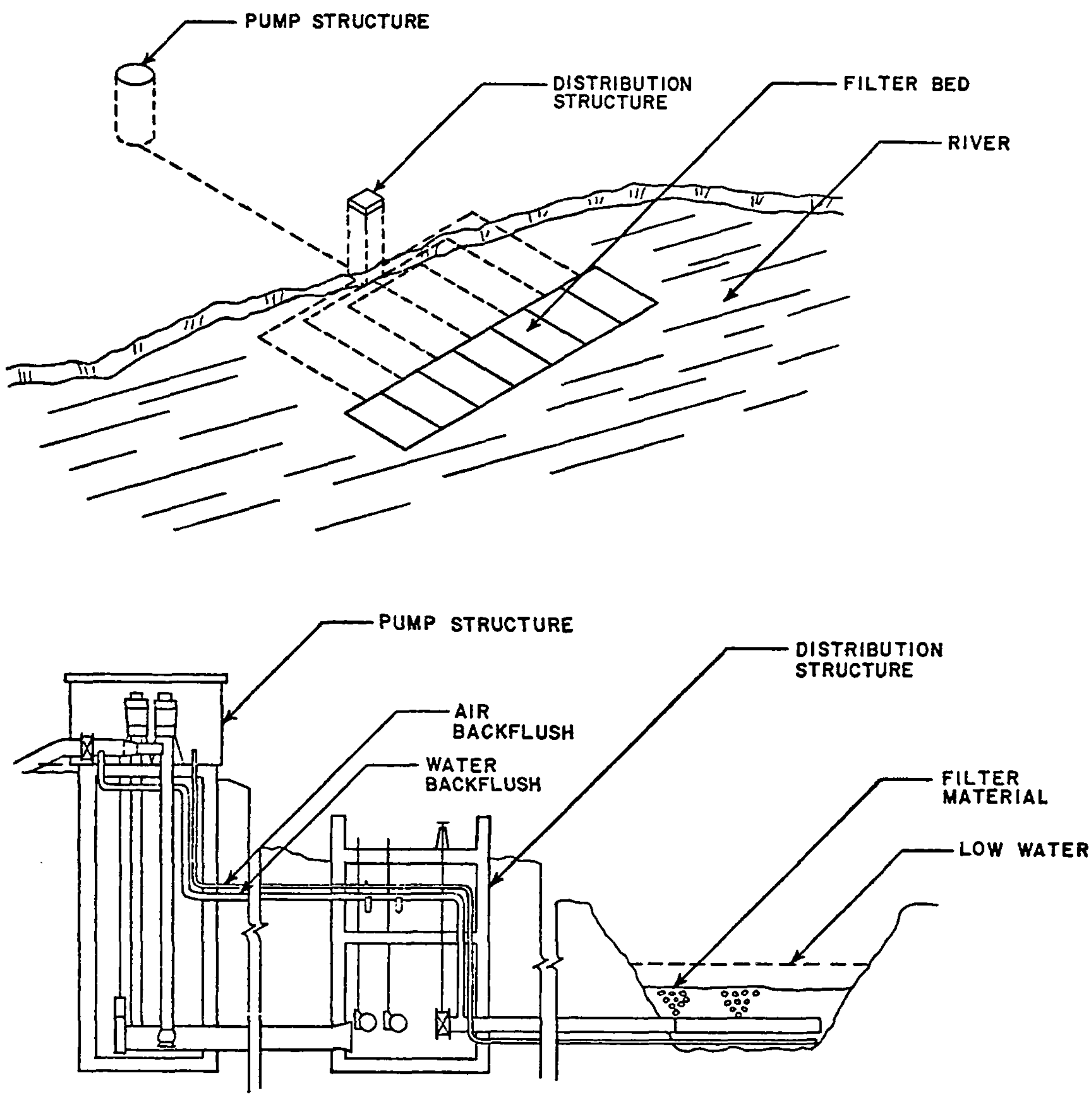


FIGURE 23. INFILTRATION FILTER BED-SCHEMATIC (47)

bed increases. When the pressure difference is excessive, the filter will be backwashed to remove the trapped particles. The filter may be divided into sections which can be individually backwashed to ensure continuously available water supply. After the water is drawn through layer filters, it is drawn into the intake by various systems, such as perforated pipes and circular well screens.[74,75]

The operational history of these systems includes the experiences of several installations. The city of Kennewick, Washington installed a filtration system on the Columbia River to provide a high quality water supply. The system was plagued with many problems of rapid clogging and was replaced by a radial well system.[47]

A filtration installation utilizing a coarse grade gravel backfill was installed in 1967 by the Oregon Fish Commission for the Elk River Salmon Hatchery. Backflushing was required to keep fine particles from clogging this system. New filter beds which were recently added are composed of a finer-grade gravel backfill with 35 cm diameter circular well screen underdrains. Although the new system worked well, it did not yield the capacity for which it was designed and a larger capacity system has now been designed.[47]

In California, several successful infiltration beds are in use at irrigation diversions. Two of these are discussed by Menchen.[76] The Merced Irrigation District (MID) of California built six "Gabion fish screens" which are designed to screen 0.57 to 1.7 m^3/sec of water. The Gabion screen consists of a thick wire cage filled with cobble and extends across the river to form a leaky dam. A perforated pipe, located beneath the Gabion screen, is covered with 15 to 20 cm of river run gravel. This 9.75 m long, 0.91 m diameter pipe has 33 percent open area and passes 0.45 m^3/sec of water with 0.3 m of head. Most of the water enters through the pipe, but some water also passes through the porous cobble-filled Gabion screen. An emergency control structure was installed to bypass the perforated pipe in case it should become clogged. In the 3 years of operation the screens have required very little maintenance, and no clogging problems have occurred. Therefore, provisions for backflushing have not been incorporated into the design. However, water and gravel were relatively clear and unsilted in this case, and these results may not be applicable in other less clean environments.

An infiltration system is used to provide makeup water to the Montour Power Plant of the Pennsylvania Power and Light Company.[47] One of three units was in service in 1971. The unit was designed for 1.0 m^3/sec but now provides only 0.71 m^3/sec. The finer-graded top material in the filter bed was washed away during the first winter of operation and was replaced with a 0.46 m layer of 19 mm diameter stone.

The major operational problem of the Montour system has been clogging of the bed with algae and fine particles. After several hours of operation, several feet of water pressure differential develops between the river and the pump house. The frequent backwashing which has been necessary increases the natural turbidity of the river. The unit was designed for a water fluid backwash, but because of unsatisfactory conditions, air lines were installed to aid in backwashing. In addition, the top 1 m of filter material has been replaced with clean material which is contained in baskets for stability.[47]

The feasibility of using a high capacity sand filter in a marine environment has been studied. Stober et al.[74] and Strandberg[75] discuss the biological model studies, fouling control techniques, and the design concepts for this method. They proposed the use of the sand filter to alleviate damage to sac fry and conducted filtration studies of the proposal near Kiket Island, Puget Sound, Washington in 1972. The system consisted of seven filter units, with a total surface area of 11,000 m^2 required for the design capacity. The design infiltration velocity was 4,100 to 6,800 $cm^3/sec/m^2$. A cross-section of the proposed filter unit is shown in Figure 25. Fifty filter units, 1.5 m wide and 18.3 m long made up the filter bed in one filter section. The filter bed was composed of both a crushed and graded anthracite coal bed supported by a layer of gravel.[74] Filter flow velocities of 0.305 to 0.61 cm/sec, which are acceptable filtration rates of 3,400 to 6,800 $cm^3/sec/m^2$, did not affect the lateral and vertical mobility of juvenile and larger fish above the filter surface.[75] These velocities were tested with an anthracite and four gravel layers.

The high capacity rapid sand filter has many attractive features for screening water intakes of power plants:[47,74,75]

1. Low sink flow rate (approach velocity) which does not affect the mobility of weak-swimming fish.
2. Flat filter surface which eliminates obstructions or traps for fish and small organisms.
3. Low profile and space requirements.

However, the sand filter system has some undesirable features also.

1. May be less reliable than other screen systems because of clogging.
2. May require more maintenance for infiltration screening because of the backwashing procedure and the necessity for keeping the entrance channel and filter bed in condition.[2,47]

SECTION 7

FISH REMOVAL SYSTEMS

This section presents a review of fish pumps and fish elevators which are designed to physically remove fish which become entrapped in intake structure screen wells.

FISH PUMP

Experimental fish pumps are currently being used to alleviate fish impingement at several power plants in the United States. In 1952, a fish run caused the traveling screens to collapse at the Contra Costa Steam Plant of the Pacific Gas and Electric Company.[77] The company subsequently installed a fish removal system. The device, much like a closed dustpan (Figure 24), was placed even with the base of the curtain wall in front of the screen. Trash pumps (volute type) are used to draw the fish into the collector which transports them to the discharge area. The device has been running continuously with relatively few mechanical problems since it was installed. A survival of 98 percent was reported at the plant with fish sizes ranging up to 35.5 cm.

A more recent version of the fish pump is being tested at Detroit Edison's Monroe plant. Fish are removed from the intake screen face by a dustpan collector, similar to the one at Contra Costa. The large 20 cm volute pump makes it possible for a 42 cm northern pike to pass unharmed through the system. Apparently the fish pump has significantly reduced the mortality rates. The initial tests were so encouraging that six additional collectors were to be installed at the Monroe plant. The fish pump (Figure 25) was placed in operation in September 1973 and resulted in 80 percent survival of fish.[78] Modification to the fish collector, including increasing the open area for fish entry and the addition of lights to attract the fish toward the dustpan, increased efficiency; however, results are still preliminary. The company believes that the fish pump is the best available technology for their situation.

A fish pump has been intermittently in operation at TVA's Browns Ferry Nuclear Plant since March 1975.[79] The 15 cm pump is connected by plastic and metal pipe to the dustpan-shaped fish collector located about mid-depth in the screen well in front of one screen. As designed, the fish enter the intake well and swim toward the surface behind the curtain wall apparently to avoid the high velocity water between the opening and the lower part of the screen. In so doing, they encounter

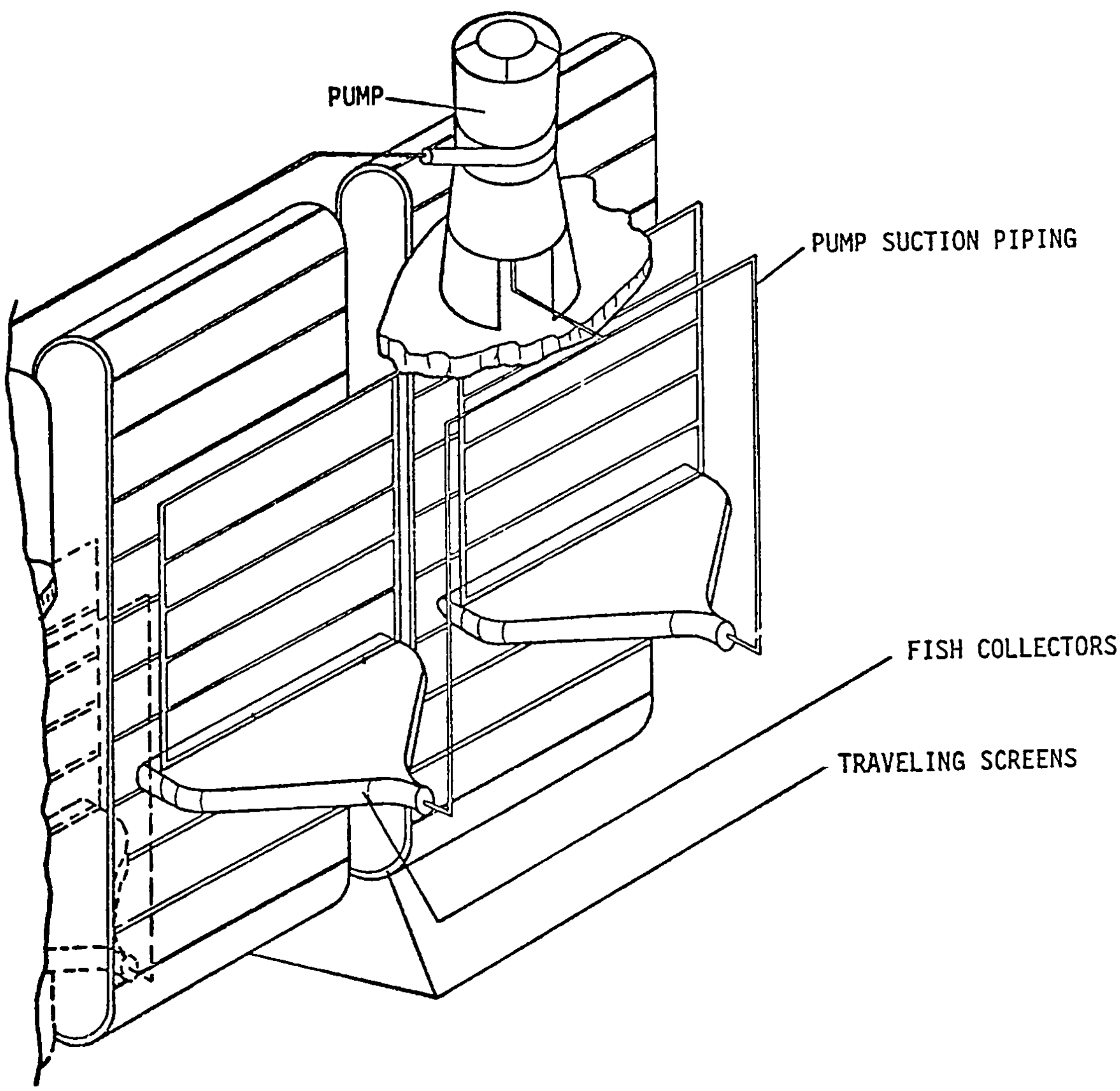
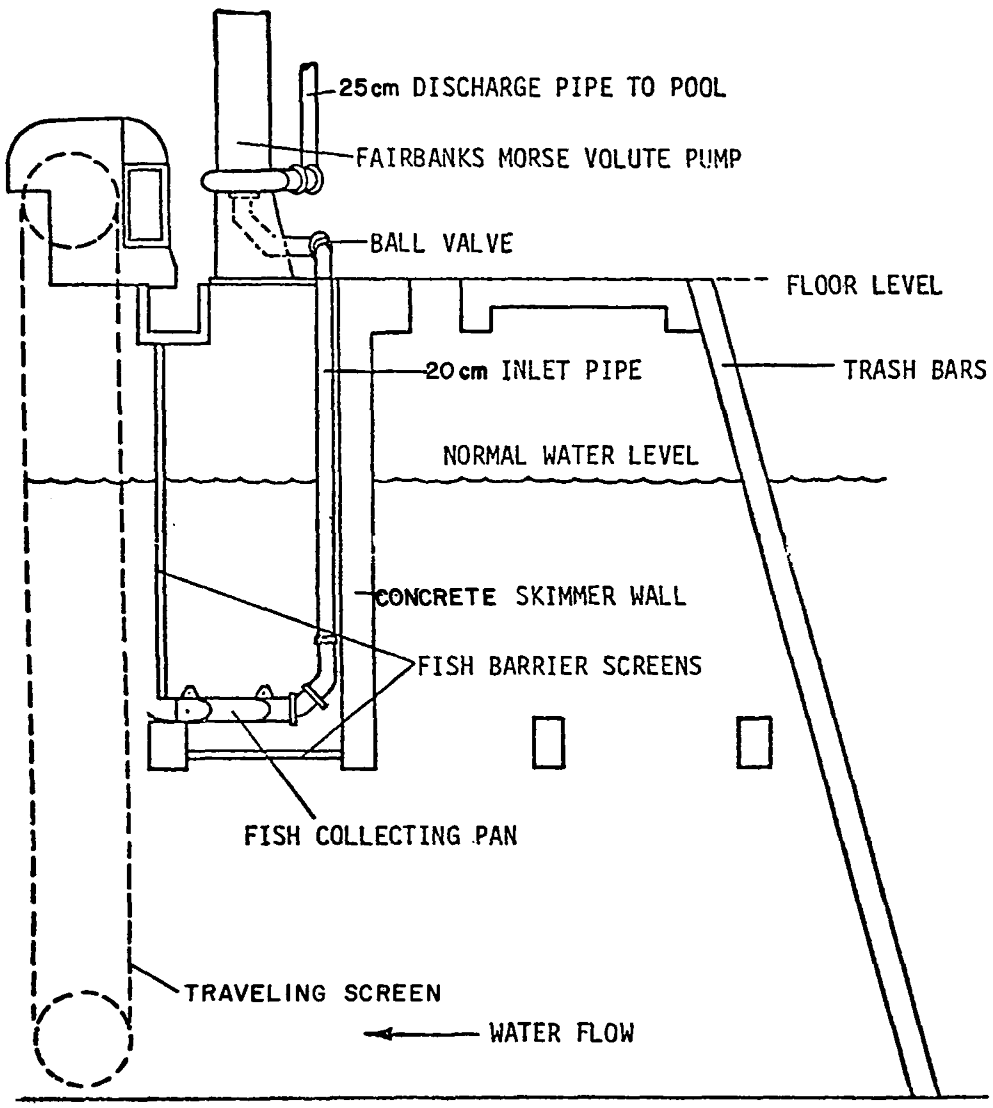


FIGURE 24. FISH DUST-PAN COLLECTORS USED WITH FISH PUMPS. (7)



ELEVATION VIEW

FIGURE 25. SCREENWELL SHOWING FISH COLLECTOR SYSTEM. (7)

the fish collector and are pulled up through the 15 cm diameter pipe, through the bladeless impeller pump, to a holding tank (where they are held and observed 24 hours to determine delayed mortality), and returned to the reservoir. The pumping success is denoted as the ratio of fish pumped of the sum of those impinged on the screen plus those pumped. After mortality of the impinged fish (assumed to be 100 percent) and the pumped fish are factored together, a net savings in numbers of fish from the screen well is determined. To date, during limited testing in spring-summer 1975, the Browns Ferry fish pump has shown a 48 percent reduction in total number of impinged fish from the test screen well. Immediate and delayed mortality reduced the overall savings to 27 percent. Testing will be resumed at the startup of the plant, which has been shut down since March 1975.[79]

Fish pumps have also been tested experimentally in California at the Huntington Beach Generating Station and the El Segundo Generating Station in conjunction with velocity capped intakes. The effectiveness of the fish pumps in removing the trapped fish was limited because the fish did not concentrate in the quiet zones where the pump was located.

VERTICAL TRAVELING FISH BASKET COLLECTOR

This scoop-shaped device is designed to travel vertically along the upstream side of a stationary barrier system located perpendicular to flow. Fish and water are carried out of the canal or screen well and spilled into a bypass trough. The prototype model tested at the secondary louver canal at Tracy, California, was 6.1 m by 2.1 m by 0.9 m. Evaluation was aimed primarily at mechanical performance.[80]

Biological studies were limited to visual observation of the effects of the system on juvenile threadfin shad and striped bass. It was found that "few of the impinged fish were injured in the transfer..."[80] About one percent of the 10,000 threadfin shad were estimated to have been maimed by the rubber scraper mounted on the collection basket.

SECTION 8

SUMMARY AND DISCUSSION

The use of barriers and fish guidance technologies to block or direct the movement of fish has a long history. Research in this area has been conducted for many years for the protection of many coastal anadromous species. Until recently, however, the designs for power plant cooling water intakes have generally not included provisions for the protection of aquatic life. With the enactment of Public Law 92-500 and the 1972 amendments which require "best technology available for minimizing adverse environmental impact" at cooling water intakes, increased attention is currently being focused on fish protection in the design and location of power plant intakes.

Several areas of intake-related research have arisen or intensified as the result of this legislation:

1. Impact assessment of impingement and entrainment of aquatic life at existing power plant intakes.
2. Selection of most favorable sites for new power plants and intakes.
3. Development of intake screening systems for new plants that will reflect "best technology available."
4. Development of fish impingement and entrainment mitigative devices for modifying existing intakes which may not meet "best technology available."

Power plant and intake siting is among the best means for minimizing fish losses at cooling water intakes. However, the selection of most favorable sites is normally complicated by several factors, such as area geology, accessibility to location, relative location with respect to critical system load areas, cost constraints, etc. An additional problem is that of quantitatively sampling the biota of an area and predicting the amount of removal and the impact of that removal on the remaining biotic community. In a river situation where many species are transient over areas several miles long during spawning migrations, the entire river may be unfavorable for part of the year. During the subsequent period in which larval fish and eggs of many species are transported with the river currents, the entire river may be considered productive area. Further, seasonal or diurnal movement of fish from shallow to deep water may preclude favoring deep water intakes over shallow water intakes in some situations.

Another plant siting enigma can arise in the choice of an unproductive body of water which may be ecologically depressed because of pollutant stresses but which may be capable of renewal given a reduction or elimination of input of the pollutants. In this case, the potential for that water body should be evaluated and compared with other unstressed or less-stressed sites.

INTAKE DESIGN

The three general types of intake configurations include: (1) approach channel, (2) off-shore conduit, and (3) shoreline or bankside. A potential for fish impingement and entrainment exists in all three designs. Ranking them for potential harm is difficult because impacts among plants are usually not directly comparable. Many variables may contribute to the number of fish lost at a power plant intake, including the following:

1. Water velocities throughout the intake system.
2. Flow patterns and eddy currents.
3. Size of the intake structure.
4. Volume of water taken in.
5. Morphometric characteristics of the intake basin.
6. Turbidity.
7. Water temperature patterns.
8. Type of source water body: marine, freshwater, river reservoir, lake.
9. Fluctuation in the water level.
10. Presence or absence of skimmer wall and underwater deflection dams.
11. Fish species characteristic of the area.
12. Standing crop of fishes subject to impingement and entrainment.

The approach channel intake, in conjunction with conventional vertical traveling screens, may create a trapping effect for fish. The presence of a skimmer wall at the entrance of the channel, coupled with high velocities, may increase this entrapment effect. Several offshore conduit intakes with high entrance velocities have experienced problems with large numbers of fish entrained into the conduit. Conventional vertical traveling screens mounted in separate wells along the shoreline have also experienced high rates of fish impingement and entrainment.

Examples of modifications to each of these basic designs exist in which the impingement of fish has been significantly reduced. These modifications include removal of screen well partitions and installation of behavioral barriers, moving screens, and fish removal systems. The channel is necessary for the optimum use of a louver barrier or horizontal traveling screen. The velocity cap has substantially reduced fish losses at offshore intakes. Elimination of separate screen wells provides for increased lateral escape from the shoreline intake.

None of the three intake configurations appears to offer any advantage for larval fish protection, apart from their location away from areas of high larval fish density. A few concepts have been proposed for new and existing intakes which may provide for larval fish protection. These concepts generally include either active or passive screening. The former usually includes impinging the fish on a continuously rotating (horizontal or vertical) fine mesh screen for a short duration and returning them back to the source water body via a bypass or sluice. Passive screening involves a low intake velocity (< 15 cm/sec) through a permeable substrate or small opening conduit from which the larval fish must be capable of swimming away to avoid impingement or entrainment.

BEHAVIORAL BARRIERS

In the diversion of juvenile and larger fish past large-volume water intakes, most behavioral barriers have not shown much promise. Of all the barriers tested, louvers appear to have the best record of fish diversion and may be capable of diverting small post-larval fish. However, behavioral barriers have not shown successful guidance of larval fish. For this reason, they should be considered only for existing large-volume intakes where cost constraints prohibit modifications for larval fish protection. In the design of new plant intakes, consideration should be given to the protection of larval fish as well as juvenile and larger fish.

The effectiveness of all the behavioral barriers can be expected to vary according to the species and size of fish. It is important to evaluate each barrier based on the species to be diverted at each intake. In this regard, special behavioral or physiological characteristics may influence the feasibility of the device. For example, in some areas of the Southeast, from 50 to 98 percent of the fish impinged at power plants are clupeid species, of which threadfin shad constitute a large percentage.[81] The annual impingement cycle shows that the majority of the fish are entrapped during the late winter when the water temperature is lowest. During this period, moribund threadfin shad can often be seen swimming in a jerky, uncoordinated manner. It is at this time that these moribund shad are copiously impinged. Since the fish are in a severely stressed condition, incapable of swimming against the intake water current, the installation of a behavioral barrier probably would have little or no effect on that species. Careful consideration (which may include extensive laboratory testing) of the many species and physical factors which affect impingement should precede the decision to install a fish barrier. Congleton,[82] describing the many variables associated with fish impingement, expressed the need for controlled laboratory testing of the fish's responses to both mechanical screens and behavioral barriers prior to field installation of full-scale devices.

PHYSICAL SCREENING BARRIERS

The use of physical screening barriers to reduce fish losses at water intakes is promising. As discussed earlier, methods have not yet been devised to reduce the entrainment of smaller larval fish at large-volume plants already in existence and having vertical traveling screens. However, in the design of new power plants or other water use facilities, particularly lower volume intakes (less than 8.5 m^3/sec), physical screens are available which offer substantial reductions in fish losses over conventional vertical traveling screens having 9.5 mm mesh screens. The applicability of each screen is highly dependent on site-specific characteristics. Special conditions imposed on several of the devices include the following:

1. Stable water levels (horizontal traveling screen, revolving drum screens).
2. Clean substrate (infiltration beds and dikes).
3. Low velocity (perforated pipe, circular well screen).
4. Backflushing provisions (perforated pipe, circular well screen).
5. Ice-free condition (horizontal traveling screen, revolving drum screens).

The mechanical screens offering the greatest protection for the smallest size fish appear to be the infiltration beds; circular well screen; perforated pipe; horizontal traveling screen; and single-entry, double-exit screen or center flow screens. The first three are attractive by virtue of their lack of moving parts but may present possible clogging problems. The horizontal traveling screen requires many moving parts and to date has no demonstrated mechanical reliability. However, given a reliably operating screen, the horizontal traveling screen probably would provide safe diversion of larval as well as postlarval fish.

The addition of fish troughs to conventional traveling screens has resulted in a high degree of success for increasing survival of impingeable size fish. However, without any reduction in screen opening size, larval and small post-larval fish entrainment remains the same. Incorporating fine mesh screens into this design may result in an increased number of fish being safely returned to the source water.

FISH PUMPS AND ELEVATORS

Fish pumps have been used with varying success for juvenile through adult fish, but probably offer little or no reduction in larval fish losses. The fish elevator concept has not been used as a mitigative device at power plant intakes.

REFERENCES

1. Maxwell, W. A. Fish Diversion for Electrical Generating Station Cooling Systems, A State-of-the-Art Report. Southern Nuclear Department, Engineering Consulting Division, NUS Corporation. Dunedin, Florida. March 1973. 78 p.

2. Development Document for Proposed Best Technology Available for Minimizing Adverse Environmental Impact of Cooling Water Intake Structures. U. S. Environmental Protection Agency. Washington, D. C. EPA 440/1-74/015. December 1973. 175 p.

3. Sonnichsen, John C., Jr., Bruce W. Bentley, George F. Bailey, and Roy E. Nakatani. A Review of Thermal Power Plant Intake Structure Designs and Related Environmental Considerations. Hanford Engineering Development Laboratory. Richland, Washington. May 1973. 77 p. plus appendixes.

4. Lake Michigan Intakes: Report on the Best Technology Available. Lake Michigan Cooling Water Intake Technical Committee. August 1973. 42 p. plus appendixes.

5. Riesbol, H. S. and R. J. L. Gear. Application of Mechanical Systems to Alleviation of Intake Entrapment Problem. In: Proceedings of the Atomic and Industrial Forum and the U. S. Department of Interior on Engineering Aspects on Siting and Operating Power Plants. February 1973. 41 p.

6. Mayo, Ronald D., William T. James, and James. L. Congleton. A Rational Approach to the Design of Power Plant Intake Fish Screens Using Both Physical and Behavioral Screening Methods. Technical Reprint No. 15. Kramer, Chin and Mayo, Consulting Engineers. 1973.

7. Sonnichsen, J. C., W. E. Farr, and H. S. Riesbol. Fish Protective Devices: A Compilation of Recent Designs, Concepts, and Operating Experience of Water Intakes Used in the United States. Hanford Engineering Development Laboratory. Richland, Washington. Energy Research and Development Administration. HEDL-TME 75-38 UC-79. July 1975. 86 p.

8. TVA Impingement Monitoring Reports. Division of Forestry, Fisheries, and Wildlife Development, Tennessee Valley Authority. Norris, Tennessee. June 1976.

9. Downs, Dallas I. and Kenneth R. Meddock. Engineering Application of Fish Behavior Studies in the Design of Intake Systems for Coastal Generating Stations. Presented at the American Society of Civil Engineers National Water Resources Conference, January 21-25, 1974.

10. Personal communication. Thomas Edwards, Duke Power Company, Charlotte, North Carolina.

11. Edwards, T. J., W. H. Hunt, L. E. Miller, and J. J. Sevic. Fish Impingement at Four Duke Power Company Steam Generating Facilities. Duke Power Company. Charlotte, North Carolina.

12. Maxfield, Galen H., Kenneth L. Liscom, and Robert H. Lander. Leading Adult Squawfish (Ptychocheilus Oresonensis) Within an Electric Field. U. S. Fish and Wildlife Service. Special Scientific Report: Fisheries No. 298. April 1959.

13. Holmes, H. B. History, Development, and Problems of Electric Fish Screens. Fish and Wildlife Service, U. S. Department of Interior. Special Scientific Report: Fisheries No. 53. June 1948.

14. Trefethen, Parker S. Exploratory Experiments in Guiding Salmon Fingerlings by a Narrow D. C. Electric Field. U. S. Fish and Wildlife Service. Special Scientific Report: Fisheries No. 158. June 1955. 42 p.

15. Hymen, A. M., W. H. Mowbray, and S. B. Saila. The Effects of Two Electrical Barriers on the Entrainment of Fish at a Freshwater Nuclear Power Plant. Symposium by Fisheries and Energy Production. 1974.

16. Personal communication. Dr. Saul Saila, University of Rhode Island, Kingston, Rhode Island.

17. Personal communication. Terrance Virnig, Northern Indiana Public Service Company, Michigan City, Indiana.

18. Burner, C. J. and H. L. Moore. Attempts to Guide Small Fish with Underwater Sound. U. S. Fish and Wildlife Service. Special Scientific Report: Fisheries No. 403. February 1962. 30 p.

19. Vanderwalker, J. G. Response of Salmonoids to Low Frequency Sound. Marine Bio Acoustics. Volume 2: p. 45-58. W. N. Lavolga, Editor. Pergammon Press. 1966.

20. Ristroph, J. D. A Free Ride for Fish. Virginia Electric and Power Company. Richmond, Virginia.

21. Schuler, V. J. and L. E. Larson. Experimental Studies Evaluating Aspects of Fish Behavior as Parameters in the Design of Generating Station Systems. Presented at the meeting of the American Society of Civil Engineers, Water Resources Engineering Program held at Los Angeles, California. January 1974.

22. Fields, P. E. Migrant Salmon Light-Guiding Studies at Columbia River Dam. Third Progress Report on Fisheries Engineering Research Program. U. S. Army Corps of Engineers. 1966. 21 p.

23. Bibko, P. N., L. Wirtenan, and P. E. Kueser. Preliminary Studies on the Effects of Air Bubbles and Intense Illumination on the Swimming Behavior of the Striped Bass (Morone Saxitalis) and the Gizzard Shad (Dorosoma Apedianum). In: Entrainment and Intake Screening, Proceedings of the Second Entrainment and Intake Screening Workshop. Report No. 15: 293-304. February 1973.

24. Personal communication. John Malaric, Detroit Edison Power Company, Detroit, Michigan.

25. Personal communication. Edward Neuman, Wisconsin Public Service Corporation, Green Bay, Wisconsin.

26. Brett, J. R. and D. MacKinnon. Preliminary Experiments Using Lights and Bubbles to Deflect Migrating Young Salmon. Journal of the Fisheries Research Board of Canada. 10(8): 548-559. 1953.

27. Bates, D. W. and J. G. Vanderwalker. Exploratory Experiments on the Deflection of Juvenile Salmon by Means of Water and Air Jets. Fish Passage Research Program. U. S. Bureau of Commercial Fisheries. Seattle, Washington. 1969. 11 p.

28. Smith, Keith A. Air Curtain Fishing for Maine Sardines. Commercial Fisheries Review. Vol. 23(3).

29. Imamura, Y. and M. Ogura. Study on the Fish-Gathering Effects of Air Curtains. Journal of the Tokyo University of Fisheries. Vol. 45, No. 2.

30. Bell, Milo C. Fisheries Handbook of Engineering Requirement and Biological Criteria. U. S. Army Corps of Engineers. Portland, Oregon. February 1973.

31. Alevras, Ronald A. Status of Air Bubble Fish Protection System at Indian Point Station on the Hudson River. Consolidated Edison Company. In: Entrainment and Intake Screening, Proceedings of the Second Entrainment and Intake Screening Workshop. Report No. 15: 289-291. February 1973.

32. Personal communication. Harold E. Pierce, Consolidated Edison Company of New York, New York, New York.

33. Kupfer, George A. and William G. Gordon. An Evaluation of the Air Bubble Curtain as a Barrier to Alewives. Commercial Fisheries Review. Vol. 28, No. 9. September 1966.

34. Personal communication. Richard Fitz, Tennessee Valley Authority, Norris, Tennessee.

35. Arkansas Power and Light Company. Biological Evaluation of Air Curtain at Arkansas Nuclear One-Unit 1. Little Rock, Arkansas. February 1976.

36. Grotbeck, Lawrence M. Evaluation of an Air Curtain as a Fish Deterrent Device at the Prairie Island Nuclear Generating Plant Cooling Water Intake. Northern States Power Company. St. Paul, Minnesota. 1976.

37. Brett, J. P. and D. F. Olderdice. Research on Guiding Young Salmon at Two British Columbia Field Stations. Fisheries Research Board of Canada, Bulletin 117. 1958.

38. Fields, P. E., G. L. Finger, and L. A. Verhoeven. The Use of a Chain Barrier to Guide Young Salmon. University of Washington, School of Fisheries. Seattle, Washington. Technical Report No. 1. 1954.

39. Fields, P. E., G. L. Finger, R. J. Adkins, R. E. Carney, and R. Pyke. A Factorial Study of the Response of Steelhead Trout, Chinook and Silver Salmon Fingerlings to Chain Barriers in Moving Water. School of Fisheries, University of Washington. Report No. 13. June 1955.

40. Hyde, H. C. Fish Collection Facilities, Louver Slat Spacing Tests at Tracy Fish Collecting Facility. State of California. Office Report. The Resources Agency. Department of Water Resources, Delta Fish Protective Facility. January 1967.

41. Bates, D. W., O. Logan, and E. A. Personen. Efficiency Evaluation, Tracy Fish Collecting Facility, Central Valley Project, California. U. S. Department of the Interior, Fish and Wildlife Service, Seattle, Washington and Bureau of Reclamation, Region 2, Sacramento, California. 1960. 70 p. plus appendixes.

42. Bates, D. W. and Russell Vinsonhaler. Use of Louvers for Guiding Fish. Transactions of the American Fisheries Society. Eighty-Sixth Annual Meeting.Toronto, Ontario, Canada. 1956. p. 38-57

43. Bates, Daniel W. and Stanley G. Jewett, Jr. Louver Efficiency in Deflecting Downstream Migrant Steelhead. Transactions of the American Fisheries Society. 90: 336-337. 1961.

44. Ducharme, L. J. A. An Application of Louver Deflectors for Guiding Atlantic Salmon. (*Salmo salar*) Smolts from Power Turbines. Journal of the Fisheries Research Board of Canada. 29: 1397-1404. 1972.

45. Interagency Ecological Study for the San Joaquin Estuary. California Department of Fish and Game. California Department of Water Resources. U. S. Bureau of Sport Fisheries and Wildlife. U. S. Bureau of Reclamation. 1973.

46. Interagency Ecological Study for the San Joaquin Estuary. California Department of Fish and Game. California Department of Water Resources. U. S. Fish and Wildlife Service. U. S. Bureau of Reclamation. 1974.

47. Schreiber, D. L., C. D. Becker, and J. J. Fuquay. Appraisal of Water Intake Systems on the Central Columbia River. Washington Public Power Supply System. Richland, Washington. March 1973.

48. Memorandum. Letter from J. D. Ristroph, Executive Manager Environmental Services, Virginia Electric and Power Company, Richmond, Virginia to R. S. Thorsell, Edison Electric Institute. April 25, 1974.

49. Water Screening Without Fish Entrapment in Virginia. ASCE Civil Engineering Conference. 1975.

50. Personal communication. J. Robinson, The Resources Agency, Department of Fish and Game, State of California, Sacramento, California.

51. Passavant Corporation. Passavant Screening Equipment. Bulletin 1002. Birmingham, Alabama. January 1976.

52. Personal communication. Kenneth R. Siddle, Industrial Sales Manager, Water Division, Passavant Corporation, Birmingham, Alabama.

53. Personal communication. Frank Mosely, Central Power and Light Company, Corpus Christi, Texas.

54. Personal communication. Scott Murray, Central Power and Light Company, Corpus Christi, Texas.

55. Wales, J. H., E. W. Murphey, and John Handley. Perforated Plate Fish Screens. California Fish and Game. 36(4): 392-403. 1950.

56. The Ranney Company, Division of Layne-New York Company. Ranney Water Collector Systems. Westerville, Ohio. November 1975.

57. Personal communication. Johnson Division, Universal Oil Products Company, St. Paul, Minnesota. March 1972.

58. Johnson Division, Universal Oil Products Company. Johnson Well Screens Modernize Water Intake Design. Bulletin 1071. St. Paul, Minnesota. 1972.

59. Personal communication. W. G. Mathews, Big Sandy Plant, Kentucky Power Company, Louisa, Kentucky.

60. Personal communication. Intake Research and Development Program Task Force, Tennessee Valley Authority, Chattanooga, Tennessee.

61. Personal communication. John Miller, Delmarva Power and Light Company, Wilmington, Delaware.

62. Eugene Water and Electric Board, Eugene, Oregon. Traveling Fish Screen, Leaburg Canal Feasibility Report. Prepared by Cornell, Howland, Hayes and Merryfield, Corvallis, Oregon. January 1971. 39 p.

63. Prentice, Earl F. and F. J. Ossiander. Fish Diversion Systems and Biological Investigation of Horizontal Traveling Screen, Model VII. In: Entrainment and Intake Screening, Proceedings of the Second Entrainment and Intake Screening Workshop. Report No. 15: 205-214. February 1973.

64. Farr, W. E. and E. F. Prentice. Mechanical Operation of Horizontal Traveling Screen Model VII. In: Entrainment and Intake Screening. Proceedings of the Second Entrainment and Intake Screening Workshop. Report No. 15: 215-222. February 1973.

65. Bates, D. W. Diversion and Collection of Juvenile Fish with Traveling Screens. U. S. Department of the Interior. Washington, D. C. Fishery Leaflet 633. March 1970.

66. Bates, D. W. and J. G. Vanderwalker. Preliminary Designs of Traveling Screens to Collect Juvenile Fish. U. S. Department of the Interior. Washington, D. C. Special Scientific Report: Fisheries No. 608. July 1970.

67. Bates, D. W., E. W. Murphey, and M. G. Beam. Traveling Screen for Removal of Debris from Rivers. U. S. Department of Commerce, National Marine Fisheries Service. Special Scientific Report: Fisheries No. 645. 1971.

68. Memorandum. D. A. Tomljanovich to C. J. Chance. Evaluation of a Horizontal Traveling Screen. Tennessee Valley Authority. July 1975.

69. Personal communication. Earl F. Prentice, Bureau of Reclamation, Seattle, Washington.

70. Personal communication. Bill Heubach, The Resources Agency, Department of Fish and Game, State of California, Sacramento, California.

71. Strassburger, A. G. Horizontal Traveling Fish Screen. Pacific Gas and Electric Company. Presented at the 41st meeting of the Hydraulic Power Conference, North Carolina, April 25-27, 1972.

72. Personal communication. Doug Green, Pacific Gas and Electric Company, San Francisco, California.

73. Tomljanovich, D. A., John H. Heuer, and Clyde W. Voigtlander Preliminary Analysis of Studies of Fine Mesh Screening of Larval Fish. Division of Forestry, Fisheries, and Wildlife Development. Tennessee Valley Authority. Norris, Tennessee. May 1976.

74. Stober, Q. J., C. H. Hanson, and P. B. Swierkowski. A High Capacity Sand Filter for Thermal Power Plant Cooling Water Intakes, Part I: Model Studies and Fouling Control Techniques. In: Entrainment and Intake Screening, Proceedings of the Second Entrainment and Intake Screening Workshop. Report No. 15: 317-334. February 1973.

75. Strandberg, H. V. A High Capacity Sand Filter for Thermal Power Plant Cooling Water Intakes, Part II: Design Concept. In: Entrainment and Intake Screening, Proceedings of the Second Entrainment and Intake Screening Workshop. Report No. 15: 335-343. February 1973.

76. Menchen, R. S. Perforated Pipe Used to Screen and Trap Juvenile Salmonids. Progressive Fish Culturist. 37(2): 85-89. 1975.

77. Kerr, J. E. Studies on Fish Preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company. State of California, Department of Game and Fish. Fish Bulletin No. 92. 1953.

78. Monroe Position Statement on Monroe Intake Program. Detroit Edison's Monroe Plant, Detroit, Michigan. March 1974.

79. Memorandum. Letter from B. G. McKinney, Power Research Staff, Tennessee Valley Authority, Chattanooga, Tennessee to T. K. Donovan, Division of Environmental Planning, Tennessee Valley Authority. April 5, 1976.

80. Prentice, E. F. Vertical Traveling Fish Basket Collector. National Oceanic and Atmospheric Administration. In: Entrainment and Intake Screening, Proceedings of the Second Entrainment and Intake Screening Workshop. Report No. 15: 223-224. February 1973.

81. Griffith, J. S. and D. A. Tomljanovich. Susceptibility of Threadfin Shad to Impingement. Prepublication copy. Tennessee Valley Authority. 1975.

82. Congleton, James L. Development of Biological Design Criteria for Fish Screens and Barriers. In: Entrainment and Intake Screening, Proceedings of the Second Entrainment and Intake Screening Workshop. John Hopkins University, Baltimore, Maryland. Report No. 15: 345-347. February 1973.

83. Personal communication. Kenneth Garrison, Florida Power Corporation, St. Petersburg, Florida.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-76-020	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE A State-of-the-Art Report on Intake Technologies		5. REPORT DATE October 1976
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) S. S. Ray, R. L. Snipes, and D. A. Tomljanovich		8. PERFORMING ORGANIZATION REPORT NO. PRS-16
9. PERFORMING ORGANIZATION NAME AND ADDRESS TVA, Power Research Staff Chattanooga, TN 37401 and, TVA, Division of Forestry, Fisheries, & Wildlife Development, Norris, TN 37828		10. PROGRAM ELEMENT NO. EHB531
		11. CONTRACT/GRANT NO. EPA-IAG-D5-E-721
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED MILESTONE; 8/75-3/76
		14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES
EPA project officer is J.P. Chasse (EPA, ERL, Corvallis, Oregon 97330).
TVA project director is H.B. Flora (TVA, Chattanooga, TN 37401)

16. ABSTRACT
The report presents an updated evaluation of mechanisms and intake designs for reducing the number of fish entrained and impinged at water intake facilities. These mechanisms consist of intake configurations, behavioral barriers for guiding fish past intake entrances, physical screening devices to physically remove or divert fish from cooling water intakes, and fish removal systems to evacuate fish already within the intake area. The report summarizes evaluations of available intake technologies. More importantly, it presents results of recent tests and studies. Where promising mechanisms are identified, recommendations are made with regard to tests needed to demonstrate the viability of a mechanism for protecting fish in a particular situation. The report considers reducing fish losses both at large-volume, once-through cooling water intakes and at lower-volume intakes at plants requiring only makeup water to replace losses due to cooling tower blowdown and evaporation. In evaluating devices for reducing impingement and entrainment, consideration was given to devices and designs that can protect very small fish and larval eggs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Electric Power Plants	Stationary Sources	10B
Cooling Water	Screens (Protectors)	13A
Water Intakes	Fish Impingement	13M
Fishes	Fish Entrainment	06C,08A

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 91
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)