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Fish protection technologies: a status report

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Abstract

Section 316(b) of the Clean Water Act has required that "best technology available" (BTA) be used to minimize adverse environmental impacts resulting from operation of the cooling water intake structure (CWIS). The primary effects of CWIS operations are the entrainment of small aquatic organisms through the cooling water system and the impingement of larger life stages on traveling water screens. Extensive research has been conducted since the early 1970s in attempts to develop technologies that will minimize entrainment and impingement. As a result, a suite of technologies is available that can be considered for application as the BTA at the CWIS. Available technologies include fish collection systems, fish diversion systems, physical barriers and behavioral barriers. The ability of a given technology to meet BTA requirements is influenced by a wide variety of biological, environmental and engineering factors that must be evaluated on a site-specific basis. The status of systems and devices in each category of fish protection alternatives is presented. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Fish protections; Water intakes; 316(b); Best technology available; Fish diversion; Fish collection; Behavioral barriers

1. Introduction

Section 316(b) of the Clean Water Act has required that "best technology available" (BTA) be used to minimize adverse environmental impacts (AEI) resulting from operation of cooling water intake structures (CWIS). The primary effects of CWIS operations are associated with the entrainment of small aquatic organisms through the cooling water system and the impingement of larger life stages on traveling water screens. Extensive research has been conducted since the early 1970s in attempts to develop technologies that will minimize entrainment and impingement. As a result, a suite of technologies is available that can be considered for application as the BTA at the CWIS. An overview of the status of fish protection technologies is presented below. A comprehensive review of these technologies is presented in a recent Electric Power Research Institute report (EPRI, 1999).

2. Fish collection systems

2.1. Modified traveling water screens

Conventional traveling water screens have been modified to incorporate modifications that improve survival of impinged fish. Such state-of-the-art modifications act to enhance fish survival related to screen impingement and spraywash removal. Screens modified in this manner are commonly called "Ristroph Screens". Each screen basket is equipped with a water-filled lifting bucket which safely contains collected fish as they are carried upward with the rotation of the screen. The screens operate continuously to minimize impingement time. When each bucket passes over the top of the screen, fish are gently rinsed into a collection trough by a low-pressure spraywash system. Once collected, the fish are transported back to a safe release

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Table 1
Summary of modified coarse and fine mesh traveling screen sites

Plant, location	Operator	Mesh size	Screened flow; water source and debris type	Screen type	Predominant species[a]	Reference
Salem Station, Delaware River	Public Service Electric and Gas Company	6.3 mm × 12.7 mm rectangular mesh	140 m^3/s; brackish water with heavy debris loading	Through-flow	Weakfish	Ronafalvy et al. (1997), Ronafalvy (1999)
Calvert Cliffs, Chesapeake Bay	Baltimore Gas and Electric	8 mm	30.5 m^3/s; salt water with light debris loading	Dual-flow	Atlantic menhaden, spot, oyster toadfish, northern searobin, bay anchovy, summer flounder	Breitburg and Thomas (1986)
Roseton Station, Hudson River	Central Hudson Electric and Gas Company	3.2 mm × 12.7 mm smooth-tex	10.3 m^3/s; fresh water with seasonal heavy debris loading	Dual-flow	Blueback herring, alewife, American shad, white perch, bay anchovy, striped bass	LMS (1991)
Big Bend Station, Tampa Bay, FL	Tampa Electric Company	0.5 mm	30.5 m^3/s; salt water with light debris loading	Dual-flow	Bay anchovy, black drum, silver perch, spotted seatrout, scaled sardine, tidewater silverside, stone crab, pink shrimp, American oyster, blue crab	Taft et al. (1981a), Bruggemeyer et al. (1988)
Indian Point, Hudson River	Consolidated Edison	9.5 mm	133 m^3/s; brackish water with heavy seasonal debris loading	Through-flow	Alewife, striped bass, white perch	Consolidated Edison Company of New York Inc. (1985)
Danskammer Point, Hudson River	Central Hudson Gas and Electric Company	9.5 mm	Flow not reported; fresh water with heavy seasonal debris loading	Through-flow	Alewife, Atlantic tomcod, bay anchovy, blueback herring, shiners, striped bass, weakfish	Ecological Analysts (1982)
Surry Station, James River	Virginia Electric Power Company	9.5 mm	111 m^3/s; brackish water with moderate debris loading	Through-flow	American shad, alewife, croaker, menhaden, silversides, bay anchovy, spotted seatrout, silver perch, weakfish	White and Brehmer (1976)
Oyster Creek, Barnegat Bay	Jersey Central Power and Light	9.5 mm	116 m^3/s; marine with heavy seasonal debris loading	Through-flow	Atlantic menhaden, bay anchovy, blueback herring, weakfish, bluefish, blue crab	Thomas and Miller (1976)
Mystic Station	Boston Edison Company	Smooth-tex	Marine with seasonally heavy debris and jellyfish loading	Through-flow	Alewife, winter flounder	SWEC (1981)
Prairie Island Station, Mississippi River, MN	Northern States Power Company	0.5 mm	39.7 m^3/s; fresh water with moderate seasonal debris loading	Through-flow	Gizzard shad, carp, shiners, catostomids, channel catfish, white bass, freshwater drum	Kuhl and Mueller (1988)
Brayton Point Station, Mt Hope Bay, MA	US Generating Company	1.0 mm/9.5 mm	16.4 m^3/s; salt water with moderate, seasonal debris loading	Angled, through-flow	Bay anchovy, Atlantic silverside, winter flounder, northern pipefish	LMS (1985a)
Barney Davis Station, Laguna Madre, TX	Central Power and Light Company	0.5 mm	21.5 m^3/s; salt water with heavy loading of grasses	Passavant, center-flow	Gulf menhaden, bay anchovy, Atlantic croaker, penaeid shrimp	Murray and Jinnette (1978)
Kintigh Station, Lake Ontario, NY	NY State Electric and Gas Company	1.0 mm	12.3 m^3/s; fresh water with light debris loading	Through-flow	Alewife, rainbow smelt, shiners	NYSEG (1990)
Dunkirk Station, Lake Erie	Niagara Mohawk Power Company	3.2 mm	Unknown	Dual-flow	Alewife, shiners, rainbow smelt, white bass, white perch, yellow perch	Beak Consultants, Inc. (1988)
Indian Point, Hudson River	Consolidated Edison	2.5 mm	133 m^3/s; brackish water with heavy seasonal debris loading	Through-flow	Striped bass, white perch, *Alosa* spp., rainbow smelt	Ecological Analysts, Inc. (1977, 1979)

Brunswick Station	Carolina Power and Light Company	1.0 mm	17.1 m^3/s; salt water with heavy seasonal debris loading	Through-flow	Croaker, spot, bay anchovy, shrimp, crabs	Carolina Power and Light (1985)
Laboratory study	ESEERCO	0.5 mm	Not applicable	Through-flow	Striped bass, winter flounder, alewife, yellow perch, walleye, channel catfish and bluegill	Taft et al. (1981b), ESEERCO (1981b)

[a] Weakfish (*Cynoscion regalis*), Atlantic menhaden (*Brevoortia tyrannus*), oyster toadfish (*Opsanus tau*), spot (*Leiostomus xanthurus*), northern searobin (*Prionotus carolinus*), bay anchovy (*Anchoa mitchilli*), silver perch (*Bairdiella chrysura*), spotted seatrout (*Synosion nebulosus*), scaled sardine (*Harengula pensacolae*), tidewater silverside (*Menidia beryllina*), Atlantic croaker (*Micropogon undulatus*), yellow perch (*Perca flavescens*), white bass (*Morone americana*), black drum (*Pogonias cromis*), walleye (*Stizostedion vitreum*), bluegill (*Lepomis macrochirus*), channel catfish (*Ichtalurus puntatus*), American shad (*Alosa sappidissima*), blueback herring (*Alosa aestivalis*), golden shiner (*Notemigonus crysoleucas*), white bass (*Morone americana*), striped bass (*Morone saxatilis*), white perch (*Morone americana*), white bass (*Morone chrysos*), winter flounder (*Pseudopleuronectes americanus*), summer flounder (*Paralichthys dentatus*), Atlantic tomcod (*Microgadus tomcod*), alewife (*Alosa pseudoharengus*), bluefish (*Pomotomus saltatrix*), gizzard shad (*Dorosoma cepedianum*), freshwater drum (*Aplodinotus grunniens*), northern pipefish (*Sygnathus fuscus*), gulf menhaden (*Brevoortia petronus*), rainbow smelt (*Osmerus mordax*), pink shrimp (*Penaeus duororum*), stone crab (*Menippe mercenaria*), American oyster (*Crassostrea virginica*), blue crab (*Callinectes sapidus*).

location. Such features have been incorporated into through-flow, dual-flow and center-flow screens.

Ristroph screens have been shown to improve fish survival and have been installed and evaluated at a number of power plants, as presented in Table 1. Improvements have been made recently to the Ristroph screen design that have resulted in increased fish survival. The most important advancement in state-of-the-art Ristroph screen design was developed through extensive laboratory and field experimentation. A series of studies conducted by Fletcher (1990) indicated that substantial injury associated with these traveling screens was due to repeated buffeting of fish inside the fish lifting buckets as a result of undesirable hydraulic conditions. To eliminate these conditions, a number of alternative bucket configurations were developed to create a sheltered area within the bucket in which fish could safely reside during screen rotation. After several attempts, a bucket configuration was developed which achieved the desired conditions (Envirex, 1996). In 1995, PSE&G performed a biological evaluation of the improved screening system installed at the Salem Generating Station in the Delaware River (Ronafalvy et al., 1997; Ronafalvy, 1999). The results of this evaluation are presented elsewhere in this issue.

Modified traveling water screens continue to be an available technology that can reduce fish losses due to impingement. Unless modified to incorporate fine mesh, as discussed below, these screens do not reduce entrainment losses.

2.2. Fine-mesh traveling screens

In addition to the fish handling provisions noted above, traveling water screens have been further modified to incorporate screen mesh with openings as small as 0.5 mm to collect fish eggs and larvae and return them to the source water body. For many species and early life stages, mesh sizes of 0.5 to 1.0 mm are required for effective screening. Various types of traveling screens, such as through-flow, dual-flow, and center-flow screens, can be fitted with fine mesh screen material.

A number of fine mesh screen installations have been evaluated for biological effectiveness, as presented in Table 1. Results of these studies indicate that survival is highly species- and life stage-specific. Species such as bay anchovy and *Alosa* spp. (American Shad, alewife and blueback herring) have shown low survival while other species such as striped bass, white perch, yellow perch and invertebrates show moderate to high survival. Therefore, evaluating fine mesh screens for potential application at a CWIS requires careful review of all available data on the survival potential of the species and life stages to be protected as well as non-target species. Generally, fine mesh screen systems

Table 2
Summary of angled screen sites

Plant, location	Owner/operator	Mesh size	Screened flow; water source and debris type	Screen type	Predominant species	Reference
Oswego Steam Station — Unit 6; Lake Ontario	Niagara Mohawk	9.5 mm	Freshwater lake with heavy seasonal debris loading	Modified through-flow screen	Alewife, rainbow smelt, shiners	LMS (1992)
Brayton Point Station, Mt Hope Bay, MA	US Generating Company	9.5 mm/ 1.0 mm	Salt water with moderate, seasonal debris loading	Modified through-flow screen with interchangeable coarse and fine mesh	Atlantic silverside, bay anchovy, northern pipefish	LMS (1985a), Davis et al. (1988)
Danskammer Station Prototype Test Facility, Hudson River	ESEERCO/ Central Hudson	9.5 mm/ 1.0 mm	Experimental facility; freshwater with heavy seasonal debris loading	Modified through-flow screen with interchangeable coarse and fine mesh	Weakfish, bay anchovy, white perch, blueback herring, alewife, American shad, shiners, sunfishes	LMS (1985b)
Laboratory studies	ESEERCO	9.5 mm	Experimental facility	Simulated angled traveling screen panels	Alewife, striped bass, white perch, Atlantic menhaden	ESEERCO (1981a)

have proven to be reliable in operation and have not experienced unusual clogging or cleaning problems as a result of the small mesh size.

In addition to these field applications, survival data on a variety of species and life stages following impingement on fine-mesh screens is available from extensive laboratory studies (Taft et al., 1981a). In these studies, larval life stages of striped bass (*Morone saxatilis*), winter flounder (*Pseudopleuronectes americanus*), alewife (*Alosa pseudoharengus*), yellow perch (*Perca flavescens*), walleye (*Stizostedium vitreum*), channel catfish (*Ictalurus punctatus*) and bluegill (*Lepomis macrochirus*) were impinged on a 0.5 mm screen mesh at velocities ranging from 0.15 to 0.91 m/s (0.5 to 3.0 ft/s) and for durations of 2, 4, 8 or 16 min. As in the field evaluations, survival was variable between species, larval stages and impingement duration and velocity.

The primary concern with fine mesh screens is that they function by impinging early organism life stages that are entrained through coarse mesh screens. Depending on species and life stage, mortality from impingement can exceed entrainment mortality. In order for fine mesh screens to offer a meaningful benefit in protecting fish, impingement survival of target species and life stages must be substantially greater than survival through the circulating water system.

2.3. *Fish pumps*

Several pumps have demonstrated an ability to transfer fish with little or no mortality, including the Hidrostal and Archimedes screw pumps that have recently undergone extensive research (Liston et al., 1993). These pumps by themselves do not represent a technology for protecting fish. However, when coupled with fish bypass systems, such as angled screens and louvers, fish pumps are biologically effective.

3. Fish division systems

3.1. *Angled screens*

A variety of species have been shown to guide effectively on screens given suitable hydraulic conditions. Angled screens require uniform flow conditions, a fairly constant approach velocity, and a low through-screen velocity to be biologically effective. Angled screen systems have been installed and biologically evaluated at a number of cooling water intakes on a prototype and full-scale basis, as presented in Table 2. Angled screen diversion efficiency varies by species, but has generally been relatively high for the many species evaluated. Survival following diversion and pumping (as required to return fish to their natural environment) has been more variable. Overall survival rates of relatively fragile species following diversion may not exceed 70%. Hardier species should exhibit survival rates approaching 100%.

In addition to the CWIS applications, angled fish diversion screens leading to bypass and return pipelines are being used extensively for guiding salmonids in the Pacific northwest. These screens are mostly of the rotary drum or vertical, flat panel (non-moving) types. They have provided effective downstream protection for juvenile salmonids at several diversion projects in the Pacific Northwest (Neitzel et al., 1991; EPRI, 1998). Like other angled screens, suitable hydraulic conditions at the screen face and a safe bypass system are required for the screens to effectively protect fish from entrainment and impingement and to divert them to a bypass for return to the source water body (Pearce and Lee, 1991).

Angled screens can be considered a viable option for protecting juvenile and adult life stages provided that proper hydraulics can be maintained and that debris can be effectively removed. To date, all angled screen applications at cooling water intakes have involved the use of conventional traveling water screens modified to provide a flush surface on which fish can guide to a bypass. Fish eggs, larvae, and small invertebrates are not protected by angled screens.

3.2. Eicher screen

The Eicher screen is a passive pressure screen that has proven effective in diverting salmon at hydroelectric projects. The first prototype of an Eicher Screen was constructed and installed in a 3-m (9-ft) diameter penstock at a hydroelectric project in the Pacific Northwest. Field testing of the screen conducted in 1990 and 1991 demonstrated that the Eicher screen effectively diverted over 98% of the steelhead (*Oncorhynchus mykiss*), coho (*Oncorhynchus kisutch*), and chinook (*Oncorhynchus tshawytscha*) smolts (EPRI, 1992). The first full-scale Eicher screen installation (two screens in two, 10-ft diameter penstocks; total flow of 28.32 m^3/s [1000 cfs]) at B. C. Hydro's Puntledge Project has shown similar results. Survival of chinook and coho salmon smolts exceeded 99%, and survival of steelhead, sockeye (*Oncorrhynchus nerka*) and chum (*Oncorhynchus keta*) salmon fry was 100, 96, and 96%, respectively, at penstock velocities up to 1.8 m/s (6 ft/s) (Smith, 1997).

While biologically effective, the Eicher Screen was not designed for use at steam electric station cooling water intakes.

3.3. Modular Inclined Screens

The Modular Inclined Screen (MIS) has recently been developed and tested by the Electric Power Research Institute (EPRI, 1994a; EPRI, 1996). The MIS is intended to protect juvenile and adult life stages of fish at all types of water intakes. An MIS module consists of an entrance with trash racks, dewatering stop logs in slots, an inclined screen set at a shallow angle (10–20°) to the flow, and a bypass for directing diverted fish to a transport pipe. The module is completely enclosed and is designed to operate at relatively high water velocities ranging from 0.61 to 3.0 m/s (2–10 ft/s), depending on species and life stages to be protected.

The MIS was evaluated in laboratory studies to determine the design configuration which yielded the best hydraulic conditions for safe fish passage and the biological effectiveness of the optimal design in diverting selected fish species to a bypass (EPRI, 1994a). Biological tests were conducted in a large flume with juvenile walleye, bluegill, channel catfish, American shad (*Alosa sapidissima*), blueback herring (*Alosa aestivalis*), golden shiner (*Notemigonus crysoleucas*), rainbow trout (*Oncorhynchus mykiss*) (two size classes), brown trout (*Salmo trutta*), chinook salmon, coho salmon, and Atlantic salmon (*Salmo salar*). Screen effectiveness (diversion efficiency and latent mortality) was evaluated at water velocities ranging from 0.61 to 3.0 m/s (2–10 ft/s). Diversion rates approached 100% for all species except American shad and blueback herring at water velocities up to at least 1.8 m/s (6 ft/s). Generally, latent mortality of test fish that was adjusted for control mortality was low (0–5%).

Based on the laboratory results, a pilot scale evaluation of the MIS was conducted at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project on the Hudson River near Albany, NY (EPRI, 1996). The results obtained in this field evaluation with rainbow trout, largemouth and smallmouth bass (*Micropterus salmoides* and *M. dolomieui*), yellow perch, bluegill and golden shiners were similar to those obtained in laboratory studies (Taft et al., 1997).

The combined results of laboratory and field evaluations of the MIS have demonstrated that this screen is an effective fish diversion device that has the potential for protecting fish at water intakes. Studies to date have only evaluated possible application at hydroelectric projects. Further, no full-scale MIS facility has been constructed and operated. As a result, the potential for effective use at cooling water intakes is unknown. Any consideration of the MIS for CWIS application should be based on future large-scale, prototype evaluations.

3.4. Louvers/angle bar racks

A louver system consists of an array of evenly spaced, vertical slats (similar to bar racks) aligned across a channel at a specified angle and leading to a bypass. Bar racks can be angled to act as louvers. Results of louver studies to date have been variable by species and site. Most of the louver installations in the US are in the Pacific Northwest at water supply intakes. Louvers generally are not considered acceptable by the fishery resource agencies in that region since they do not meet the current 100% effectiveness criterion. However, numerous studies have demonstrated that louvers can be on the order of 80–95% effective in diverting a wide variety of species over a wide range of conditions (EPRI, 1986; EPRI, 1994b; Stira and Robinson, 1997). Studies sponsored by EPRI are currently being conducted at Alden Research Laboratory with various fish species and louver/bar rack configurations. Results are expected to be available in late 2000.

Most of the louver applications to date have been with migratory species in riverine environments. No studies have been conducted to determine the potential for effective use at CWIS. Therefore, the ability of this alternative to protect species commonly impinged at CWIS is largely unknown. Further, due to the large spacings between louver slats, louver systems do not protect early life stages of fish. Future consideration of louver systems for protecting fish at cooling water intakes is warranted, but will require large-scale evaluations.

4. Physical barriers

4.1. Traveling (through-flow, dual-flow, center-flow, drum)

The traveling water screen is a standard feature at most CWIS. The ability of traveling screens to act as a barrier to fish while not resulting in impingement is dependent on many site-specific factors, such as size of fish, flow velocity, location of the screens and presence of escape routes. It is considered advantageous to locate screens flush with the shoreline at the point of water withdrawal. Traveling screens, as barrier devices, cannot be considered for protection of early life stages or aquatic organisms that have little or no motility (EPRI, 1999).

4.2. Cylindrical wedge-wire screens

Wedge-wire screens reduce entrainment and impingement at water intakes due to their small screen slot sizes, low slot velocities and appropriate location in the water column. They are designed to function passively; that is, to be effective, ambient cross-currents must be present in the water body to carry waterborne organisms and debris past the screens. Wedge-wire screens utilize "V" or wedge-shaped, cross-section wire

Table 3
Summary of cylindrical wedge wire screen sites

Plant, location	Owner/operator	Mesh size	Screened flow (cfs); water source and debris type	Screen type	Predominant species	Reference
J. H. Campbell Plant — Unit 3; Lake Michigan	Consumers Power Company	10 mm	340,000 gallons per min; light debris loading	Submerged, offshore structure with 28 individual screens	Gizzard shad, smelt, yellow perch, alewife, shiner species	EPRI (1994)
Eddystone Station, Delaware River	Philadelphia Electric Company	6.4 mm	440,000 gallons per min; heavy seasonal debris loading	Shoreline, bulkhead structure with 16 screens	Spot, Atlantic menhaden, blueback herring, white perch	Veneziale (1991)

welded to a framing system to form a slotted screening element. In order for cylindrical wedge-wire screens to reduce impingement and entrainment, the following conditions must exist: (1) sufficiently small screen slot size to physically block passage of the smallest lifestage to be protected (typically 0.5–1.0 mm); (2) low through-slot velocity; (3) relatively high velocity ambient current cross-flow (to carry organisms around and away from the screen); and (4) ambient currents providing high velocity cross-flow (to provide continuous flushing of debris). Where all of these conditions are present, wedge-wire screens can reduce entrainment and impingement (Hanson et al., 1978; Lifton, 1979).

Full-scale CWIS applications of wedge-wire screens to date have been limited to two plants (Table 3). These screens have been biologically effective in preventing entrainment and impingement of larger fish and have not caused unusual maintenance problems. This technology can be considered for application at CWIS. However, there are major concerns with clogging potential and biogrowth. Since the only two large CWIS to employ wedge-wire screens to date use 6.4 and 10 mm slot openings, the potential for clogging and fouling that would exist with slot sizes as small as 0.5 mm, as would be required for protection of many entrainable life stages, is unknown. In general, consideration of wedge-wire screens with small slot dimensions for CWIS application should include *in situ* prototype scale studies to determine potential biological effectiveness and identify the ability to control clogging and fouling in a way that does not impact station operation (EPRI, 1999; Smith and Ferguson, 1979).

4.3. Infiltration intakes

Radial wells and artificial filter beds are successfully used to supply small quantities of water. While such systems have little if any biological impact, they have not been developed for screening large flow volumes as required for CWIS application (EPRI, 1999).

4.4. Porous dike

Rock dikes which allow water to pass while preventing fish passage have been shown to be effective on an experimental basis. The effectiveness of porous dike and leaky dam systems in minimizing impingement and entrainment at power plant intakes was assessed from monitoring studies conducted by the Wisconsin Electric Power Company (Michaud, 1981). The results of this study indicated that, for several species of adult and larval fish, the impingement and entrainment rates of the porous dike and leaky dam structures were lower than the rates at nearby onshore intake structures. The accuracy of these results was limited by the variable densities of Lake Michigan ichthyoplankton populations; data interpretation was also limited by differences in operating characteristics and environmental conditions among the four plants. Results of additional laboratory and small-scale pilot studies have indicated that these dikes might be effective in preventing passage of juvenile and adult fish. However, entrainable organisms will generally be trapped in the porous medium or entrained into the pump flow. Such dikes have not been used to filter large quantities of water and generally are not considered a viable option for use at CWIS.

4.5. Gunderboom

The Gunderboom is a full-water-depth filter curtain consisting of polyester fiber strands which are pressed into a water-permeable fabric mat. Optimum performance requires flow rates below 0.002 m^3/s per square meter (10 gpm per square foot) of fabric mat (MEM, 1999). Beginning in 1995, Orange and Rockland Utilities, Inc. has sponsored an evaluation of the Gunderboom to determine its ability to minimize ichthyoplankton entrainment at the Lovett Generating Station on the Hudson River (LMS, 1997). Despite difficulties in keeping the boom deployed and providing adequate cleaning in 1995–1997 studies, results of studies in 1998 show a large reduction in entrainment and it appears that deployment and cleaning problems may have been resolved for this site. At this time, the Gunderboom system is still considered to be experimental, but its successful use at Lovett may change that status within several years. Debris loading and anchoring system requirements must be carefully evaluated at any site considered for possible installation of the Gunderboom system. Given the low flow per unit area required for optimal biological performance, a relatively large deployment area is required in the vicinity of the intake.

4.6. Barrier nets

Barrier nets have been effectively applied at several power plant cooling water systems, as well as a number of hydroelectric projects. Under the proper hydraulic conditions (primarily low velocity) and without heavy debris loading, barrier nets have been effective in blocking fish passage into water intakes. The mesh size must be selected to block fish passage, but not cause fish to become gilled in the net. Debris cleaning and biofouling control can be labor-intensive. Several recent applications in the mid-West are presented elsewhere in this paper (Michaud and Taft, 1999).

A barrier net was originally deployed at Chalk Point Station in July 1981 to combat condenser blockage problems due to seasonal invasion of blue crabs and to reduce impingement of fish and crabs on the traveling water screens. The initial barrier net had a poor performance due to fouling and clogging of the net and an inadequate anchoring system. The barrier net system at Chalk Point has undergone several modifications, including the addition of a second barrier net in 1984. The system has been successful in reducing blue crab impingement numbers. Clogging and fouling of the net is controlled through regular changing of the barrier net panels (Loos, 1986).

At the Ludington Pumped Storage Plant on Lake Michigan, a 4.02-km (2.5-mile) long barrier net, set in open water around the intake jetties, has been successful in reducing entrainment of all fish species that occur in the vicinity of the intake (Reider et al., 1997). The net was first deployed in 1989. Modifications to the design in subsequent years led to a net effectiveness for target species [five salmonid species, yellow perch, rainbow smelt (*Osmerus mordax*), alewife and bloater (*Coregonus hoyii*)] of over 80% since 1991, with an effectiveness of 96% in 1995 and 1996.

In 1993 and 1994, Orange and Rockland Utilities, Inc. sponsored a study of a 3.0-mm, fine mesh net at its Bowline Point Generating Station on the Hudson River (LMS, 1996). In 1993, clogging with fine suspended silt caused the net to clog and sink. In 1994, spraying was not effective in cleaning the net when it became fouled by the algae *Ectocarpus*. Excessive fouling caused two of the support piles to snap, ending the evaluation (LMS, 1996). In both years, an abundance of the target ichthyoplankton species, bay anchovy, was too low to determine the biological effectiveness of the net. On the basis of studies to date, the researchers conclude that a fine mesh net may be a potentially effective method for preventing entrainment at Bowline Point (LMS, 1996). However, pending further evaluation, this concept is considered to be experimental.

In conclusion, barrier nets can be considered a viable option for protecting fish provided that relatively low velocities [generally less than 0.3 m/s (1 ft/s)] can be achieved and debris loading is light. A thorough evaluation of site-specific environmental and operational conditions is generally recommended.

5. Behavioral barriers

5.1. Strobe lights

Strobe lights have been shown to effectively and consistently repel a number of lacustrine, riverine, and anadromous fish species in both laboratory and field experiments. Conversely, other studies have indicated that other species do not respond to strobe lights. Therefore, the potential use of strobe lights requires site- and species-specific evaluation. A review of recent strobe light applications is presented elsewhere in this issue (Brown, 2000).

5.2. Air bubble curtains

These curtains have generally been ineffective in blocking or diverting fish in a variety of field applications. Air bubble curtains have been evaluated at a number of sites on the Great Lakes with a variety of species. In no case have air bubble curtains been shown to effectively and consistently repel any species. Therefore, the potential for application of this technology appears limited. All air bubble curtains at these sites have been removed from service. It is possible that air bubble curtains combined with other behavioral technologies, such as light sources, might indicate improved potential for this hybrid technology in the future (GLEC, 1994; McCauley et al., 1996).

5.3. Sound

The focus of recent fish protection studies involving underwater sound technologies has been on the use of new types of low- and high-frequency acoustic systems that have not previously been available for commercial use. High-frequency (120 kHz) sound has been shown to effectively and repeatedly repel members of the Genus *Alosa* at sites throughout the US (Ploskey et al., 1995; Dunning, 1995; Consolidated Edison Company of New York Inc., 1994). Other studies have not shown sound to be consistently effective in repelling species such as largemouth bass, smallmouth bass, yellow perch, walleye, rainbow trout (EPRI, 1998), gizzard shad (*Dorosoma cepedianum*), Atlantic herring (*Clupea harengus harengus*), and bay anchovy (*Anchoa mitchilli*) (Consolidated Edison Company of New York, Inc., 1994).

Given the species-specific responses to different frequencies that have been evaluated, and the variable results that have often been produced, additional research is warranted at sites where there is no or limited data to indicate that the species of concern may respond to sound.

5.4. Infrasound

In the near field, fish response to "sound" is probably more related to particle motion than acoustic pressure (Kalmijn, 1988). Particle motion is very pronounced in the near field of a sound source and is a major component of what fish most likely sense from infrasound (frequencies less than 50 Hz). In the first practical application of infrasound for repelling fish, Knudsen et al. (1992, 1994) found a piston-type particle motion generator operating at 10 Hz to be effective in repelling Atlantic salmon smolts in a tank and in a small diversion channel.

Following the success of Knudsen et al. (1992, 1994), there was a general belief in the scientific community that infrasound could represent an effective fish repellent since there was a physiological basis for understanding the response of fish to particle motion. The potential for currently available infrasound sources to effectively repel fish has been brought into question by the results of more recent studies. Given these results, it appears that infrasound sources need to be further developed and evaluated before they can be considered an available technology for application at CWIS.

5.5. Mercury light

Response to mercury light has been shown to be species specific; some fish species are attracted, others repelled, and others have demonstrated no obvious response (EPRI, 1999). Therefore, careful consideration must be given for any application of mercury lights to avoid increasing impingement of some species. The use of mercury lights as a primary or sole fish protection device has not been supported by the results of past studies.

5.6. Electric screens

Electric barriers have been shown to effectively prevent the upstream passage of fish. However, a number of attempts to divert or deter the downstream movement of fish have met with limited success (Bengeyfield, 1990; Kynard and O'Leary, 1990). Consequently, past evaluations have not led to permanent applications. Given their past ineffectiveness and hazard potential, electric screens are not considered a viable technology for application at CWIS.

5.7. Other behavioral barriers

Devices such as water jet curtains, hanging chains, visual cues and chemicals have been suggested, and in some cases evaluated, as fish protection measures. However, no practical applications of these devices have been developed and they are not considered available technologies for application at CWIS.

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ATTACHMENT A

CWIS Technology Fact Sheets

Intake Screening Systems	Fact Sheet No. 1: Single-Entry, Single-Exit Vertical Traveling Screens (Conventional Traveling Screens)

DESCRIPTION:

The single-entry, single-exit vertical traveling screens (conventional traveling screens) consist of screen panels mounted on an endless belt; the belt rotates through the water vertically. The screen mechanism consists of the screen, the drive mechanism, and the spray cleaning system. Most of the conventional traveling screens are fitted with 3/8-inch mesh and are designed to screen out and prevent debris from clogging the pump and the condenser tubes. The screen mesh is usually supplied in individual removable panels referred to as " baskets" or "trays".

The screen washing system consists of a line of spray nozzles operating at a relatively high pressure of 80 to 120 pounds per square inch (psi). The screens are usually designed to rotate at a single speed. The screens are rotated either at predetermined intervals or when a predetermined differential pressure is reached across the screens based on the amount of debris in the intake waters.

Because of this intermittent operation of the conventional traveling screens, fish can become impinged against the screens during the extended period of time while the screens are stationary and eventually die. When the screens are rotated the fish are removed from the water and then subjected to a high pressure spray; the fish may fall back into the water and become re-impinged or they may be damaged (EPA, 1976, Pagano et *al*, 1977).

Conventional Traveling Screen (EPA, 1976)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

- The conventional traveling screens are the most common screening device presently used at steam electric power plants. Sixty percent of all the facilities use this technology at their intake structure (EEI, 1993).

RESEARCH/OPERATION FINDINGS:

- The conventional single-entry single screen is the most common device resulting in impacts from entrainment and impingement (Fritz, 1980).

DESIGN CONSIDERATIONS:

- The screens are usually designed structurally to withstand a differential pressure across their face of 4 to 8 feet of water.

- The recommended normal maximum water velocity through the screen is about 2.5 feet per second (ft/sec). This recommended velocity is where fish protection is not a factor to consider.

- The screens normally travel at one speed (10 to 12 feet per minute) or two speeds (2.5 to 3 feet per minute and 10 to 12 feet per minute). These speeds can be increased to handle heavy debris load.

ADVANTAGES:

- Conventional traveling screens are a proven "off-the-shelf" technology that is readily available.

LIMITATIONS:

- Impingement and entrainment are both major problems in this unmodified standard screen installation, which is designed for debris removal not fish protection.

REFERENCES:

ASCE. Design of Water Intake Structures for Fish Protection. Task Committee on Fish-Handling Capability of Intake Structures of the Committee on Hydraulic Structures of the Hydraulic Division of the American Society of Civil Engineers, New York, NY. 1982.

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Intake Screening Systems	Fact Sheet No. 2: Modified Vertical Traveling Screens

DESCRIPTION:

Modified vertical traveling screens are conventional traveling screens fitted with a collection "bucket" beneath the screen panel. This intake screening system is also called a bucket screen, Ristroph screen, or a Surry Type screen. The screens are modified to achieve maximum recovery of impinged fish by maintaining them in water while they are lifted to a release point. The buckets run along the entire width of the screen panels and retain water while in upward motion. At the uppermost point of travel, water drains from the bucket but impinged organisms and debris are retained in the screen panel by a deflector plate. Two material removal systems are often provided instead of the usual single high pressure one. The first uses low-pressure spray that gently washes fish into a recovery trough. The second system uses the typical high-pressure spray that blasts debris into a second trough. Typically, an essential feature of this screening device is continuous operation which keeps impingement times relatively short (Richards, 1977; Mussalli, 1977; Pagano et al., 1977; EPA , 1976).

Modified Vertical Traveling Screens (White et al, 1976)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

Facilities which have tested the screens include: the Surry Power Station in Virginia (White et al, 1976) (the screens have been in operation since 1974), the Madgett Generating Station in , Wisconsin, the Indian Point Nuclear Generating Station Unit 2 in New York, the Kintigh (formerly Somerset) Generating Station in New Jersey, the Bowline Point Generating Station (King et al, 1977), the Roseton Generating Station in New York, the Danskammer Generating Station in New York (King et al, 1977), the Hanford Generating Plant on the Columbia River in Washington (Page et al, 1975; Fritz, 1980), the Salem Genereating on the Delaware River in New Jersey, and the Monroe Power Plant on the Raisin River in Michigan.

RESEARCH/OPERATION FINDINGS:

Modified traveling screens have been shown to have good potential for alleviating impingement mortality. Some information is available on initial and long-term survival of impinged fish (EPRI, 1999; ASCE, 1982; Fritz, 1980). Specific research and operation findings are listed below:

- In 1986, the operator of the Indian Point Station redesigned fish troughs on the Unit 2 intake to enhance survival. Impingement injuries and mortality were reduced from 53 to 9 percent for striped bass, 64 to14 percent for white perch, 80 to 17 percent for Atlantic tomcod, and 47 to 7 percent for pumpkinseed (EPRI, 1999).
- The Kintigh Generating Station has modified traveling screens with low pressure sprays and a fish return system. After enhancements to the system in 1989, survivals of generally greater than 80 percent have been observed for rainbow smelt, rock bass, spottail shiner, white bass, white perch, and yellow perch. Gizzard shad survivals have been 54 to 65 percent and alewife survivals have been 15 to 44 percent (EPRI, 1999).
- Long-term survival testing was conducted at the Hanford Generating Plant on the Columbia River (Page et al, 1975; Fritz, 1980). In this study, 79 to 95 percent of the impinged and collected Chinook salmon fry survived for over 96 hours.
- Impingement data collected during the 1970s from Dominion Power's Surry Station indicated a 93.8 percent survival rate of all fish impinged. Bay anchovies had the lowest survival rate of 83 percent. The facility has modified Ristroph screens with low pressure wash and fish return systems (EPRI 1999).
- At the Arthur Kill Station, 2 of 8 screens are modified Ristroph type; the remaining six screens are conventional type. The modified screens have fish collection troughs, low pressure spray washes, fish flap seals, and separate fish collection sluices. 24-hour survival for the unmodified screens averages 15 percent, while the two modified screens have 79 and 92 percent average survival rates (EPRI 1999).

DESIGN CONSIDERATIONS:

- The same design considerations as for Fact Sheet No. 1: Conventional Vertical Traveling Screens apply (ASCE, 1982).

ADVANTAGES:

- Traveling screens are a proven "off-the-shelf" technology that is readily available. An essential feature of such screens is continuous operation during periods where fish are being impinged compared to conventional traveling screens which operate on an intermittent basis

LIMITATIONS:

- The continuous operation can result in undesirable maintenance problems (Mussalli, 1977).

- Velocity distribution across the face of the screen is generally very poor.

- Latent mortality can be high, especially where fragile species are present.

REFERENCES:

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Intake Screening Systems	**Fact Sheet No. 3: Inclined Single-Entry, Single-Exit Traveling Screens (Angled Screens)**

DESCRIPTION:

Inclined traveling screens utilize standard through-flow traveling screens where the screens are set at an angle to the incoming flow as shown in the figure below. Angling the screens improves the fish protection effectiveness of the flush mounted vertical screens since the fish tend to avoid the screen face and move toward the end of the screen line, assisted by a component of the inflow velocity. A fish bypass facility with independently induced flow must be provided. The fish have to be lifted by fish pump, elevator, or conveyor and discharged to a point of safety away from the main water intake (Richards, 1977).

fig : Richards, 4th page 419

Inclined Traveling Screens (Richards, 1977)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

Angled screens have been tested/used at the following facilities: the Brayton Point Station Unit 4 in Massachusetts; the San Onofre Station in California; and at power plants on Lake Ontario and the Hudson River (ASCE, 1982; EPRI, 1999).

RESEARCH/OPERATION FINDINGS:

- Angled traveling screens with a fish return system have been used on the intake for Brayton Point Unit 4. Studies from 1984 through 1986 that evaluated the angled screens showed a diversion efficiency of 76 percent with latent survival of 63 percent. Much higher results were observed excluding bay anchovy. Survival efficiency for the major taxa exhibited an extremely wide range, from 0.1 percent for bay anchovy to 97 percent for tautog. Generally, the taxa fell into two groups: a hardy group with efficiency greater than 65 percent and a sensitive group with efficiency less than 25 percent (EPRI, 1999).

- Southern California Edison at its San Onofre steam power plant had more success with angled louvers than with angled screens. The angled screen was rejected for full-scale use because of the large bypass flow required to yield good guidance efficiencies in the test facility.

DESIGN CONSIDERATIONS:

Many variables influence the performance of angled screens. The following recommended preliminary design criteria were developed in the studies for the Lake Ontario and Hudson River intakes (ASCE, 1982):

- Angle of screen to the waterway: 25 degrees

- Average velocity of approach in the waterway upstream of the screens: 1 foot per second

- Ratio of screen velocity to bypass velocity: 1:1

- Minimum width of bypass opening: 6 inches

ADVANTAGES:

- The fish are guided instead of being impinged.

- The fish remain in water and are not subject to high pressure rinsing.

LIMITATIONS:

- Higher cost than the conventional traveling screen

- Angled screens need a stable water elevation.

- Angled screens require fish handling devices with independently induced flow (Richards, 1977).

REFERENCES:

ASCE. Design of Water Intake Structures for Fish Protection. Task Committee on Fish-Handling Capability of Intake Structures of the Committee on Hydraulic Structures of the Hydraulic Division of the American Society of Civil Engineers, New York, NY. 1982.

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Intake Screening Systems	Fact Sheet No.4: Fine Mesh Screens Mounted on Traveling Screens

DESCRIPTION:

Fine mesh screens are used for screening eggs, larvae, and juvenile fish from cooling water intake systems. The concept of using fine mesh screens for exclusion of larvae relies on gentle impingement on the screen surface or retention of larvae within the screening basket, washing of screen panels or baskets to transfer organisms into a sluiceway, and then sluicing the organisms back to the source waterbody (Sharma, 1978). Fine mesh with openings as small as 0.5 millimeters (mm) has been used depending on the size of the organisms to be protected. Fine mesh screens have been used on conventional traveling screens and single-entry, double-exit screens. The ultimate success of an installation using fine mesh screens is contingent on the application of satisfactory handling and recovery facilities to allow the safe return of impinged organisms to the aquatic environment (Pagano et al, 1977).

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

The Big Bend Power Plant along Tampa Bay area has an intake canal with 0.5-mm mesh Ristroph screens that are used seasonally on the intakes for Units 3 and 4. At the Brunswick Power Plant in North Carolina, fine mesh is used seasonally on two of four screens has shown 84 percent reduction in entrainment compared to the conventional screen systems.

RESEARCH/OPERATION FINDINGS:

- During the mid-1980s when the screens were initially installed at Big Bend, their efficiency in reducing impingement and entrainment mortality was highly variable. The operator evaluated different approach velocities and screen rotational speeds. In addition, the operator recognized that frequent maintenance (manual cleaning) was necessary to avoid biofouling. By 1988, system performance had improved greatly. The system's efficiency in screening fish eggs (primarily drums and bay anchovy) exceeded 95 percent with 80 percent latent survival for drum and 93 percent for bay anchovy. For larvae (primarily drums, bay anchovies, blennies, and gobies), screening efficiency was 86 percent with 65 percent latent survival for drum and 66 percent for bay anchovy. Note that latent survival in control samples was also approximately 60 percent (EPRI, 1999).

- At the Brunswick Power Plant in North Carolina, fine mesh screen has led to 84 percent reduction in entrainment compared to the conventional screen systems. Similar results were obtained during pilot testing of 1-mm screens at the Chalk Point Generating Station in Maryland. At the Kintigh Generating Station in New Jersey, pilot testing indicated 1-mm screens provided 2 to 35 times reductions in entrainment over conventional 9.5-mm screens (EPRI, 1999).

- Tennessee Valley Authority (TVA) pilot-scale studies performed in the 1970s showed reductions in striped bass larvae entrainment up to 99 percent using a 0.5-mm screen and 75 and 70 percent for 0.97-mm and 1.3-mm screens. A full-scale test by TVA at the John Sevier Plant showed less than half as many larvae entrained with a 0.5-mm screen than 1.0 and 2.0-mm screens combined (TVA, 1976).

- Preliminary results from a study initiated in 1987 by the Central Hudson and Gas Electric Corporation indicated that the fine mesh screens collect smaller fish compared to conventional screens; mortality for the smaller fish was relatively high, with similar survival between screens for fish in the same length category (EPRI, 1989).

DESIGN CONSIDERATIONS:

Biological effectiveness for the whole cycle, from impingement to survival in the source water body, should be investigated thoroughly prior to implementation of this option. This includes:

- The intake velocity should be very low so that if there is any impingement of larvae on the screens, it is gentle enough not to result in damage or mortality.

- The wash spray for the screen panels or the baskets should be low-pressure so as not to result in mortality.

- The sluiceway should provide smooth flow so that there are no areas of high turbulence; enough flow should be maintained so that the sluiceway is not dry at any time.

- The species life stage, size and body shape and the ability of the organisms to withstand impingement should be considered with time and flow velocities.

- The type of screen mesh material used is important. For instance, synthetic meshes may be smooth and have a low coefficient of friction, features that might help to minimize abrasion of small organisms. However, they also may be more susceptible to puncture than metallic meshes (Mussalli, 1977).

ADVANTAGES:

- There are indications that fine mesh screens reduce entrainment.

LIMITATIONS:

- Fine mesh screens may increase the impingement of fish, i.e., they need to be used in conjunction with properly designed and operated fish collection and return systems.

- Due to the small screen openings, these screens will clog much faster than those with conventional 3/8-inch mesh. Frequent maintenance is required, especially in marine environments.

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Passive Intake Systems	Fact Sheet No. 5: Wedgewire Screens

DESCRIPTION:

Wedgewire screens are designed to reduce entrainment by physical exclusion and by exploiting hydrodynamics. Physical exclusion occurs when the mesh size of the screen is smaller than the organisms susceptible to entrainment. Hydrodynamic exclusion results from maintenance of a low through-slot velocity, which, because of the screen's cylindrical configuration, is quickly dissipated, thereby allowing organisms to escape the flow field (Weisberd et al, 1984). The screens can be fine or wide mesh. The name of these screens arise from the triangular or "wedge" cross section of the wire that makes up the screen. The screen is composed of wedgewire loops welded at the apex of their triangular cross section to supporting axial rods presenting the base of the cross section to the incoming flow (Pagano et al, 1977). A cylindrical wedgewire screen is shown in the figure below. Wedgewire screens are also called profile screens or Johnson screens.

mitre report

Schematic of Cylindrical Wedgewire Screen (Pagano et al, 1977)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

Wide mesh wedgewire screens are used at two large power plants, Eddystone and Campbell. Smaller facilities with wedgewire screens include Logan and Cope with fine mesh and Jeffrey with wide mesh (EPRI 1999).

RESEARCH/OPERATION FINDINGS:

- In-situ observations have shown that impingement is virtually eliminated when wedgewire screens are used (Hanson, 1977; Weisberg et al, 1984).
- At Campbell Unit 3, impingement of gizzard shad, smelt, yellow perch, alewife, and shiner species is significantly lower than Units 1 and 2 that do not have wedgewire screens (EPRI, 1999).
- The cooling water intakes for Eddystone Units 1 and 2 were retrofitted with wedgewire screens because over 3 million fish were reportedly impinged over a 20-month period. The wedgewire screens have generally eliminated impingement at Eddystone (EPRI, 1999).
- Laboratory studies (Heuer and Tomljanovitch, 1978) and prototype field studies (Lifton, 1979; Delmarva Power and Light, 1982; Weisberg et al, 1983) have shown that fine mesh wedgewire screens reduce entrainment.
- One study (Hanson, 1977) found that entrainment of fish eggs (striped bass), ranging in diameter from 1.8 mm to 3.2 mm, could be eliminated with a cylindrical wedgewire screen incorporating 0.5 mm slot openings. However, striped bass larvae, measuring 5.2 mm to 9.2 mm were generally entrained through a 1 mm slot at a level exceeding 75 percent within one minute of release in the test flume.
- At the Logan Generating Station in New Jersey, monitoring shows shows 90 percent less entrainment of larvae and eggs through the 1 mm wedgewire screen then conventional screens. In situ testing of1 and 2-mm wedgewire screens was performed in the St. John River for the Seminole Generating Station Units 1 and 2 in Florida in the late 1970s. This testing showed virtually no impingement and 99 and 62 percent reductions in larvae entrainment for the 1-mm and 2-mm screens, respectively, over conventional screen (9.5 mm) systems (EPRI, 1999).

DESIGN CONSIDERATIONS:

- To minimize clogging, the screen should be located in an ambient current of at least 1 feet per second (ft/sec).

- A uniform velocity distribution along the screen face is required to minimize the entrapment of motile organisms and to minimize the need of debris backflushing.

- In northern latitudes, provisions for the prevention of frazil ice formation on the screens must be considered.

- Allowance should be provided below the screens for silt accumulation to avoid blockage of the water flow (Mussalli et al, 1980).

ADVANTAGES:

- Wedgewire screens have been demonstrated to reduce impingement and entrainment in laboratory and prototype field studies.

LIMITATIONS:

- The physical size of the screening device is limiting in most passive systems, thus, requiring the clustering of a number of screening units. Siltation, biofouling and frazil ice also limit areas where passive screens such as wedgewire can be utilized.

- Because of these limitations, wedgewire screens may be more suitable for closed-cycle make-up intakes than once-through systems. Closed-cycle systems require less flow and fewer screens than once-through intakes; back-up conventional screens can therefore be used during maintenance work on the wedge-wire screens (Mussalli et al, 1980).

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Passive Intake Systems	Fact Sheet No. 6: Perforated Pipes

DESCRIPTION:

Perforated pipes draw water through perforations or slots in a cylindrical section placed in the waterway. The term "perforated" is applied to round perforations and elongated slots as shown in the figure below. The early technology was not efficient: velocity distribution was poor, it served specifically to screen out detritus, and was not used for fish protection (ASCE, 1982). Inner sleeves have been added to perforated pipes to equalize the velocities entering the outer perforations. Water entering a single perforated pipe intake without an internal sleeve will have a wide range of entrance velocities and the highest will be concentrated at the supply pipe end. These systems have been used at locations requiring small amounts of water such as make-up water. However, experience at steam electric plants is very limited (Sharma, 1978).

(Figure ASCE page 79).

Perforations and Slots in Perforated Pipe (ASCE, 1982)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

Nine steam electric units in the U.S. use perforated pipes. Each of these units uses closed-cycle cooling systems with relatively low make-up intake flow ranging from 7 to 36 MGD (EEI, 1993).

RESEARCH/OPERATION FINDINGS:

- Maintenance of perforated pipe systems requires control of biofouling and removal of debris from clogged screens.

- For withdrawal of relatively small quantities of water, up to 50,000 gpm, the perforated pipe inlet with an internal perforated sleeve offers substantial protection for fish. This particular design serves the Washington Public Power Supply System on the Columbia River (Richards, 1977).

- No information is available on the fate of the organisms impinged at the face of such screens.

DESIGN CONSIDERATIONS:

The design of these systems is fairly well established for various water intakes (ASCE, 1982).

ADVANTAGES:

The primary advantage is the absence of a confined channel in which fish might become trapped.

LIMITATIONS:

Clogging, frazil ice formation, biofouling and removal of debris limit this technology to small flow withdrawals.

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Passive intake Systems	Fact Sheet No. 7: Porous Dikes/Leaky Dams

DESCRIPTION:

Porous dikes, also known as leaky dams or leaky dikes, are filters resembling a breakwater surrounding a cooling water intake. The core of the dike consists of cobble or gravel, which permits free passage of water. The dike acts both as a physical and a behavioral barrier to aquatic organisms and is depicted in the figure below. The filtering mechanism includes a breakwater or some other type of barrier and the filtering core (Fritz, 1980). Tests conducted to date have indicated that the technology is effective in excluding juvenile and adult fish. However, its effectiveness in screening fish eggs and larvae is not established (ASCE, 1982).

Porous Dike (Schrader and Ketschke, 1978)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

- Two facilities which are both testing facilities and have used the technology are: the Point Beach Nuclear Plant in Wisconsin and the Baily Generating Station in Indiana (EPRI, 1985). The Brayton Point Generating Station in Massachusetts has also tested the technology.

RESEARCH/OPERATION FINDINGS:

- Schrader and Ketschke (1978) studied a porous dike system at the Lakeside Plant on Lake Michigan and found that numerous fish penetrated large void spaces, but for most fish accessibility was limited.
- The biological effectiveness of screening of fish larvae and the engineering practicability have not been established (ASCE, 1982).
- The size of the pores in the dike dictates the degree of maintenance due to biofouling and clogging by debris.
- Ice build-up and frazil ice may create problems as evidenced at the Point Beach Nuclear Plant (EPRI, 1985).

DESIGN CONSIDERATIONS:

- The presence of currents past the dike is an important factor which may probably increase biological effectiveness.
- The size of pores in the dike determines the extent of biofouling and clogging by debris (Sharma, 1978).
- Filtering material must be of a size that permits free passage of water but still prevents entrainment and impingement.

ADVANTAGES:

- Dikes can be used at marine, fresh water, and estuarine locations.

LIMITATIONS:

- The major problem with porous dikes comes from clogging by debris and silt, and from fouling by colonization of fish and plant life.
- Backflushing, which is often used by other systems for debris removal, is not feasible at a dike installation.
- Predation of organisms screened at these dikes may offset any biological effectiveness (Sharma, 1978).

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Fish Diversion or Avoidance Systems	Fact Sheet No. 8: Louver Systems

DESCRIPTION:

Louver systems are comprised of a series of vertical panels placed at an angle to the direction of the flow (typically 15 to 20 degrees). Each panel is placed at an angle of 90 degrees to the direction of the flow (Hadderingh, 1979). The louver panels provide an abrupt change in both the flow direction and velocity (see figure below). This creates a barrier, which fish can immediately sense and will avoid. Once the change in flow/velocity is sensed by fish, they typically align with the direction of the current and move away laterally from the turbulence. This behavior further guides fish into a current created by the system, which is parallel to the face of the louvers. This current pulls the fish along the line of the louvers until they enter a fish bypass or other fish handling device at the end of the louver line. The louvers may be either fixed or rotated similar to a traveling screen. Flow straighteners are frequently placed behind the louver systems.

These types of barriers have been very successful and have been installed at numerous irrigation intakes, water diversion projects, and steam electric and hydroelectric facilities. It appears that this technology has, in general, become accepted as a viable option to divert juvenile and adult fish.

Top view of a Louver Barrier with Fish By-Pass (Hadderingh, 1979)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

Louver barrier devices have been tested and/or are in use at the following facilities: the California Department of Water Resource's Tracy Pumping Plant; the California Department of Fish and Game's Delta Fish Protective Facility in Bryon; the Conte Anadromous Fish Research Center in Massachusetts, and the San Onofre Nuclear Generating Station in

California (EPA, 1976; EPRI, 1985; EPRI, 1999). In addition, three other plants also have louvers at their facilities: the Ruth Falls Power Plant in Nova Scotia, the Nine Mile Point Nuclear Power Station on Lake Erie, and T.W. Sullivan Hydroelectric Plant in Oregon. Louvers have also been tested at the Ontario Hydro Laboratories in Ontario, Canada (Ray et al, 1976).

RESEARCH/OPERATION FINDINGS:

Research has shown the following generalizations to be true regarding louver barriers: 1) the fish separation performance of the louver barrier decreases with an increase in the velocity of the flow through the barrier; 2) efficiency increases with fish size (EPA, 1976; Hadderingh, 1979); 3) individual louver misalignment has a beneficial effect on the efficiency of the barrier; 4) the use of center walls provides the fish with a guide wall to swim along thereby improving efficiency (EPA, 1976); and 5) the most effective slat spacing and array angle to flow depends upon the size, species and ability of the fish to be diverted (Ray et al, 1976).

In addition, the following conclusions were drawn during specific studies:

- Testing of louvered intake structures offshore was performed at a New York facility. The louvers were spaced 10 inches apart to minimize clogging. The array was angled at 11.5 percent to the flow. Center walls were provided for fish guidance to the bypass. Test species included alewife and rainbow smelt. The mean efficiency predicted was between 22 and 48 percent (Mussalli 1980).

- During testing at the Delta Facility's intake in Byron California, the design flow was 6,000 cubic feet per second (cfs), the approach velocity was 1.5 to 3.5 feet per second (ft/sec), and the bypass velocities were 1.2 to 1.6 times the approach velocity. Efficiencies were found to drop with an increase in velocity through the louvers. For example, at 1.5 to 2 ft/sec the efficiency was 61 percent for 15 millimeter long fish and 95 percent for 40 millimeter fish. At 3.5 ft/sec, the efficiencies were 35 and 70 percent (Ray et al. 1976).

- The efficiency of a louver device is highly dependent upon the length and swimming performance of a fish. Efficiencies of lower than 80 percent have been seen at facilities where fish were less than 1 to 1.6 inches in length (Mussalli, 1980).

- In the 1990s, an experimental louver bypass system was tested at the USGS' Conte Anadromous Fish Research Center in Massachusetts. This testing showed guidance efficiencies for Connecticut River species of 97 percent for a "wide array" of louvers and 100 percent for a "narrow array" (EPRI, 1999).

- At the Tracy Fish Collection Facility located along the San Joaquin River in California, testing was performed from 1993 and 1995 to determine the guidance efficiency of a system with primary and secondary louvers. The results for green and white sturgeon, American shad, splittail, white catfish, delta smelt, Chinook salmon, and striped bass showed mean diversion efficiencies ranging from 63 (splittail) to 89 percent (white catfish) (EPRI, 1999).

- In 1984 at the San Onofre Station, a total of 196,978 fish entered the louver system with 188,583 returned to the waterbody and 8,395 impinged. In 1985, 407,755 entered the louver system with 306,200 returned and 101,555 impinged. Therefore, the guidance efficiencies in 1984 and 1985 were 96 and 75 percent, respectively. However, 96-hour survival rates for some species, i.e., anchovies and croakers, were 50 percent or less. Louvers were originally considered for use at San Onofre because of 1970s pilot testing at the Redondo Beach Station in California where maximum guidance efficiencies of 96-100 percent were observed. (EPRI, 1999)

- At the Maxwell Irrigation Canal in Oregon, louver spacing was 5.0 cm with a 98 percent efficiency of deflecting immature steelhead and above 90 percent efficiency for the same species with a louver spacing of 10.8 cm.

- At the Ruth Falls Power Plant in Nova Scotia, the results of a five-year evaluation for guiding salmon smelts showed that the optimum spacing was to have wide bar spacing at the widest part of the louver with a gradual reduction in the spacing approaching the bypass. The site used a bypass:approach velocity ratio of 1.0 : 1.5 (Ray et al, 1976).

- Coastal species in California were deflected optimally (Schuler and Larson, 1974 in Ray et al, 1976) with 2.5 cm spacing of the louvers, 20 degree louver array to the direction of flow and approach velocities of 0.6 cm per second.

- At the T.W. Sullivan Hydroelectric Plant along the Williamette River in Oregon, the louver system is estimated to be 92 percent effective in diverting spring Chinook, 82 percent for all Chinook, and 85 percent for steelhead. The system has been optimized to reduce fish injuries such that the average injury occurrence is only 0.44 percent (EPRI, 1999).

DESIGN CONSIDERATIONS:

The most important parameters of the design of louver barriers include the following:

- The angle of the louver vanes in relation to the channel velocity ,

- The spacing between the louvers which is related to the size of the fish,

- Ratio of bypass velocity to channel velocity,

- Shape of guide walls,
- Louver array angles, and
- Approach velocities.

Site-specific modeling may be needed to take into account species-specific considerations and optimize the design efficiency (EPA, 1976; O'Keefe, 1978).

ADVANTAGES:

- Louver designs have been shown to be very effective in diverting fish (EPA, 1976).

LIMITATIONS:

- The costs of installing intakes with louvers may be substantially higher than other technologies due to design costs and the precision required during construction.
- Extensive species-specific field testing may be required.
- The shallow angles required for the efficient design of a louver system require a long line of louvers increasing the cost as compared to other systems (Ray et al, 1976).
- Water level changes must be kept to a minimum to maintain the most efficient flow velocity.
- Fish handling devices are needed to take fish away from the louver barrier.
- Louver barriers may, or may not, require additional screening devices for removing solids from the intake waters. If such devices are required, they may add a substantial cost to the system (EPA, 1976).
- Louvers may not be appropriate for offshore intakes (Mussalli, 1980).

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Fish Diversion or Avoidance Systems	Fact Sheet No. 9: Velocity Cap

DESCRIPTION:

A velocity cap is a device that is placed over vertical inlets at offshore intakes (see figure below). This cover converts vertical flow into horizontal flow at the entrance into the intake. The device works on the premise that fish will avoid rapid changes in horizontal flow. Fish do not exhibit this same avoidance behavior to the vertical flow that occurs without the use of such a device. Velocity caps have been implemented at many offshore intakes and have been successful in decreasing the impingement of fish.

Typical Offshore Coling Water Intake Structure with Velocity Caps (Helrey, 1985; ASCE, 1982)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

The available literature (EPA, 1976; Hanson, 1979; and Pagano et al, 1977) states that velocity caps have been installed at offshore intakes in Southern California, the Great Lakes Region, the Pacific Coast, the Caribbean and overseas; however, exact locations are not specified.

Velocity caps are known to have been installed at the El Segundo, Redondo Beach, and Huntington Beach Steam Electric Stations and the San Onofre Nuclear Generation Station in Southern California (Mussalli, 1980; Pagano et al, 1977; EPRI, 1985).

Model tests have been conducted by a New York State Utility (ASCE, 1982) and several facilities have installed velocity caps in the New York State /Great Lakes Area including the Nine Mile Point Nuclear Station, the Oswego Steam Electric Station, and the Kintigh Generating Station (EPRI, 1985).

Additional known facilities with velocity caps include the Edgewater Generation Station in Wisconsin, the Seabrook Power Plant in New Hampshire, and the Nanticoke Thermal Generating Station in Ontario, Canada (EPRI, 1985).

RESEARCH/OPERATION FINDINGS:

- Horizontal velocities within a range of 0.5 to 1.5 feet per second (ft/sec) did not significantly affect the efficiency of a velocity cap tested at a New York facility; however, this design velocity may be specific to the species present at that site (ASCE, 1982).
- Preliminary decreases in fish entrapment averaging 80 to 90 percent were seen at the El Segundo and Huntington Beach Steam Electric Plants (Mussalli, 1980).
- Performance of the velocity cap may be associated with cap design and the total volumes of water flowing into the cap rather than to the critical velocity threshold of the cap (Mussalli, 1980).

DESIGN CONSIDERATIONS:

- Designs with rims around the cap edge prevent water from sweeping around the edge causing turbulence and high velocities, thereby providing more uniform horizontal flows (EPA, 1976; Mussalli, 1980).
- Site-specific testing should be conducted to determine appropriate velocities to minimize entrainment of particular species in the intake (ASCE, 1982).
- Most structures are sized to achieve a low intake velocity between 0.5 and 1.5 ft/sec to lessen the chances of entrainment (ASCE, 1982).
- Design criteria developed for a model test conducted by Southern California Edison Company used a velocity through the cap of 0.5 to 1.5 ft/sec; the ratio of the dimension of the rim to the height of the intake areas was 1.5 to 1 (ASCE, 1982; Schuler, 1975).

ADVANTAGES:

- Efficiencies of velocity caps on West Coast offshore intakes have exceeded 90 percent (ASCE, 1982).

LIMITATIONS:

- Velocity caps are difficult to inspect due to their location under water (EPA, 1976).

- In some studies, the velocity cap only minimized the entrainment of fish and did not eliminate it. Therefore, additional fish recovery devices are be needed in when using such systems (ASCE, 1982; Mussalli, 1980).

- Velocity caps are ineffective in preventing passage of non-motile organisms and early life stage fish (Mussalli, 1980).

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Fish Diversion or Avoidance Systems	Fact Sheet No. 10: Fish Barrier Nets

DESCRIPTION:

Fish barrier nets are wide mesh nets, which are placed in front of the entrance to an intake structure (see figure below). The size of the mesh needed is a function of the species that are present at a particular site. Fish barrier nets have been used at numerous facilities and lend themselves to intakes where the seasonal migration of fish and other organisms require fish diversion facilities for only specific times of the year.

V-Arrangement of Fish Barrier Net (ASCE, 1982)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

The Bowline Point Generating Station, the J.P. Pulliam Power Plant in Wisconsin, the Ludington Storage Plant in Michigan, and the Nanticoke Thermal Generating Station in Ontario use barrier nets (EPRI, 1999).

Barrier Nets have been tested at the Detroit Edison Monroe Plant on Lake Erie and the Chalk Point Station on the Patuxent River in Maryland (ASCE, 1982; EPRI, 1985). The Chalk Point Station now uses barrier nets seasonally to reduce fish and Blue Crab entry into the intake canal (EPRI, 1985). The Pickering Generation Station in Ontario evaluated rope nets in 1981 illuminated by strobe lights (EPRI, 1985).

RESEARCH/OPERATION FINDINGS:

- At the Bowline Point Generating Station in New York, good results (91 percent impingement reductions) have been realized with a net placed in a V arrangement around the intake structure (ASCE, 1982; EPRI, 1999).

- In 1980, a barrier net was installed at the J.R. Whiting Plant (Michigan) to protect Maumee Bay. Prior to net installation, 17,378,518 fish were impinged on conventional traveling screens. With the net, sampling in 1983 and 84 showed 421,978 fish impinged (97 percent effective), sampling in 1987 showed 82,872 fish impinged (99 percent effective), and sampling in 1991 showed 316,575 fish impinged (98 percent effective) (EPRI, 1999).

- Nets tested with high intake velocities (greater than 1.3 feet per second) at the Monroe Plant have clogged and subsequentially collapsed. This has not occurred at facilities where the velocities are 0.4 to 0.5 feet per second (ASCE, 1982).

- Barrier nets at the Nanticoke Thermal Generating Station in Ontario reduced intake of fish by 50 percent (EPRI, 1985).

- The J.P Pulliam Generating Station in Wisconsin uses dual barrier nets (0.64 centimeters stretch mesh) to permit net rotation for cleaning. Nets are used from April to December or when water temperatures go above 4 degrees Celsius. Impingement has been reduced by as much as 90 percent. Operating costs run about $5,000 per year, and nets are replaced every two years at $2,500 per net (EPRI, 1985).

- The Chalk Point Station in Maryland realized operational costs of $5,000-10,000 per year with the nets being replaced every two years (EPRI, 1985). However, crab impingement has been reduced by 84 percent and overall impingrment liability has been reduced from $2 million to $140,000 (EPRI, 1999).

- The Ludington Storage Plant (Michigan) provides water from Lake Michigan to a number of power plant facilities. The plant has a 2.5-mile long barrier net that has successfully reduced impingement and entrainment. The overall net effectiveness for target species (five salmonids, yellow perch, rainbow smelt, alewife, and chub) has been over 80 percent since 1991 and 96 percent since 1995. The net is deployed from mid-April to mid-October, with storms and icing preventing use during the remainder of the year (EPRI, 1999).

DESIGN CONSIDERATIONS:

- The most important factors to consider in the design of a net barrier are the site-specific velocities and the potential for clogging with debris (ASCE, 1982).

- The size of the mesh must permit effective operations, without excessive clogging. Designs at the Bowline Point Station in New York have 0.15 and 0.2 inch openings in the mesh nets, while the J.P. Pulliam Plant in Wisconsin has 0.25 inch openings (ASCE, 1982).

ADVANTAGES:

- Net barriers, if operating properly, should require very little maintenance.
- Net barriers have relatively little cost associated with them.

LIMITATIONS:

- Net barriers are not effective for the protection of the early life stages of fish or zooplankton (ASCE, 1982).

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Fish Diversion or Avoidance Systems	Fact Sheet No. 11: Aquatic Filter Barrier Systems

DESCRIPTION:

Aquatic filter barrier systems are barriers that employ a filter fabric designed to allow for passage of water into a cooling water intake structure, but exclude aquatic organisms. These systems are designed to be placed some distance from the cooling water intake structure within the source waterbody and act as a filter for the water that enters into the cooling water system. These systems may be floating, flexible, or fixed. Since these systems generally have such a large surface area, the velocities that are maintained at the face of the permeable curtain are very low. One company, Gunderboom, Inc., has a patented full-water-depth filter curtain comprised of polyethylene or polypropylene fabric that is suspended by flotation billets at the surface of the water and anchored to the substrate below. The curtain fabric is manufactured as a matting of minute unwoven fibers with an apparent opening size of 20 microns. The Gunderboom Marine/Aquatic Life Exclusion System (MLES)™ also employs an automated "air burst"™ technology to periodically shake the material and pass air bubbles through the curtain system to clean it of sediment buildup and release any other material back in to the water column.

Gunderboom Marine/Aquatic Life Exclusion System (Gunderboom, Inc., 1999)

TESTING FACILITIES AND/OR FACILITIES USING THE TECHNOLOGY:

- Gunderboom MLES ™ have been tested and are currently installed on a seasonal basis at Unit 3 of the Lovett Station in New York. Prototype testing of the Gunderboom system began in 1994 as a means of lowering ichthyoplankton entrainment at Unit 3. This was the first use of the technology at a cooling water intake structure. The Gunderboom tested was a single layer fabric. Material clogging resulted in loss of filtration capacity and boom submergence within 12 hours of deployment. Ichthyoplankton monitoring while the boom was intact indicated an 80 percent reduction in entrainable organisms (Lawler, Matusky, and Skelly Engineers, 1996).

- A Gunderboom MLES ™ was effectively deployed at the Lovett Station for 43 days in June and July of 1998 using an Air-Burst cleaning system and newly designed deadweight anchoring system. The cleaning system coupled with a perforated material proved effective at limiting sediment on the boom, however it required an intensive operational schedule (Lawler, Matusky, and Skelly Engineers, 1998).

- A 1999 study was performed on the Gunderboom MLES ™ at the Lovett Station in New York to qualitatively determine the characteristics of the fabric with respect to the impingement of ichthyoplankton at various flow regimes. Conclusions were that the viability of striped bass eggs and larvae were not affected (Lawler, Matusky, and Skelly Engineers, 1999).

- Ichthyoplankton sampling at Unit 3 (with Gunderboom MLES ™ deployed) and Unit 4 (without Gunderboom) in May through August 2000 showed an overall effectiveness of approximately 80 percent. For juvenile fish, the density at Unit 3 was 58 percent lower. For post yolk-sac larvae, densities were 76 percent lower. For yolk-sac larvae, densities were 87 percent lower (Lawler, Matusky & Skelly Engineers 2000).

RESEARCH/OPERATION FINDINGS:

Extensive testing of the Gunderboom MLES ™ has been performed at the Lovett Station in New York. Anchoring, material, cleaning, and monitoring systems have all been redesigned to meet the site-specific conditions in the waterbody and to optimize the operations of the Gunderboom. Although this technology has been implemented at only one cooling water intake structure, it appears to be a promising technology to reduce impingement and entrainment impacts. It is also being evaluated for use at the Contre Costa Power Plant in California.

DESIGN CONSIDERATIONS:

The most important parameters in the design of a Gunderboom ® Marine/Aquatic Life Exclusion System include the following (Gunderboom, Inc. 1999):

- Size of booms designed for 3-5 gpm per square foot of submerged fabric. Flows greater than 10-12 gallons per minute.

- Flow-through velocity is approximately 0.02 ft/s.

- Performance monitoring and regular maintenance.

ADVANTAGES:

- Can be used in all waterbody types.
- All larger and nearly all other organisms can swim away from the barrier because of low velocities.
- Little damage is caused to fish eggs and larvae if they are drawn up against the fabric.
- Modulized panels may easily be replaced.
- Easily deployed for seasonal use.
- Biofouling not significant.
- Impinged organisms released back into the waterbody.
- Benefits relative to cost appear to be very promising, but remain unproven to date.
- Installation can occur with no or minimal plant shutdown.

LIMITATIONS:

- Currently only a proven technology for this application at one facility.
- Extensive waterbody-specific field testing may be required.
- May not be appropriate for conditions with large fluctuations in ambient flow and heavy currents and wave action.
- High level of maintenance and monitoring required.
- Higher flow facilities may require very large surface areas; could interfere with other waterbody uses.

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Fish Diversion or Avoidance Systems	Fact Sheet No. 12: Sound Barriers

DESCRIPTION:

Sound barriers are non-contact barriers that rely on mechanical_or electronic equipment that generates various sound patterns to elicit avoidance responses in fish. Acoustic barriers are used to deter fish from entering industrial water intakes and power plant turbines. Historically, the most widely-used acoustical barrier is a pneumatic air gun or "popper." The pneumatic air gun is a modified seismic device which produces high-amplitude, low-frequency sounds to exclude fish. Closely related devices include "fishdrones" and "fishpulsers" (also called "hammers"). The fishdrone produces a wider range of sound frequencies and amplitudes than the popper. The fishpulser produces a repetitive sharp hammering sound of low-frequency and high-amplitude. Both instruments have ahd limited effectiveness in the field (EPRI, 1995; EPRI, 1989; Hanson, et al., 1977; EPA, 1976; Taft, et al., 1988; ASCE, 1992).

Researchers have generally been unable to demonstrate or apply acoustic barriers as fish deterrents, even though fish studies showed that fish respond to sound, because the response varies as a function of fish species, age, and size as well as environmental factors at specific locations. Fish may also acclimate to the sound patterns used (EPA, 1976; Taft et al., 1988; EPRI, 1995; Ray at al., 1976; Hadderingh, 1979; Hanson et al., 1977; ASCE, 1982).

Since about 1989, the application of highly refined sound generation equipment originally developed for military use (e.g., sonar in submarines) has greatly advanced acoustic barrier technology. Ibis technology has the ability to generate a wide array of frequencies, patterns, and volumes, which are monitored and controlled by computer. Video and computer monitoring provide immediate feedback on the effectiveness of an experimental sound pattern at a given location. In a particular environment, background sounds can be accounted for, target fish species or fish populations can quickly be characterized, and the most effective sound pattern can be selected (Menezes, at al., 1991; Sonalysts, Inc.).

TESTING FACILITIES AND/OR FACILITIES WITH TECHNOLOGY IN USE:

No fishpulsers and pneumatic air guns are currently in use at power plant water intakes.

Research facilities that have completed studies or have on-going testing involving fishpulsers or pneumatic air guns include the Ludington Storage Plant on Lake Michigan; Nova Scotia Power; the Hells Gate Hydroelectric Station on the Black River; the Annapolis Generating Station on the Bay of Fundy; Ontario Hydro's Pickering Nuclear Generating station; the Roseton Generating Station in New York; the Seton Hydroelectric Station in British Columbia; the Surry Power Plant in Virginia; the Indian Point Nuclear Generating Station Unit 3 in New York; and the U.S. Army Corps of Engineers on the Savannah River (EPRI, 1985; EPRI, 1989; EPRI, 1988; and Taft, et al., 1998).

Updated acoustic technology developed by Sonalysts, Inc. has been applied at the James A. Fitzpatrick Nuclear Power Plant in New York on Lake Ontario; the Vernon Hydroelectric plant on the Connecticut River (New England Power Company, 1993; Menezes, et al., 1991; personal communication with Sonalysts, Inc., by SAIC, 1993); and in a quarry in Verplank, New York (Dunning, et al., 1993).

RESEARCH/OPERATION FINDINGS:

- Most pre-1976 research was related to fish response to sound rather than on field applications of sound barriers (EPA, 1976; Ray et al., 1976; Uziel, 1980; Hanson, et al., 1977).

- Before 1986, no acoustic barriers were deemed reliable for field use. Since 1986, several facilities have tried to use pneumatic poppers with limited successes. Even in combination with light barriers and air bubble barriers, poppers and fishpulsers, were ineffective for most intakes (Taft and Downing, 1988; EPRI, 1985; Patrick, et al., 1988; EPRI, 1989; EPRI, 1988; Taft, et al., 1988; McKinley and Patrick, 1998; Chow, 1981).

- A 1991 full-scale 4-month demonstration at the James A. FitzPatrick (JAF) Nuclear Power Plant in New York on Lake Ontario showed that the Sonalysts, Inc. FishStartle System reduced alewife impingement by 97 percent as compared to a control power plant located 1 mile away. (Ross, et al., 1993; Menezes, et al., 1991). JAF experienced a 96 percent reduction compared to fish impingement when the acoustic system was not in use. A 1993 3-month test of the system at JAF was reported to be successful, i.e., 85 percent reduction in alewife impingement. (Menezes, et al., 1991; EPRI, 1999).

- In tests at the Pickering Station in Ontario, poppers were found to be effective in reducing alewife impingement and entrainment by 73 percent in 1985 and 76 percent in 1986. No benefits were observed for rainbow smelt and gizzard shad. Sound provided little or no deterrence for any species at the Roseton Generating Station in New York.

- During marine construction of Boston's third Harbor Tunnel in 1992, the Sonalysts, Inc. FishStartle System was used to prevent shad, blueback herring, and alewives from entering underwater blasting areas during the fishes' annual spring migration. The portable system was used prior to each blast to temporarily deter fish and allow periods of blastmg as necessary for the construction of the tunnel (personal communication to SAIC from M. Curtin, Sonalysts, Inc., September 17, 1993).

- In fall 1992, the Sonalysts, Inc. FishStartle System was tested in a series of experiments conducted at the Vernon Hydroelectric plant on the Connecticut River. Caged juvenile shad were exposed to various acoustical signals to see which signals elicited the strongest reactions. Successful in situ tests involved applying the signals with a transducer system to divert juvenile shad from the forebay to a bypass pipe. Shad exhibited consistent avoidance reactions to the signals and did not show evidence of acclimation to the source (New England Power Company, 1993).

DESIGN CONSIDERATIONS:

- Sonalysts Inc.'s FishStartle system uses frequencies between 15 hertz to130 kilohertz at sound pressure levels ranging from 130 to 206+ decibels referenced to one micropascal (dB//uPa). To develop a site-specific FishStartle program, a test program using frequencies in the low frequency portion of the spectrum between 25 and 3300 herz were used. Fish species tested by Sonalysts, Inc. include white perch, striped bass, atlantic tomcod, spottail shiner, and golden shiner (Menezes et al., 1991).

- Sonalysts' FishStartle system used fixed programming contained on Erasable Programmable Read Only Memory (EPROM) micro circuitry. For field applications, a system was developed using IBM PC compatible software. Sonalysts' FishStartle system includes a power source, power amplifiers, computer controls and analyzer in a control room, all of which are connected to a noise hydrophone in the water. The system also uses a television monitor and camera controller that is linked to an underwater light and camera to count fish and evaluate their behavior.

- One Sonalysts, Inc. system has transducers placed 5 m from the bar rack of the intake.

- At the Seton Hydroelectric Station in British Columbia, the distance from the water intake to the fishpulser was 350 m (1150 ft); at Hells Gate, a fishpulser was installed at a distance of 500 feet from the intake.

- The pneumatic gun evaluated at the Roseton intake had a 16.4 cubic cm (1.0 cubic inch) chamber connected by a high pressure hose and pipe assembly to an Air Power Supply Model APS-F2-25 air compressor. The pressure used was a line pressure of 20.7 MPa (3000 psi) (EPRI, 1988).

ADVANTAGES:

- The pneumatic air gun, hammer, and fishpulser are easily implemented at low costs.

- Behavioral barriers do not require physical handling of the fish.

LIMITATIONS:

- The pneumatic air gun, hammer, and fishpulser are not considered reliable.
- Sophisticated acoustic sound generating system require relatively expensive systems, including cameras, sound generating systems, and control systems. No cost information is available since a permanent system has yet to be installed.
- Sound barrier systems require site-specific designs consisting of relatively high technology equipment that must be maintained at the site.

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