Chapter 5: Efficacy of Cooling Water Intake Structure Technologies

INTRODUCTION

Chapter Contents

To support the Section 316(b) new facility rulemaking, the Agency has compiled data on the performance of the range of technologies currently used to minimize impingement and entrainment (I&E) at power plants nationwide. The goal of this data collection and analysis effort has been to determine whether specific technologies can be demonstrated to provide a consistent level of proven performance. This information has been used throughout the rulemaking process including comparing specific regulatory options and their associated costs and benefits. It provides the supporting information for the selected alternatives, which require wet, closed-cycle cooling systems (under Track 1) with the option of demonstrating comparable performance (under Track II) using alternative technologies. Throughout this chapter, baseline technology performance refers to the performance of conventional, wide mesh traveling screens that are not intended to prevent I&E. Alternative technologies generally refer to those technologies, other than closed-cycle cooling systems that can be used to minimize I&E. Overall, the Agency has found that performance and applicability vary to some degree based on site-specific conditions. However, the Agency has also determined that alternative technologies can be used effectively on a widespread basis with proper design, operation, and maintenance.

5.1 SCOPE OF DATA COLLECTION EFFORTS

Since 1992, the Agency has been evaluating regulatory alternatives under Section 316(b) of the Clean Water Act. As part of these efforts, the Agency has compiled readily available information on the nationwide performance of I&E reduction technologies. This information has been obtained through:

- Literature searches and associated collection of relevant documents on facility-specific performance.
- Contacts with governmental (e.g., TVA) and non-governmental entities (e.g., EPRI) that have undertaken national or regional data collection efforts/performance studies
- Meetings with and visits to the offices of EPA Regional and State agency staff as well as site visits to operating power plants.

It is important to recognize that the Agency did not undertake a systematic approach to data collection, i.e., the Agency did not obtain all of the facility performance data that are available nor did it obtain the same level of information for each facility. The Agency is not aware of such an evaluation ever being performed nationally. The most recent national data compilation was undertaken by the Electric Power Research Institute (EPRI) in 2000, see *Fish Protection at Cooling Water Intakes, Status Report*. The findings of this report are cited extensively in the following subsections. However, EPRI's analysis was primarily a literature collection and review effort and was not intended to be an exhaustive compilation and analysis of all data.

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5.2 DATA LIMITATIONS

Because the Agency did not undertake a systematic data collection effort with consistent data collection procedures, there is significant variability in the information available from different data sources. This leads to the following data limitations:

- Some facility data include all of the major species and associated life stages present at an individual facility. Other facilities only include data for selected species and/or life stages.
- Much of the data were collected in the 1970s and early 1980s when existing facilities were required to complete their initial 316(b) demonstrations.
- Some facility data includes only initial survival results, while other facilities have 48 to 96-hour survival data. These data are relevant because some technologies can exhibit significant latent mortality after initial survival.
- The Agency did not review data collection procedures, including quality assurance/quality control protocols.
- Some data come from laboratory and pilot-scale testing rather than full-scale evaluations.

The Agency recognizes that other than closed-cycle cooling and velocity reduction technologies the practicality or effectiveness of alternative technologies not be uniform under all conditions. The chemical and physical nature of the waterbody, the facility intake requirements, climatic conditions, and biology of the area all effect feasibility and performance. However, despite the above limitations, the Agency has concluded that significant general performance expectations can be implied for the range of technologies and that one or more technologies (or groups of technologies) can provide significant I&E protection at most sites. In addition, in the Agency's view many of the technologies have the potential for even greater applicability and higher performance when facilities are required to optimize their use.

The remainder of this chapter is organized by groups of technologies. A discussion of wet, closed-cycle cooling tower performance is included to present the Agency's view of the likely minimum standard that Track II facilities will be required to achieve (although each facility will have to present it's own closed-cycle system scenario). A brief description of conventional, once-through traveling screens is also provided for comparison purposes. Fact sheets describing each technology, available performance data, and design requirements and limitations are provided in Attachment A. It is important to note that this chapter does not provide descriptions of all potential CWIS technologies. (ASCE 1982 generally provides such an all-inclusive discussion). Instead, the Agency has focused on those technologies that have shown significant promise at the laboratory, pilot-scale, and/or full-scale levels in consistently minimizing impingement and/or entrainment. In addition, this chapter does not identify every facility where alternative technologies have been used but rather only those where some measure of performance in comparison to conventional screens has been made. The chapter concludes with a brief discussion of how the location of intakes (as well as the timing of water withdrawals) could also be used to limit potential I&E effects at new facilities.

Finally, under Track II in the new facility rule, facilities may use habitat restoration projects as an additional means to demonstrate consistency with Track I performance. Such projects have not had widespread application at existing facilities. Because the nature, feasibility, and likely effectiveness of such projects would be highly site-specific, the Agency has not attempted to quantify their expected performance level herein.

5.3 Closed-Cycle Wet Cooling System Performance

Under Track I, facilities are required meet requirements based on the design and installation of wet, closed-cycle cooling systems. Although flow reduction serves the purpose of reducing both impingement and entrainment, these requirements function as the primary entrainment reduction portion of Track I. Under Track II, new facilities must demonstrate I&E performance comparable to 90 percent of the performance of a wet, closed-cycle system designed for their facility. In part, to evaluate the feasibility of meeting this requirement and to allow comparison of costs/benefits of alternatives, the Agency determined the likely range in flow reductions between wet, closed-cycle cooling systems compared to once-through systems. In closed-cycle systems, certain chemicals will concentrate as they continue to be recirculated through the tower. Excess buildup of such chemicals, especially total dissolved solids, affects the tower performance. Therefore, some water (blowdown) must be discharged and make-up water added periodically to the system.

See Section 2.3.5 of Chapter 2 of this document for further discussion of flow reduction using wet, closed-cycle cooling.

An additional question that the Agency has considered is the feasibility of constructing salt-water make-up cooling towers. The Agency contacted Marley Cooling Tower (Marley), which is one of the largest cooling tower manufacturers in the world. Marley provided a list of facilities (Marley, 2001) that have installed cooling towers with marine or otherwise high total dissolved solids/brackish make-up water. It is important to recognize that this represents only a selected group of facilities constructed by Marley worldwide; there are also facilities constructed by other cooling tower manufacturers. For example, Florida Power and Light's (FPL) Crystal River Units 4 and 5 (about 1500 MW) use estuarine water make-up.

5.4 Conventional Traveling Screens

For impingement control technologies, performance is compared to conventional traveling screens as a baseline technology. These screens are the most commonly used intakes at older existing facilities and their operational performance is well established. In general, these technologies are designed to prevent debris from entering the cooling water system, not to minimize I&E. The most common intake designs include front-end trash racks (usually consisting of fixed bars) to prevent large debris from entering system. They are equipped with screen panels mounted on an endless belt that rotates through the water vertically. Most conventional screens have 3/8-inch mesh that prevents smaller debris from clogging the condenser tubes. The screen wash is typically high pressure (80 to 120 pounds per square inch (psi)). Screens are rotated and washed intermittently and fish that are impinged often die because they are trapped on the stationary screens for extended periods. The high-pressure wash also frequently kills fish or they are re-impinged on the screens. Conventional traveling screens are used by approximately 60 percent of all existing steam electric generating units in the U.S. (EEI, 1993).

5.5 ALTERNATIVE TECHNOLOGIES

5.5.1 Modified Traveling Screens and Fish Handling and Return Systems

Technology Overview
Conventional traveling screens can be modified so that fish, which are impinged on the screens, can be removed with minimal stress and mortality. "Ristroph Screens" have water-filled lifting buckets which collect the impinged organisms and transport them to a fish return system. The buckets are designed such that they will hold approximately 2 inches of water once they have cleared the surface of the water during the normal rotation of the traveling screens. The fish bucket holds the fish in water until the screen rises to a point where the fish are spilled onto a bypass, trough, or other protected area (Mussalli, Taft, and Hoffman, 1978). Fish baskets are also a modification of a conventional traveling screen and may be used in conjunction with fish buckets. Fish baskets are separate framed screen panels that are attached to vertical traveling screens. An essential feature of modified traveling screens is continuous operation during periods where fish are being impinged. Conventional traveling screens typically operate on an intermittent basis. (EPRI, 2000 and 1989; Fritz, 1980). Removed fish are typically returned to the source water body by sluiceway or pipeline. ASCE 1982 provides guidance on the design and operation of fish return systems.

Technology Performance
Modified screens and fish handling and return systems have been used to minimize impingement mortality at a wide range of facilities nationwide. In recent years, some researchers, primarily *Fletcher 1996,* have evaluated the factors that effect the success of these systems and described how they can be optimized for specific applications. Fletcher cited the following as key design factors:

- Shaping fish buckets/baskets to minimize hydrodynamic turbulence within the bucket/basket
- Using smooth woven screen mesh to minimize fish descaling
- Using fish rails to keep fish from escaping the buckets/baskets
- Performing fish removal prior to high pressure wash for debris removal
- Optimizing the location of spray systems to provide gentler fish transfer to sloughs
- Ensuring proper sizing and design of return troughs, sluiceways, and pipes to minimize harm.

In 1993 and 1994, the Salem Generating Station specifically considered Fletcher's work in the modification of their fish handling system. In 1996, the facility subsequently reported an increase in juvenile weakfish impingement survival from 58 percent to 79 percent with an overall weakfish reduction in impingement losses of 51 percent. 1997 and 1998 test data for Units 1 and 2 showed: white perch had 93 to 98 percent survival, bay anchovy had 20 to 72 percent survival, Atlantic croaker had 58 to 98 percent survival, spot had 93 percent survival, herring had 78 to 82 percent survival, and weakfish had 18 to 88 percent survival.

Additional performance results for modified screens and fish return systems include:

- 1988 studies at the Diablo Canyon and Moss Landing Power Plants in California found that overall impingement mortality could be reduced by as much as 75 percent with modified traveling screens and fish return sluiceways.

- Impingement data collected during the 1970s from Dominion Power's Surry Station (Virginia) indicated a 93.8 percent survival rate of all fish impinged. Bay anchovies had the lowest survival 83 percent. The facility has modified Ristroph screens with low pressure wash and fish return systems.

- In 1986, the operator of the Indian Point Station (New York) 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.

- 1996 data for Brayton Point Units 1-3 showed 62 percent impingement survival for continuously rotated conventional traveling screens with a fish return system.

- In the 1970s, a fish pump and return system was added to the traveling screens at the Monroe Power Plant in Michigan. Initial studies showed 70 to 80 percent survival for adult and young-of-year gizzard shad and yellow perch.

- At the Hanford Generating Plant on the Columbia River, late 1970s studies of modified screens with a fish return system showed 79 to 95 percent latent survival of impinged Chinook salmon fry.

- The Kintigh Generating Station in New Jersey 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.

- The Calvert Cliffs Station in Maryland has 12 traveling screens that are rotated for 10 minutes every hour or when pressure sensors show pressure differences. The screens were originally conventional and are now dual flow. A high pressure wash and return system leads back to the Chesapeake Bay. Twenty-one years of impingement monitoring show total fish survival of 73 percent.

- At the Arthur Kill Station in New York, 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, respectively.

In summary, performance data for modified screens and fish returns are somewhat variable due to site conditions and variations in unit design and operation. However, the above results generally show that at least 70-80 percent reductions in impingement can be achieved over conventional traveling screens.

5.5.2 Cylindrical Wedgewire Screens

Technology Overview

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. The screen mesh ranges from 0.5 to 10 mm. 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). Adequate countercurrent flow is needed to transport organisms away from the screens. The name of these screens arises from the triangular or "wedge" cross section of the wire that makes up the screen. The screen is composed of wedge-wire 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).

Wedgewire screens may also be referred to as profile screens or Johnson screens.

Technology Performance

Wide mesh wedgewire screens have been used at 2 Ahigh flow@ power plants: J.H. Campbell Unit 3 (770 MW) and Eddystone Units 1 and 2 (approximately 700 MW combined). At Campbell, Unit 3 withdraws 400 million gallons per day (mgd) of water from Lake Michigan approximately 1,000 feet from shore. 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. Entrainment is not a major concern at the site because of the deep water, offshore location of the Unit 3 intake. Eddystone Units 1 and 2 withdraw over 500 mgd of water from the Delaware River. The cooling water intakes for these units 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. Both the Campbell and Eddystone wedgewire screens require periodic cleaning but have operated with minimal operational difficulties.

Other plants with lower intake flows have installed wedgewire screens but there are limited biological performance data for these facilities. The Logan Generating Station in New Jersey withdraws 19 MGD from the Delaware River through a 1-mm wedgewire screen. Entrainment data show 90 percent less entrainment of larvae and eggs then conventional screens. No impingement data are available. Unit 1 at the Cope Generating Station in South Carolina is a closed cycle unit that withdraws about 6 MGD through a 2-mm wedgewire screen, however, no biological data are available. Performance data are also unavailable for the Jeffrey Energy Center, which withdraws about 56 MGD through a 10-mm screen from the Kansas River in Kansas. The system at the Jeffrey Plant has specifically operated since 1982 with no operational difficulties. Finally, the American Electric Power Corporation has installed wedgewire screens at the Big Sandy (2 MGD) and Mountaineer (22 MGD) Power Plants, which withdraw water from the Big Sandy and Ohio Rivers, respectively. Again, no biological test data are available for these facilities.

Wedgewire screens have been considered/tested for several other large facilities. In situ testing of 1 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. The State of Maryland conducted testing in 1982 and 1983 of 1, 2, and 3-mm wedgewire screens at the Chalk Point Generating Station, which withdraws water from the Patuxent River in Maryland. The 1-mm wedgewire screens were found to reduce entrainment by 80 percent. No impingement data were available. Some biofouling and clogging was observed during the tests. In the late 1970s, Delmarva Power and Light conducted laboratory testing of fine mesh wedgewire screens for the proposed 1540 MW Summit Power Plant. This testing showed that entrainment of fish eggs (including striped bass) could effectively be prevented with slot widths of l mm or less, while impingement mortality was expected to be less than 5 percent. Actual field testing in the brackish water of the proposed intake canal required the screens to be removed and cleaned as often as once every three weeks.

As shown by the above data, it is clear that wedgewire screen technology has not been widely applied in the steam electric industry to date. It has only been installed at a handful of power plant facilities nationwide. However, the limited data for Eddystone and Campbell indicate that wide mesh screens, in particular, can be used to minimize impingement. Successful use of the wedgewire screens at Eddystone as well as Logan in the Delaware River (high debris flows) suggests that the screens can have widespread applicability. This is especially true for facilities that have relatively low intake flow requirements (i.e., closed-cycle systems). Yet, the lack of more representative full-scale plant data makes it impossible to conclusively say that wedgewire screens can be used in all environmental conditions. There are no full-scale data specifically for marine environments where biofouling and clogging are significant concerns. In addition, it is important to recognize that there must sufficient crosscurrent in the waterbody to carry organisms away from the screens.

Fine mesh wedgewire screens (0.5 - 1 mm) also have the *potential* for use to control both I&E. The Agency is not aware of any fine-mesh wedgewire screens that have been installed at power plants with high intake flows (>100 MGD). However, they have been used at some power plants with lower intake flow requirements (25-50 MGD) that would be comparable to a large power plant with a closed-cycle cooling system. With the exception of Logan, the Agency has not identified any full-scale performance data for these systems. They would be even more susceptible to clogging than wide-mesh wedgewire screens (especially in marine environments). It is unclear whether this simply would necessitate more intensive maintenance or preclude their day-to-day use at many sites. Their successful application at Logan and Cope and the historic test data from Florida, Maryland, and Delaware at least suggests promise for addressing both fish impingement and entrainment of eggs and larvae. However, based on the fine-mesh screen experience at Big Bend Units 3 and 4, it is clear that frequent maintenance would be required. Therefore, relatively deep water sufficient to accommodate the large number of screen units, would preferably be close to shore (i.e., be readily accessible). Manual cleaning needs might be reduced or eliminated through use of an automated flushing (e.g., microburst) system.

5.5.3 Fine-Mesh Screens

Technology Overview
Fine-mesh screens are typically mounted on conventional traveling screens and are used to exclude eggs, larvae, and juvenile forms of fish from intakes. These screens rely on gentle impingement of organisms on the screen surface. Successful use of fine-mesh screens is contingent on the application of satisfactory handling and return systems to allow the safe return of impinged organisms to the aquatic environment (Pagano et al, 1977; Sharma, 1978). Fine mesh screens generally include those with mesh sizes of 5 mm or less.

Technology Performance
Similar to fine-mesh wedgewire screens, fine-mesh traveling screens with fish return systems show promise for both I&E control. However, they have not been installed, maintained, and optimized at many facilities. The most significant example of long-term fine-mesh screen use has been at the Big Bend Power Plant in the Tampa Bay area. The facility has an intake canal with 0.5-mm mesh Ristroph screens that are used seasonally on the intakes for Units 3 and 4. During the mid-1980s when the screens were initially installed, their efficiency in reducing I&E mortality was highly variable. The operator, Florida Power & Light (FPL) evaluated different approach velocities and screen rotational speeds. In addition, FPL 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). Although more recent data are generally not available, the screens continue to operate successfully at Big Bend in an estuarine environment with proper maintenance. While egg and larvae entrainment performance are not available, fine mesh (0.5 mm) Passavant screens (single entry/double exit) have been used successfully in a marine environment at the Barney Davis Station in Corpus Christi, Texas. Impingement data for this facility show overall 86 percent initial survivals for bay anchovy, menhaden, Atlantic croaker, killfish, spot, silverside, and shrimp.

Additional full-scale performance data for fine mesh screens at large power stations are generally not available. However, some data are available from limited use/study at several sites and from laboratory and pilot-scale tests. Seasonal use of fine mesh on two of four screens at the Brunswick Power Plant in North Carolina has shown 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, and, 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. Finally, 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, respectively. 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.

Despite the lack of full-scale data, the experiences at Big Bend (as well as Brunswick) show that fine-mesh screens can reduce entrainment by 80 percent or more. This is contingent on optimized operation and intensive maintenance to avoid biofouling and clogging, especially in marine environments. It also may be appropriate to have removable fine mesh that is only used during periods of egg and larval abundance, thereby reduced the potential for clogging and wear and tear on the systems.

5.5.4 Fish Net Barriers

Technology Overview

Fish net barriers are wide-mesh nets, which are placed in front of the entrance to intake structures. The size of the mesh needed is a function of the species that are present at a particular site and vary from 4 mm to 32 mm (EPRI, 2000). The mesh must be sized to prevent fish from passing through the net causing them to become gilled. Relatively low velocities are maintained because the area through which the water can flow is usually large. Fish net barriers 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.

Technology Performance

Barrier nets can provide a high degree of impingement reduction. Because of typically wide openings, they do not reduce entrainment of eggs and larvae. A number of barrier net systems have been used/studied at large power plants. Specific examples include:

- At the J.P. Pulliam Station (Wisconsin), the operator installed 100 and 260-foot barrier nets across the two intake canals, which withdraw water from the Fox River prior to flowing into Lake Michigan. The barrier nets have been shown to reduce impingement by 90 percent over conventional traveling screens without the barrier nets. The facility has the barrier nets in place when the water temperature is greater than 37°F or April 1 through December 1.

- 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 I&E. 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.

- At the Chalk Point Generating Station (Maryland), a barrier net system has been used since 1981, primarily to reduce crab impingement from the Patuxent River. Eventually, the system was redesigned to include two nets: a 1,200-foot wide outer net prevents debris flows and a 1,000-foot inner net prevents organism flow into the intake. Crab impingement has been reduced by 84 percent. The Agency did not obtain specific fish impingement performance data for other species, but the nets have reduced overall impingement liability for all species from over $2 million to less than $140,000. Net panels are changed twice per week to control biofouling and clogging.

- The Bowline Point Station (New York) has an approximately 150-foot barrier net in a v-shape around the intake structure. Testing during 1976 through 1985 showed that the net effectively reduces white perch and striped bass impingement by 91 percent. Based on tests of a “fine” mesh net (3.0 mm) in 1993 and 1994, researchers found that it could be used to generally prevent entrainment. Unfortunately, species’ abundances were too low to determine the specific biological effectiveness.

- 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).

Barrier nets have clearly proven effective for controlling *impingement* (i.e., 80+ percent reductions over conventional screens without nets) in areas with limited debris flows. Experience has shown that high debris flows can cause significant damage to net systems. Biofouling concerns can also be a concern but this can be addressed through frequent maintenance. Barrier nets are also often only used seasonally, where the source waterbody is subject to freezing. Fine-mesh barrier nets show some promise for entrainment control but would likely require even more intensive maintenance. In some cases, the use of barrier nets may be further limited by the physical constraints and other uses of the waterbody.

5.5.5 Aquatic Microfiltration Barriers

Technology Overview
Aquatic microfiltration 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. Gunderboom systems also employ an automated “air burst” system 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 into the water column.

Technology Performance
The Agency has determined that microfiltration barriers, including the Gunderboom, show significant *promise* for minimizing entrainment. However, the Agency acknowledges that Gunderboom technology is currently “experimental in nature.” At this juncture, the only power plant where the Gunderboom has been used at a “full-scale” level is the Lovett Generating Station along the Hudson River in New York, where pilot testing began in the mid-1990s. Initial testing at this facility showed significant potential for reducing entrainment. Entrainment reductions up to 82 percent were observed for eggs and larvae and these levels have been maintained for extended month-to-month periods during 1999 through 2001. At Lovett, there have been some operational difficulties that have affected long-term performance. These difficulties, including tearing, overtopping, and plugging/clogging, have been addressed, to a large extent, through subsequent design modifications. Gunderboom, Inc. specifically has designed and installed a “microburst” cleaning system to remove particulates. Each of the challenges encountered

at Lovett could be significantly greater concern at marine sites with higher wave action and debris flows. Gunderboom systems have been otherwise deployed in marine conditions to prevent migration of particulates and bacteria. They have been used successfully in areas with waves up to five feet. The Gunderboom system is currently being tested for potential use at the Contra Costa Plant along the San Joaquin River in Northern California.

An additional question related to the utility of the Gunderboom and other microfiltration systems is sizing and the physical limitations and other uses of the source waterbody. With a 20-micron mesh, 100,000 and 200,000 gallon per minute intakes would require filter systems 500 and 1,000 feet long (assuming 20 foot depth). In some locations, this may preclude its successful deployment due space limitations and/or conflicts with other waterbody uses.

5.5.6 Louver Systems

Technology Overview
Louver systems consist of series of vertical panels placed at 90 degree angles to the direction of water flow (Hadderingh, 1979). The placement of the louver panels provides both changes in the flow direction and velocity, which fish tend to avoid. The angles and flow velocities of the louvers create a current parallel to the face of the louvers which carries fish away from the intake and into a fish bypass system for return to the source waterbody.

Technology Performance
Louver systems can reduce impingement losses based on fishes' abilities to recognize and swim away from the barriers. Their performance, i.e., guidance efficiency, is highly dependant on the length and swimming abilities of the resident species. Since eggs and early stages of larvae cannot "swim away," they are not affected by the diversions and there is no associated reduction in entrainment.

While louver systems have been tested at a number of laboratory and pilot-scale facilities, they have not been used at many full-scale facilities. The only large power plant facility where a louver system has been used is San Onofre Units 2 and 3 (2,200 MW combined) in Southern California. The operator initially tested both louver and wide mesh, angled traveling screens during the 1970s. Louvers were subsequently selected for full-scale use at the intakes for the two units. In 1984, 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. The facility also has encountered some difficulties with predator species congregating in the vicinity of the outlet from the fish return system. 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 2000 indicated that louver systems could provide 80-95 percent diversion efficiency for a wide variety of species under a range of site conditions. This is generally consistent with the American Society of Civil Engineers' (ASCE) findings from the late 1970s which showed almost all systems had diversion efficiencies exceeding 60 percent with many more than 90 percent. As indicated above, much of the EPRI and ASCE data come from pilot/laboratory tests and hydroelectric facilities where louver use has been more widespread than at steam electric facilities. Louvers were specifically tested by the Northeast Utilities Service Company in the Holyoke Canal on the Connecticut River for juvenile clupeids (American shad and blueback herring). Overall guidance efficiency was found to be 75-90 percent. In the 1970s, Alden Research Laboratory observed similar results for Hudson River species (including alewife and smelt). 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). Also 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." Finally, 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.

Overall, the above data indicate that louvers can be highly effective (70+ percent) in diverting fish from potential impingement. Latent mortality is a concern, especially where fragile species are present. Similar to modified screens with fish return systems, operators must optimize louver system design to minimize fish injury and mortality

5.5.7 Angled and Modular Inclined Screens

Technology Overview

Angled traveling screens use standard through-flow traveling screens where the screens are set at an angle to the incoming flow. Angling the screens improves the fish protection effectiveness 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 (Richards 1977). Modular inclined screens (MISs) are a specific variation on angled traveling screens, where each module in the intake consists of trash racks, dewatering stop logs, an inclined screen set at a 10 to 20 degree angle to the flow, and a fish bypass (EPRI 1999).

Technology Performance

Angled traveling screens with fish bypass and return systems work similarly to louver systems. They also only provide potential reductions in impingement mortality since eggs and larvae will not generally detect the factors that influence diversion. Similar to louver systems, they were tested extensively at the laboratory and pilot scales, especially during the 1970s and early 1980s. Testing of angled screens (45 degrees to the flow) in the 1970s at San Onofre showed poor to good guidance (0-70 percent) for northern anchovies with moderate to good guidance (60-90 percent) for other species. Latent survival varied by species with fragile species only having 25 percent survival, while hardy species showed greater than 65 percent survival. The intake for Unit 6 at the Oswego Steam plant along Lake Ontario in New York has traveling screens angled to 25 degrees. Testing during 1981 through 1984 showed a combined diversion efficiency of 78 percent for all species; ranging from 53 percent for mottled sculpin to 95 percent for gizzard shad. Latent survival testing results ranged from 22 percent for alewife to nearly 94 percent for mottled sculpin.

Additional testing of angled traveling screens was performed in the late 1970s and early 1980s for power plants on Lake Ontario and along the Hudson River. This testing showed that a screen angled at 25 degrees was 100 percent effective in diverting 1 to 6 inch long Lake Ontario fish. Similar results were observed for Hudson River species (striped bass, white perch, and Atlantic tomcod). One-week mortality tests for these species showed 96 percent survival. Angled traveling screens with a fish return system have been used on the intake from 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. Finally, 1981 full-scale studies of an angled screen system at the Danskammer Station along the Hudson River in New York showed diversion efficiencies of 95 to 100 percent with a mean of 99 percent. Diversion efficiency combined with latent survival yielded a total effectiveness of 84 percent. Species included bay anchovy, blueback herring, white perch, spottail shiner, alewife, Atlantic tomcod, pumpkinseed, and American shad.

During the late 1970s and early 1980s, Alden Research Laboratories (Alden) conducted a range of tests on a variety of angled screen designs. Alden specifically performed screen diversion tests for three northeastern utilities. In initial studies for Niagara Mohawk, diversion efficiencies were found to be nearly 100 percent for alewife and smolt. Follow-up tests for Niagara Mohawk confirmed 100 percent diversion efficiency for alewife with mortalities only four percent higher than control samples. Subsequent tests by Alden for Consolidated Edison, Inc. using striped bass, white perch, and tomcod also found nearly 100 percent diversion efficiency with a 25 degree angled screen. The one-week mean mortality was only 3 percent.

Alden further performed tests during 1978-1990 to determine the effectiveness of fine-mesh, angled screens. In 1978, tests were performed with striped bass larvae using both 1.5 and 2.5-mm mesh and different screen materials and approach velocity. Diversion efficiency was found to clearly be a function of larvae length. Synthetic materials were also found to be more effective than metal screens. Subsequent testing using only synthetic materials found that 1.0 mm screens can provide post larvae diversion efficiencies of greater than 80 percent. However, the tests found that latent mortality for diverted species was also high.

Finally, EPRI tested modular inclined screens (MIS) in a laboratory in the early 1990s. Most fish had diversion efficiencies of 47 to 88 percent. Diversion efficiencies of greater than 98 percent were observed for channel catfish, golden shiner, brown trout, Coho and Chinook salmon, trout fry and juveniles, and Atlantic salmon smolts. Lower diversion efficiency and higher mortality were found for American shad and blueback herring but comparable to control mortalities. Based on the laboratory data, a MIS system was pilot-tested at a Niagara Mohawk hydroelectric facility on the Hudson River. This testing showed diversion efficiencies and survival rates approaching 100 percent for golden shiners and rainbow trout. High diversion and survival was also observed for largemouth and smallmouth bass, yellow perch, and bluegill. Lower diversion efficiency and survival was found for herring.

Similar to louvers, angled screens show potential to minimize impingement by greater than 80 to 90 percent. More widespread full-scale use is necessary to determine optimal design specifications and verify that they can be used on a widespread basis.

5.5.8 Velocity Caps

Technology Description

A velocity cap is a device that is placed over vertical inlets at offshore intakes. 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. In general, velocity caps have been installed at many offshore intakes and have been successful in minimizing impingement.

Technology Performance

Velocity caps can reduce fish drawn into intakes based on the concept that they tend to avoid horizontal flow. They do not provide reductions in entrainment of eggs and larvae, which cannot distinguish flow characteristics. As noted in *ASCE 1981*, velocity caps are often used in conjunction with other fish protection devices. Therefore, there are somewhat limited data on their performance when used alone. Facilities that have velocity caps include:

- Oswego Steam Units 5 and 6 in New York (combined with angled screens on Unit 6).
- San Onofre Units 2 and 3 in California (combined with louver system).
- El Segundo Station in California
- Huntington Beach Station in California
- Edgewater Power Plant Unit 5 in Wisconsin (combined with 9.5 mm wedgewire screen)

- Nanticoke Power Plant in Ontario, Canada
- Nine Mile Point in New York
- Redondo Beach Station in California
- Kintigh Generation Station in New York (combined with modified traveling screens)
- Seabrook Power Plant in New Hampshire
- St. Lucie Power Plant in Florida.

At the Huntington Beach and Segundo Stations in California, velocity caps have been found to provide 80 to 90 percent reductions in fish entrapment. At Seabrook, the velocity cap on the offshore intake has minimized the number of pelagic fish entrained except for pollock. Finally, two facilities in England have velocity caps on one of each's two intakes. At the Sizewell Power Station, intake B has a velocity cap, which reduces impingement about 50 percent compared to intake A. Similarly, at the Dungeness Power Station, intake B has a velocity cap, which reduces impingement about 62 percent compared to intake A.

5.5.9 Porous Dikes and Leaky Dams

Technology Overview
Porous dikes, also known as leaky dams or dikes, are filters resembling a breakwater surrounding a cooling water intake. The core of the dike consists of cobble or gravel that permits free passage of water. The dike acts both as a physical and behavioral barrier to aquatic organisms. Tests conducted to date have indicated that the technology is effective in excluding juvenile and adult fish. The major problems associated with porous dikes come from clogging by debris and silt, ice build-up, and by colonization of fish and plant life.

Technology Performance
Porous dike technologies work on the premise that aquatic organisms will not pass through physical barriers in front of an intake. They also operate with low approach velocity further increasing the potential for avoidance. However, they will not prevent entrainment by non-motile larvae and eggs. Much of the research on porous dikes and leaky dams was performed in the 1970s. This work was generally performed in a laboratory or on a pilot level, i.e., the Agency is not aware of any full-scale porous dike or leaky dam systems currently used at power plants in the U.S. Examples of early study results include:

- Studies of porous dike and leaky dam systems by Wisconsin Electric Power at Lake Michigan plants showed generally lower I&E rates than other nearby onshore intakes.

- Laboratory work by Ketschke showed that porous dikes could be a physical barrier to juvenile and adult fish and a physical or behavioral barrier to some larvae. All larvae except winter flounder showed some avoidance of the rock dike.

- Testing at the Brayton Point Power Plant showed that densities of bay anchovy larvae downstream of the dam were reduced by 94 to 99 percent. For winter flounder, downstream densities were lower by 23 to 87 percent. Entrainment avoidance for juvenile and adult finfish was observed to be nearly 100 percent.

As indicated in the above examples, porous dikes and leaky dams show *potential* for use in limiting passage of adult and juvenile fish, and, to some degree, motile larvae. However, the lack of more recent, full-scale performance data makes it difficult to predict their widespread applicability and specific levels of performance.

5.5.10 Behavioral Systems

Technology Overview
Behavioral devices are designed to enhance fish avoidance of intake structures and/or promote attraction to fish diversion or bypass systems. Specific technologies that have been considered include:

- Light Barriers: Light barriers consist of controlled application of strobe lights or mercury vapor lights to lure fish away from the cooling water intake structure or deflect natural migration patterns. This technology is based on research that shows that some fish avoid light, however it is also known that some species are attracted by light.

- Sound Barriers: 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 cooling water intake structures. The most widely used acoustical barrier is a pneumatic air gun or "popper."

- Air bubble barriers: Air bubble barriers consist of an air header with jets arranged to provide a continuous curtain of air bubbles over a cross section area. The general purpose of air bubble barriers is to repel fish that may attempt to approach the face of a CWIS.

Technology Performance
Many studies have been conducted and reports prepared on the application of behavioral devices to control I&E, see EPRI 2000. For the most part, these studies have either been inconclusive or shown no tangible reduction in impingement or entrainment. As a result, the full-scale application of behavioral devices has been limited. Where data are available, performance appears to be highly dependent on the types and sizes of species and environmental conditions. One exception may be the use of sound systems to divert alewife. In tests at the Pickering Station in Ontario, poppers were found to be effective in reducing alewife I&E by 73 percent in 1985 and 76 percent in 1986. No benefits were observed for rainbow smelt and gizzard shad. 1993 testing of sound systems at the James A. Fitzpatrick Station in New York showed similar results, i.e., 85 percent reductions in alewife I&E through use of a high frequency sound system. At the Arthur Kill Station, pilot- and full-scale, high frequency sound tests showed comparable results for alewife to Fitzpatrick and Pickering. Impingement of gizzard shad was also three times less than without the system. No deterrence was observed for American shad or bay anchovy using the full-scale system. In contrast, sound provided little or no deterrence for any species at the Roseton Station in New York. Overall, the Agency expects that behavioral systems would be used in conjunction with other technologies to reduce I&E and perhaps targeted towards an individual species (e.g., alewife).

5.5.11 Other Technology Alternatives

The proposed new facility rule does not specify the individual technology (or group of technologies) to be used to minimize I&E to same levels as those achieved with the Track I requirements based, in part, on wet, closed-cycle cooling system. In addition to the above technologies, there are other approaches that may be used on a site-by-site basis. For example:

- Use of variable speed pumps can provide for greater system efficiency and reduced flow requirements (and associated entrainment) by 10-30 percent. EPA Region 4 estimated that use of variable speed pumps at the Canaveral and Indian River Stations in the Indian River estuary would reduce entrainment by 20 percent. Presumably, such pumps would have to be used in conjunction with other technologies. EPA conservatively estimated that facilities complying with the requirements final rule would install variable speed pumps regardless of the baseline cooling system projected for the facility. See Chapter 2 of this document for more information.

- Perforated pipes draw water through perforations or elongated slots in a cylindrical section placed in the waterway. Early designs of this technology were not efficient, velocity distribution was poor, and they were specifically designed to screen out detritus (i.e., not used for fish protection) (ASCE, 1982). Inner sleeves were subsequently added to perforated pipes to equalize the velocities entering the outer perforations. These systems have historically been used at locations requiring small amounts of make-up water. Experience at steam electric plants is very limited (Sharma, 1978). Perforated pipes are used on the intakes for the Amos and Mountaineer Stations along the Ohio River. However, I&E performance data for these facilities are unavailable. In general, EPA projects that perforated pipe system performance should be comparable to wide-mesh wedgewire screens (e.g., at Eddystone Units 1 and 2 and Campbell Unit 3).

- At the Pittsburg Plant in California, impingement survival was studied for continuously rotated screens versus intermittent rotation. Ninety-six-hour survival for young-of-year white perch was 19 to 32 percent for intermittent screen rotation versus 26 to 56 percent for continuous rotation. Striped bass latent survival increased from 26 to 62 percent when continuous rotation was used. Similar studies were also performed at Moss Landing Units 6 and 7, where no increased survival was observed for hardy and very fragile species, however, there was a substantial increase in impingement survival for surfperch and rockfish.

- Facilities may be able to use recycled cooling water to reduce intake flow needs. The Brayton Point Station has a "piggyback" system where the entire intake requirements for Unit 4 can be met by recycled cooling water from Units 1 through 3. The system has been used sporadically since 1993 and reduces the make-up water needs (and thereby entrainment) by 29 percent.

5.6 INTAKE LOCATION

Beyond design alternatives for CWISs, an operator may able to locate CWISs offshore or otherwise in areas that minimize I&E (compared to conventional onshore locations). It is well known that there are certain areas within every waterbody with increased biological productivity, and therefore where the potential for I&E of organisms is higher.

In large lakes and reservoirs, the littoral zone (i.e., shorezone areas where light penetrates to the bottom) of lakes/reservoirs serves as the principal spawning and nursery area for most species of freshwater fish and is considered one of the most productive areas of the waterbody. Fish of this zone typically follow a spawning strategy wherein eggs are deposited in prepared nests, on the bottom, and/or are attached to submerged substrates where they incubate and hatch. As the larvae mature, some species disperse to the open water regions, whereas many others complete their life cycle in the littoral zone. Clearly, the impact potential for intakes located in the littoral zone of lakes and reservoirs is high. The profundal zone of lakes/reservoirs is the deeper, colder area of the waterbody. Rooted plants are absent because of insufficient light, and for the same reason, primary productivity is minimal. A well-oxygenated profundal zone can support benthic macroinvertebrates and cold-water fish; however, most of the fish species seek shallower areas to spawn (either in littoral areas or in adjacent streams/rivers). Use of the deepest open water region of a lake and reservoir (e.g., within the profundal zone) as a source of cooling water typically offers lower I&E impact potential (than use of littoral zone waters).

As with lakes/reservoirs, rivers are managed for numerous benefits, which include sustainable and robust fisheries.

Unlike lakes and reservoirs, the hydrodynamics of rivers typically result in a mixed water column and (overall) unidirectional flow. There are many similarities in the reproductive strategies of shoreline fish populations in rivers and the reproductive strategies of fish within the littoral zone of lakes/reservoirs. Planktonic movement of eggs, larvae, post larvae, and early juvenile organisms along the shorezone are generally limited to relatively short distances. As a result, the shorezone placement of CWISs in rivers may potentially impact local spawning populations of fish. The impact potential associated with entrainment may be diminished if the main source of cooling water is recruited from near the bottom strata of the open water channel region of the river. With such an intake configuration, entrainment of shorezone eggs and larvae, as well as the near surface drift community of ichthyoplankton, is minimized. Impacts could also be minimized by the control of the timing and frequency of withdrawals from rivers. In temperate regions, the number of entrainable/impingeable organisms of rivers increases during spring and summer (when many riverine fishes reproduce). The number of eggs and larvae peak at that time, whereas entrainment potential during the remainder of the year may be minimal.

In estuaries, species distribution and abundance are determined by a number of physical and chemical attributes including: geographic location, estuary origin (or type), salinity, temperature, oxygen, circulation (currents), and substrate. These factors, in conjunction with the degree of vertical and horizontal stratification (mixing) in the estuary, help dictate the spatial distribution and movement of estuarine organisms. However, with local knowledge of these characteristics, the entrainment effects of a CWIS could be minimized by adjusting the intake design to areas (e.g., depths) least likely to impact upon concentrated numbers and species of organisms.

In oceans, nearshore coastal waters are generally the most biologically productive areas. The euphotic zone (zone of photosynthetic available light) typically does not extend beyond the first 100 meters (328 feet) of depth. Therefore, inshore waters are generally more productive due to photosynthetic activity, and due to the input from estuaries and runoff of nutrients from land.

There are limited published data *quantifying* the locational differences in I&E rates at individual power plants. However, some information is available for selected sites. For example,

- For the St. Lucie plant in Florida, EPA Region 4 permitted the use of a once through cooling system instead of closed-cycle cooling by locating the outfall 1,200 offshore (with a velocity cap) in the Atlantic Ocean. This avoided impacts on the biologically sensitive Indian River estuary.

- In *Entrainment of Fish Larvae and Eggs on the Great Lakes, with Special Reference to the D.C. Cook Nuclear Plant, Southeastern Lake Michigan* (1976), researchers noted that larval abundance is greatest within about the 12.2-m (40 ft) contour to shore in Lake Michigan and that the abundance of larvae tends to decrease as one proceeds deeper and farther offshore. This led to the suggestion of locating CWISs in deep waters.

- During biological studies near the Fort Calhoun Power Station along the Missouri River, results of transect studies indicated significantly higher fish larvae densities along the cutting bank of the river, adjacent to the Station's intake structure. Densities were generally were lowest in the middle of the channel.

5.7 SUMMARY

Tables 5-1 and 5-2 summarize I&E performance data for selected, existing facilities. The Agency recognizes that these data are somewhat variable, in part depending on site-specific conditions. This is also because there generally have not been uniform performance standards for specific technologies. However, during the past 30 years, significant experience has been gained in optimizing the design and maintenance of CWIS technologies under various site and environmental conditions. Through this experience and the performance requirements under Track II of the proposed new facility rule, the Agency is confident that technology applicability and performance will continue to be improved

The Agency has concluded that the data indicate that several technologies, i.e., wide-mesh wedgewire screens and barrier systems, will generally minimize impingement to levels comparable to wet, closed cycle cooling systems. Other technologies, such as modified traveling screens with fish handling and return systems, and fish diversion systems, are likely to be viable at some sites (especially those with hardy species present). In addition, these technologies may be used in groups, e.g., barrier nets and modified screens, depending on site-specific conditions.

Demonstrating that alternative design technologies can achieve comparable entrainment performance to closed-cycle systems is more problematic largely because there are relatively few fully successful examples of full-scale systems being deployed and tested. However, the Agency has determined that fine-mesh traveling screens with fish return systems, fine-mesh wedgewire screens and microfiltration barriers (e.g., gunderbooms) are all promising technologies that could provide a level of protection reasonably consistent with the I&E protection afforded by wet, closed-cycle cooling. In addition, the Agency is also confident that on a site-by-site basis, many facilities will be able to further minimize entrainment (and impingement) by optimizing the location and timing of cooling water withdrawals. Similarly, habitat restoration could also be used, as appropriate as needed, in conjunction with CWIS technologies and/or locational requirements.

Table 5-1: Impingement Performance

Site	Location	Name/Type of Waterbody	Technology	Impingement	Entrainment	Notes
Diablo Canyon/Moss Landing	California	Pacific Ocean	Modified traveling/fish return	75	0	
Brayton Point	Massachusetts	Mt. Hope Bay (Estuary)	Angled screens/fish return	76	0	63% latent
Danskammer	New York	Tidal River (Hudson)	Angled screens/fish return	99	0	84% latent
Monroe	Michigan	River/Great Lake	Fish pump/return (screenwell)	70-80	0	Raisin River trib to L. Erie
Holyoke Canal	Connecticut	Connecticut River Basin	Louvers	85-90	0	Test results
Tracy Fish Collection	California	San Joaquin River	Louvers	63-89	0	
Salem	New Jersey	Tidal River (Delaware)	Ristroph screens	18-98	0	Species specific (no avg.)
Redondo Beach	California	Pacific Ocean	Louvers	96-100	0	Test for San Onofre
San Onofre	California	Pacific Ocean	Louvers	75-96	0	
Dominion Power Surry	Virginia	Estuary (James River)	Modified Fish/fish return	94	0	Includes survival
Barney Davis	Texas	Estuary (coastal lagoon)	Passavant screens (1.5 mm)	86	NA	Entrainment data Not Avail
Kintigh	New York	Great Lake	Modified with fish return	>80	50-97	Except shad 54-65, alewife 15-44
Calvert Cliffs	Maryland	Bay/estuary	Dual flow, cont. rot., return	73	0	Includes survival
Arthur Kill	New York	Estuary	Ristroph screens	79-92	0	
J.H. Campbell	Michigan	Great Lake	Wide mesh wedgewire	99+	0	
Eddystone	Pennsylvania	Estuary (Delaware)	Wide mesh wedgewire	99+	0	
Lovett	New York	Tidal River (Hudson)	Gunderboom	99	82	
J.P. Pulliam	Wisconsin	River/Great Lake	Barrier net	90	0	Only when above 37 degrees C
Ludington Storage	Michigan	Great Lake	Barrier net	96	0	
Chalk Point	Maryland	Bay/Estuary	Barrier net	90+	0	Based on liability reduced 93%
Bowline	New York	Tidal River (Hudson)	Barrier net	91	0	
J.R. Whiting	New York	Great Lake	Barrier net	97-99	0	
D.C. Cook	Michigan	Great Lake	Barrier net	80	0	Estimated by U. of Michigan
Oswego Steam	New York	Great Lake	Velocity cap	78	0	

Table 5-2: Entrainment Performance

Site	Location	Name/Type of Waterbody	Technology	Impingement	Entrainment	Notes
Big Bend	Florida	Tampa Bay	Fine mesh traveling	NA	86-95	66-93% survival
Seminole	Florida	River/Estuary	Fine mesh wedgewire	NA	99	Testing, not full-scale
Logan	New Jersey	River/Estuary	Fine mesh wedgewire	NA	90	19 mgd
TVA (studies)	Various	Fresh Water	Fine mesh traveling	NA	99	lab testing, striped bass larvae only
Lovett	New York	River/Tidal	Gunderboom	99	82	
Brunswick	North Carolina	River/Estuary	Fine mesh traveling	NA	84	used only when less than 84 deg F
Chalk Point	Maryland	Bay/Estuary	Fine mesh wedgewire	NA	80	Testing, not full-scale
Kintigh	New York	Great Lake	Fine mesh traveling	>80	50-97	
Summit	Delaware	Bay/Estuary	Fine mesh wedgewire	NA	90+	"impingement eliminated"

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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:

- C 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:

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

DESIGN CONSIDERATIONS:

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

- C 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.

- C 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:

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

LIMITATIONS:

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

REFERENCES:

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U.S. EPA. Development Document for Best Technology Available for the Location, Design, Construction, and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact. U.S. Environmental Protection Agency, Effluent Guidelines Division, Office of Water and Hazardous Materials. EPA 440/1-76/015-a. April 1976.

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:

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

ADVANTAGES:

- C 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:

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

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

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

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. 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.

REFERENCES:

Bruggemeyer, V., D. Condrick, K. Durrel, S. Mahadevan, and D. Brizck. "Full Scale Operational Demonstration of Fine Mesh Screens at Power Plant Intakes". In Fish Protection at Steam and Hydroelectric Power Plants. EPRI CS/EA/AP-5664-SR, March 1988, pp 251-265.

Electric Power Research Institute (EPRI). Fish Protection at Cooling Water Intakes: Status Report. 1999.

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Mussalli, Y.G., E.P. Taft, and P. Hofmann. "Engineering Implications of New Fish Screening Concepts". In Fourth Workshop on Larval Exclusion Systems For Power Plant Cooling Water Intakes, San-Diego, California, February 1978, pp 367-376.

Sharma, R.K., "A Synthesis of Views Presented at the Workshop". In Larval Exclusion Systems For Power Plant Cooling Water Intakes. San-Diego, California, February 1978, pp 235-237.

Tennessee Valley Authority (TVA). A State of the Art Report on Intake Technologies. 1976.

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:

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

- C 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.

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

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

ADVANTAGES:

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

LIMITATIONS:

- C 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.

- C 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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Using Wedge-Wire Screening". In Larval Exclusion Systems For Power Plant Cooling Water Intakes. R.K. Sharmer and J.B. Palmer, eds, Argonne National Lab., Argonne, IL. February 1978, pp 169-194.

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Weisberg, S.B., F. Jacobs, W.H. Burton, and R.N. Ross. Report on Preliminary Studies Using the Wedge Wire Screen Model Intake Facility. Prepared for State of Maryland, Power Plant Siting Program. Prepared by Martin Marietta Environmental Center, Baltimore, MD. 1983.

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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.

REFERENCES:

American Society of Civil Engineers. Task Committee on Fish-handling of Intake Structures of the Committee of Hydraulic Structures. Design of Water Intake Structures for Fish Protection. ASCE, New York, N.Y. 1982.

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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).

REFERENCES:

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Sharma, R.K. "A Synthesis of Views Presented at the Workshop". In Larval Exclusion Systems For Power Plant Cooling Water Intakes. San-Diego, California, February 1978, pp 235-237.

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:

C 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.

- C 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).

- C 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:

- C 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).

- C 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.

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

- C 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.

- C 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:

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

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

LIMITATIONS:

- C The pneumatic air gun, hammer, and fishpulser are not considered reliable.

- C 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.

- C Sound barrier systems require site-specific designs consisting of relatively high technology equipment that must be maintained at the site.

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Chapter 6: Industry Profile: Oil and Gas Extraction Industry

Chapter Contents

INTRODUCTION

The oil and gas industry uses non-contact, once-through water to cool crude oil, produced water, power generators, and various other pieces of machinery at oil and gas extraction facilities.[1] EPA did not consider oil and gas extraction facilities in the Phase I 316(b) rulemaking.

The Phase I proposal and its record included no analysis of issues associated with offshore and coastal oil and gas extraction facilities (such as significant space limitations on mobile drilling platforms and ships) that could significantly increase the costs and economic impacts and affect the technical feasibility of complying with the proposed requirements for land-based industrial operations. Additionally, EPA believes it is not appropriate to include these facilities in the Phase II regulations scheduled for proposal in February 2002; the Phase II regulations are intended to address the largest existing facilities in the steam-electric generating industry. During Phase III, EPA will address cooling water intake structures at existing facilities in a variety of industry sectors. Therefore, EPA believes it is most appropriate to defer rulemaking for offshore and coastal oil and gas extraction facilities to Phase III.

This chapter provides a starting point for future discussions with industry and other stakeholders on future Phase III regulatory decisions.

6.1 HISTORIC AND PROJECTED DRILLING ACTIVITIES

The oil and gas extraction industry drills wells both onshore, coastal, and offshore regions for the exploration and development of oil and natural gas. Various engines and brakes are employed which require some type of cooling system. The U.S. oil and gas extraction industry currently produces over 60 billion cubic feet of natural gas and over 9 million barrels of oil per day.[2] There were roughly 1,096 onshore drilling rigs in operation in August 2001.[3] This section focuses on the OCS oil and gas extraction activities as onshore facilities have less demand for cooling water and have more available options for using dry cooling systems. Moreover, OCS facilities are limited in physical space, payload capacity, and operating environments. EPA will further investigate onshore oil and gas extraction facilities for the Phase III rulemaking.

A large majority of the OCS oil and gas extraction occurs in the Gulf of Mexico (GOM). The Federal OCS generally starts three miles from shore and extends out to the outer territorial boundary (about 200 miles).[†] The U.S. Department of Interior's Mineral Management Service (MMS) is the Federal agency responsible for managing OCS mineral resources. The following summary statistics are from the 1999 MMS factbook.[2]

- The OCS accounts for about 27% of the Nation's domestic natural gas production and about 20% of its domestic oil production. On an energy basis (BTU), about 67 percent of the energy currently produced offshore is natural gas.

- The OCS contains about 19% of the Nation's proven natural gas reserves and 15% of its proven oil reserves. The OCS is estimated to contain more than 50% of the Nation's remaining undiscovered natural gas and oil resources.

- To date, the OCS has produced about 131 trillion cubic feet of natural gas and about 12 billion barrels of oil. The Federal OCS provides the bulk—about 89%—of all U.S. offshore production. Five coastal States—Alaska, Alabama, California, Louisiana and Texas—make up the remaining 11%.

Table 1 presents the number of wells drilled in three areas (GOM, Offshore California, and Coastal Cook Inlet, Alaska) for 1995 through 1997. The table also separates the wells into four categories: shallow water development, shallow water exploratory, deep water development, and deep water exploratory. Exploratory drilling includes those operations drilling wells to determine potential hydrocarbon reserves. Development drilling includes those operations drilling production wells once a hydrocarbon reserve has been discovered and delineated. Although the rigs used in exploratory and development drilling sometimes differ, the drilling process is generally the same for both types of drilling operations.

The water depth in which either exploratory or development drilling occurs may determine the operator's choice of drill rigs and drilling systems. MMS and the drilling industry classify wells as located in either deep water or shallow water, depending on whether drilling is in water depths greater than 1,000 feet or less than 1,000 feet, respectively.

[†]The Federal OCS starts approximately 10 miles from the Florida and Texas shores.

Table 6-1: Number of Wells Drilled Annually, 1995 - 1997, by Geographic Area						
Data Source		**Shallow Water (<1,000 ft)**		**Deep Water (≥ 1,000 ft)**		**Total Wells**
		Development	**Exploration**	**Development**	**Exploration**	
Gulf of Mexico†						
MMS:	1995	557	314	32	52	975
	1996	617	348	42	73	1,080
	1997	726	403	69	104	1,302
	Average Annual	640	355	48	76	1,119
RRC		5	3	NA	NA	8
Total Gulf of Mexico		**645**	**358**	**48**	**76**	**1,127**
Offshore California						
MMS:	1995	4	0	15	0	19
	1996	15	0	16	0	31
	1997	14	0	14	0	28
	Average Annual	**11**	**0**	**15**	**0**	**26**
Coastal Cook Inlet						
AOGC:	1995	12	0	0	0	12
	1996	5	1	0	0	6
	1997	5	2	0	0	7
	Average Annual	**7**	**1**	**0**	**0**	**8**

Source: Ref. 4

† Note: GOM figures do not include wells within State bay and inlet waters (considered "coastal" under 40 CFR 435) and State offshore waters (0-3 miles from shore). In August 2001, there were 1 and 23 drilling rigs in State bay and inlet waters of Texas and Louisiana, respectively. There were also 19 and 112 drilling rigs in State offshore waters (0-3 miles from shore), respectively.[3]

Offshore production in the Gulf of Mexico began in 1949 with a shallow well drilled in shallow water. It took another 25 years until the first deepwater well ($1,000 ft. of water) was drilled in 1974. Barriers to deepwater activity include technological difficulties of stabilizing a drilling rig in the open ocean, high financial costs, and natural and manmade barriers to oil and gas activities in the deep waters.

These barriers have been offset in recent years by technological developments (e.g., 3-D seismic data covering large areas of the deepwater Gulf and innovative structure designs) and economic incentives. As a result, deepwater oil and gas activity in the Gulf of Mexico has dramatically increased from 1992 to 1999. In fact, in late 1999, oil production from deepwater wells surpassed that produced from shallow water wells for the first time in the history of oil production in the Gulf of Mexico.[5]

As shown in Table 1, 1,127 wells were drilled in the Gulf of Mexico, on average, from 1995 to 1997, compared to 26 wells in California and 8 wells in Cook Inlet. In the Gulf of Mexico, over the last few years, there has been high growth in the number of wells drilled in deep water, defined as water greater than 1,000 feet deep. For example, in 1995, 84 wells were drilled in deep water, or 8.6 percent of all Gulf of Mexico wells drilled that year. By 1997, that number increased to 173 wells drilled, or over 13 percent of all Gulf of Mexico wells drilled. Nearly all exploration and development activities in the Gulf are taking place in the Western Gulf of Mexico, that is, the regions off the Texas and Louisiana shores.

6.2 Offshore and Coastal Oil and Gas Extraction Facilities

There are numerous different types of offshore and coastal oil extraction facilities. Some facilities are fixed for development drilling while other facilities are mobile for both exploration and development drilling. Previous EPA estimates of non-contact cooling water for offshore and coastal oil and gas extraction facilities (OCOGEF) showed a wide range of cooling water demands (294 - 5,208,000 gal/day).[1]

6.2.1 Fixed Oil and Gas Extraction Facilities

Most of these structures use a pipe with passive screens (strainers) to convey cooling water. Non-contact, once-through water is used to cool crude oil, produced water, power generators and various other pieces of machinery (e.g., drawworks brakes). Due to the number of oil and gas extraction facilities in the GOM in relation to other OCS regions, EPA estimated the number of fixed active platforms in the Federal OCS region of the Gulf of Mexico using the MMS Platform Inspection System, Complex/Structure database. These fixed structures are generally used for development drilling. Out of a total of 5,026 structures, EPA identified 2,381 active platforms where drilling is likely to occur (Table 2).

Table 6-2: Identification of Structures in the Gulf of Mexico OCS

Category	Count	Remaining Count
All Structures	5,026	5,026
Abandoned Structures	1,403	3,623
Structures classified as production structures, i.e., with no well slots and production equipment	245	3,378
Structures known not to be in production	688	2,690
Structures with missing information on product type (oil or gas or both)	309	2,381
Structures whose drilled well slots are used solely for injection, disposal, or as a water source	0	2,381

Source: Ref. 5

The Offshore Operators Committee (OOC) and the National Oceans Industries Association (NOIA) also noted in their comments to the May 25, 2001 316(b) Federal Register Notice that a typical platform rig for a Tension Leg Platform[††] will require 10 - 15 MM Btu/hr heat removal for its engines and 3 - 6 MM Btu/hr heat removal for the drawworks brake. The total heat removal (cooling capacity) is 13 - 21 MM Btu/hr. OOC/NOIA also estimated that approximately 200 production facilities have seawater intake requirements that exceed 2 MGD. OOC/NOIA estimate that these facilities have seawater intake requirements ranging from 2 - 10 MGD with one-third or more of the volume needed for cooling water. Other seawater intake requirements include firewater and ballasting. The firewater system on offshore platforms must maintain a positive pressure at all times and therefore requires the

[††]A Tension Leg Platform (TLP) is a fixed production facilities in deepwater environments (> 1,000 ft).

firewater pumps in the deep well casings to run continuously. Ballasting water for floating facilities may not be a continuous flow but is an essential intake to maintain the stability of the facility.

EPA and MMS could only identify one case where the environmental impacts of a fixed OCOGEF CWIS were considered.[6] BP Exploration (Alaska) Inc. (BPXA) plans to locate a vertical intake pipe for a seawater-treatment plant on the south side of Liberty Island, Beaufort Sea, Alaska. The pipe would have an opening 8 feet by 5.67 feet and would be located approximately 7.5 feet below the mean low-water level (Fig. 6-1). The discharge from the continuous flush system consists of the seawater that would be continuously pumped through the process-water system to prevent ice formation and blockage. Recirculation pipes located just inside the opening would help keep large fish, other animals, and debris out of the intake. Two vertically parallel screens (6 inches apart) would be located in the intake pipe above the intake opening. They would have a mesh size of 1 inch by 1/4 inch. Maximum water velocity would be 0.29 feet per second at the first screen and 0.33 feet per second at the second screen. These velocities typically would occur only for a few hours each week while testing the fire-control water system. At other times, the velocities would be considerably lower. Periodically, the screens would be removed, cleaned, and replaced.

MMS states in the Liberty Draft Environmental Impact Statement that the proposed seawater-intake structure will likely harm or kill some young-of-the-year arctic cisco during the summer migration period and some eggs and fry of other species in the immediate vicinity of the intake. However, MMS estimates that less than 1% of the arctic cisco in the Liberty area are likely to be harmed or killed by the intake structure. Further, MMS concludes that: (1) the intake structure is not expected to have a measurable effect on young-of-the-year arctic cisco in the migration corridor; and (2) the intake structure is not expected to have a measurable effect on other fishes populations because of the wide distribution/low density of their eggs and fry.

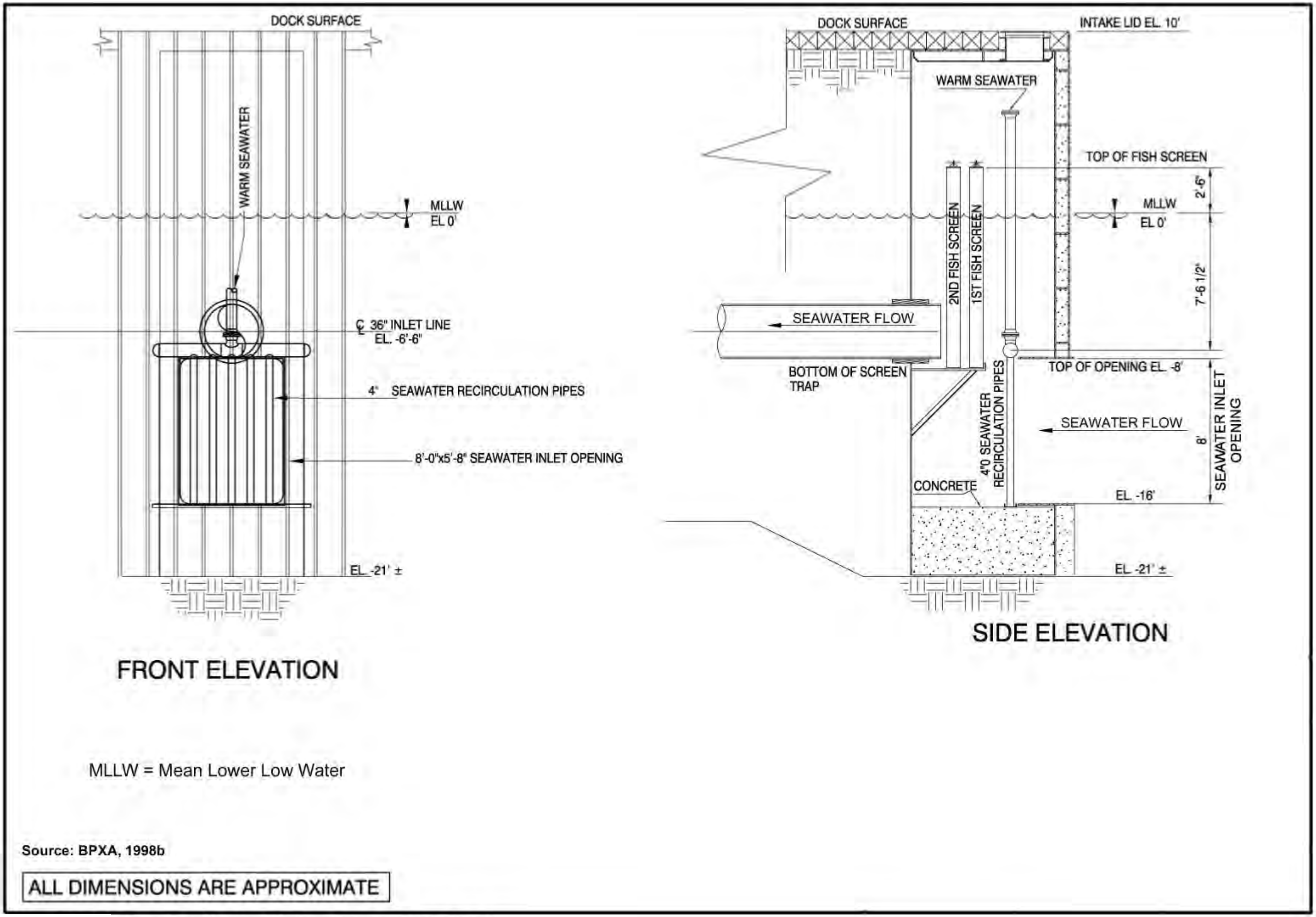

Figure 6-1 Liberty Development Project: Seawater Intake Detail

6.2.2 Mobile Oil and Gas Extraction Facilities

EPA also estimated the number of mobile offshore drilling units (MODUs) currently in operation. These numbers change in response to market demands. Over the past five years the total number of mobile offshore drilling units (MODUs) operating at one time in areas under U.S. jurisdiction has ranged from less than 100 to more than 200. There are five main types of MODUs operating in areas under U.S. jurisdiction: drillships, semi-submersibles, jack-ups, submersibles and drilling barges. Table 3 gives a brief summary of each MODU. EPA and MMS could not identify any cases where the environmental impacts of a MODU CWIS were considered.

Table 6-3: Description of Mobile Offshore Drilling Units and their CWIS

MODU Type	Water Intake† and Design	Water Depth	No. Currently in GOM	No. Currently Under Construction Over Next Three Years
Drill Ships	16 - 20 MGD Seachest	Greater than 400 ft	5	0
Semi-submersibles	2 - 15+ MGD Seachest	Greater than 400 ft	37	5
Jack-ups	2 - 10+ MGD Intake Pipe	Less than 400 ft	140	9
Submersibles	< 2 MGD Intake Pipe	Shallow Water (Bays and Inlet Waters)	6	0
Drill Barges	< 2 MGD Intake Pipe	Shallow Water (Bays and Inlet Waters)	20	0

Sources: Ref. 7, Ref. 8, Ref. 9, Ref. 10

† Approximately 80% of the water intake is used for cooling water with the remainder being used for hotel loads, fire water testing, cleaning, and ballast water.[7]

The particular type of MODU selected for operation at a specific location is governed primarily by water depth (which may be controlling), anticipated environmental conditions, and the design (depth, wellbore diameter, and pressure) of the well in relation to the units equipment. In general, deeper water depths or deeper wells demand units with a higher peak power-generation and drawworks brake cooling capacities, and this directly impacts the demand for cooling water.[10]

Drillships and Semi-Submersibles MODUs

Drill ships and semi-submersibles use a "seachest" as a CWIS. In general there are three pipes for each sea chest (these include CWIs and fire pumps). One of the three intake pipes is always set aside for use solely for emergency fire fighting operations. These pipes are usually back on the flush line of the sea chest. The sea chest is a cavity in the hull or pontoon of the MODU and is exposed to the ocean with a passive screen (strainer) often set along the flush line of the sea chest. These passive screens or weirs generally have a maximum opening of 1 inch.[9] There are generally two sea chests for each drill ship or semi-submersible (port and starboard) for redundancy and ship stability considerations. In general, only one seachest is required at any given time for drilling operations.[7]

While engaged in drilling operations most drillships and one-third of semi-submersibles maintain their position over the well by means of "dynamic positioning" thrusters which counter the effects of wind and current. Additional power is required to operate the drilling and associated industrial machinery, which is most often powered electrically from the same diesel generators that supply propulsion power. While the equipment powered by the ship's electrical generating system changes, the total power requirements for drillships are similar to those while in transit. Thus, during drilling operations the total seawater intake on a drillship is approximately the same as while underway. The majority of semi-submersibles are not self- propelled, and thus require the assistance of towing vessels to move from location to location.

Information from the U.S. Coast Guard indicates that when semi-submersibles are drilling their sea chests are 80 to 100 feet below the water surface and are less than 20 feet below water when the pontoons are raised for transit or screen cleaning operations.[7] Drill ships have their sea chests on the bottom of their hulls and are typically 20 to 40 feet below water at all times.

IADC notes that one of the earlier semi-submersible designs still in use is the “victory” class unit.[10] This unit is provided with two seawater-cooling pumps, each with a design capacity of 2.3 MGD with a 300 head. At operating draft the center of the inlet, measuring approximately 4 feet by 6 feet, is located 80 feet below the sea surface and is covered by an inlet screen. In the original design this screen had 3024 holes of 15mm diameter. The approximate inlet velocity is therefore 0.9 feet/sec.

The more recent semi-submersible designs typically have higher installed power to meet the challenges of operating in deeper water, harsher environmental condition, or for propulsion or positioning. IADC notes that a new design, newly-built unit has a seawater intake capacity of 34.8 MGD (including salt water service pumps and ballast pumps) and averages 10.7 MGD of seawater intake of which 7.4 MGD is used for cooling water.

Jack-up MODUs

Jack-up, submersibles, and drill barges use intake pipes for CWIS. These OCOGEF basically use a pipe with a passive screens (strainers) to convey cooling water. Non-contact, once-through water is used to cool crude oil, produced water, power generators and various other pieces of machinery on OCOGEF (e.g., drawworks brakes).

The jack-up is the most numerous type of MODU. These vessels are rarely self- propelled and must be towed from location to location. Once on location, their legs are lowered to the seabed, and the hull is raised (jacked-up) above the sea surface to an elevation that prevents wave impingement with the hull. Although all of these ships do use seawater cooling for some purposes (e.g., desalinators), as with the semi-submersibles a few use air-cooled diesel-electric generators because of the height of the machinery above the sea surface.[9] Seawater is drawn from deep-well or submersible pumps that are lowered far enough below the sea surface to assure that suction is not lost through wave action. Total seawater intake of these ships varies considerably and ranges from less than 2 MGD to more than 10 MGD. Jack-ups are limited to operating in water depths of less than 500 feet, and may rarely operate in water depths of less than 20 feet.

The most widely used of the jack-up unit designs is the Marathon Letourneau 116-C.[10] For these types of jack-ups typically one pump is used during rig operations with a 6” diameter suction at 20 to 50 feet below water level which delivers cooling water intake rates of 1.73 MGD at an inlet velocity of 13.33 ft/sec.[10] Additionally, pre-loading involves the use of two or three pumps in sequence. Pre-loading is not a cooling water procedure, but a ballasting procedure (ballast water is later discharged). Each pump is fitted with its own passive screen (strainer) at the suction point which provides for primary protection against foreign materials entering the system.

In their early configurations, these jack-up MODUs were typically outfitted with either 5 diesel generator units (each rated at about 1,200 horsepower) or three diesel generator units (each rated at about 2,200 horsepower).[10] In subsequent configurations of this design or re-powering of these units, more installed power has generally been provided, as it has in more recent designs. With more installed power, there is a demand for more cooling water. The International Association of Drilling Contractors (IADC) reports that a newly-built jack-up, of a new design, typically requires 3.17 MGD of cooling water for its drawworks brakes and cooling of six diesel generator units, each rated at 1,845 horsepower.[10] In this case, one pump is typically used during rig operations with a 10" diameter suction at 20 to 50 feet below water level, delivering the cooling water at 3.2 MGD.

Submersibles and Drill Barge MODUs

The submersible MODU is used most often in very shallow waters of bays and inlet waters. These MODUs are not self-propelled. Most are powered by air-cooled diesel-electric
generators, but require seawater intake for cooling of other equipment, desalinators, and for other purposes. Total seawater intake varies considerably with most below 2 MGD.

The drilling barge MODU There are approximately 50 drilling barges available for operation in areas under U.S. jurisdiction, although the number currently in operation is less than 20. These ships operate in shallow bays and inlets along the Gulf Coast, and occasionally in shallow offshore areas. Many are powered by air-cooled diesel-electric generators. While they have some water intake for sanitary and some cooling purposes, water intake is generally below 2 MGD.

6.3 316(b) Issues Related to Offshore and Coastal Oil and Gas Extraction Facilities

There are several important 316(b) issues related to OCOGEF CWIS that EPA will be investigating in the Phase III 316(b) rulemaking: (1) Biofouling; (2) Definition of New Source; (3) Potential Costs and Scheduling Impacts. EPA will work with stakeholders to identify other issues for resolution during the Phase III 316(b) rulemaking process.

6.3.1 Biofouling

Industry comments to the 316(b) Phase I proposal assert that operators must maintain a minimum intake velocity of 2 to 5 ft/sec in order to prevent biofouling of the offshore oil and gas extraction facility CWIS. EPA requested documentation from industry regarding the relationship between marine growth (biofouling) and intake velocities.[11] Industry was unable to provide any authoritative information to support the assertion that a minimum intake velocity of 2 to 5 ft/sec is required in order to prevent biofouling of the OCOGEF CWIS. IADC asserts that it is common marine engineering practice to maintain high velocities in the seachest to inhibit attachment of marine biofouling organisms.[10]

The Offshore Operators Committee (OOC) and the National Oceans Industries Association (NOIA) also noted in their comments to the May 25, 2001 316(b) Federal Register Notice that the ASCE "Design of Water Intake Structures for Fish Protection" recommends an approach velocity in the range of 0.5 to 1 ft/s for fish protection and 1 ft/s for debris management but does not address biofouling specifically. OOC/NOIA were unable to find technical papers to support a higher intake velocity. The U.S. Coast Guard and MMS were also unable to provide EPA with any information on velocity requirements or preventative measures regarding marine growth inhibition or has a history of excessive marine growth at the sea chest.

EPA was able to identify some of the major factors affecting marine growth on offshore structures. These factors include temperature, oxygen content, pH, current, turbidity, and light.[12,13] Fouling is particularly troublesome in the more fertile coastal waters, and although it diminishes with distance from the shoreline, it does not disappear in midoceanic and in the abyssal depths.[13] Moreover, operators are required to perform regular inspection and cleaning of these CWIS in accordance with USCG regulations.

Operators are also required by the U.S. Coast Guard to inspect sea chests twice in five years with at least one cleaning to prevent blockages of firewater lines. The requirement to drydock MODUs twice in five years and inspect and clean their sea chests and sea valves are found in U.S. Coast Guard regulations (46 CFR 107.261 and 46 CFR 61.20-5). The U.S. Coast Guard may require the sea chests to be cleaned twice in 5 years at every drydocking if the unit is in an area of high marine growth or has had history of excessive marine growth at the sea chests.

EPA and industry also identified that there are a variety of specialty screens, coatings, or treatments to reduce biofouling. Industry and a technology vendor (Johnson Screens) also identified several technologies currently being used to control biofouling (e.g., air sparing, Ni-Cu alloy materials). Johnson Screens asserted in May 25, 2001 316(b) Federal Register Notice comments to EPA that their copper based material can reduce biofouling in many applications including coastal and offshore drilling facilities in marine environments.

Biocide treatment can also be used to minimize biofouling. IADC reports that one of their members uses Chloropac systems to reduce biofouling (www.elcat.co.uk/chloro_anti_mar.htm). The Liberty Project plans to use chlorine, in the form of calcium hypochlorite, to reduce biofouling. The operator (BPXA) will reduce the total residual chlorine concentration in the discharged cooling water by adding sodium metabisulfate in order to comply with limits of the National Pollution Discharge Elimination System Permit. MMS estimates that the effluent pH will vary slightly from the intake seawater because of the chlorination/dechlorination processes, but this variation is not expected to be more than 0.1 pH units.

In summary, EPA has not yet identified any relationship between the intake velocity and biofouling of a offshore oil and gas extraction facility CWIS. However, EPA will be pursuing this and other matters related to biofouling in the offshore oil and gas industry in the Phase III 316(b) regulation.

6.3.2 Definition of New Source

Industry claimed in comments to the Phase I 316(b) proposal and the May 25, 2001 316(b) Federal Register Notice that existing MODUs could be considered "new sources" when they drill new development wells under 40 CFR 435.11 (exploration facilities are excluded from the definition of new sources). EPA will work with stakeholders to clarify the regulatory status of existing MODUs in the Phase III 316(b) proposal and final rule.

6.3.3 Potential Costs and Scheduling Impacts

Costs to Retrofit for Velocity Standard

EPA did not identify any additional costs to incorporate the 0.5 fps maximum velocity standard into new designs for future (not yet built) OCOGEF CWIS. Retrofit cost for production facilities will vary depending on the type of cooling water intake structure the facility has in place. The U.S. Coast Guard did not have a good estimate of seachest CWIS retrofit costs but did have a general idea of the work requirements for these potential retrofits.[7] The Coast Guard stated that retrofits for drill ships and semi-submersibles that use seachests as the CWI structure could probably be in the millions of dollars (approximately 8-10 million dollars) and require several weeks to months for drydocking operations. Complicating matters is that there are only a few deepwater drydock harbors capable of handling semi-submersibles. MMS did not have any information on costs and issues relating to retrofitting sea chests or other offshore CWIS.

OOC/NOIA estimated costs for retrofitting a larger intake for a floating production system tension leg platform (TLP).[14] Under their costing scenario, it was assumed that the TLP had a seachest intake structure with a pre-existing flange on the exterior of the intake structure which could be used to bolt on a larger diameter intake in order to reduce the intake velocity to below 0.5 ft/s. The estimated cost to retrofit this new intake is $75,000. OOC/NOIA estimates that this same cost can be assumed for retrofiting a deep well pump casing with a larger diameter intake provided the bottom of the casing is not obstructed and the intake structure can be clamped over the casing.

OOC/NOIA further estimates that for TLP's with seachests without a pre-existing flange for an intake structure and for deep well pump casings that are obstructed and prevent the installation of an intake structure, the retrofit costs are estimated to be much higher.[14] OOC/NOIA estimates that if underwater welding or the installation of new pump casing are required, the costs can be as high as $500,000. In these cases, the platform would need to be shut-in for some period of time (1-3 days) to allow for this installation. Included in this estimate is the need to provide for additional stiffening of underwater legs and supports to resist the wave loading forces of the new intake structures. OOC/NOIA estimates that many facilities have multiple deepwell casings or seachests that would require retrofitting.

IADC notes that the feasibility of redesigning seachests to reduce intake velocity would need to be examined on a case-by-case basis.[10] As interior space is typically optimized for the particular machinery installation, IADC further notes that a prerequisite for enlarging any seachest would be repositioning of machinery, piping and electrical systems and that such operations could only be undertaken in a drydock. Seachests on semi-submersible units are not likely located in stress-critical areas, so effective compensation of hull strength is unlikely to be a major concern, unlike a drillship where, depending on the design, it might be difficult to provide effective compensation to hull girder strength for an enlarged seachest

Costs for retro-fitting jack-ups would likely be much less complicated and expensive than semi-submersible and drillship sea chest retro-fits.[7] The U.S. Coast Guard estimates that operators could install a bell or cone intake device on the existing CWIS to reduce CWI velocities. IADC notes that installing passive screens (strainers) with a larger surface area on jack-up CWIS in order to reduce the intake velocity at the face of the screen would add weight and pose handling problems (e.g., require more frequent cleaning).

Costs to Retrofit to Dry Cooling

OOC/NOIA stated in their May 25, 2001 316(b) Federal Register Notice comments that offshore production platforms will typically use direct air cooling or cooling with a closed loop system for cooling requirements where technically feasible. The following items are typically direct air cooled: gas coolers on compressors, lubrication oil coolers on compressors and generators, and hydraulic oil coolers on pumps. These coolers will range from 1 to 35 MM Btu/hr heat removal capacity. Seawater cooling is necessary in many cases because space and weight limitations render air cooling infeasible. This is particularly true for floating production systems which have strict payload limitations.

IADC reports that some jack-up MODUs were converted from sea water cooling systems to closed-loop air cooling systems for engine and drawworks brake cooling.[10] IADC reported the cost of the conversion, completed during a regular shipyard period, was approximately $1.2 million and required a six-month lead-time to obtain the required equipment. The conversion resulted in the loss of deck space associated with the installation of the air-cooling units, and a small loss in variable deck load equal to the additional weight of the air-cooling units and associated piping.

OOC/NOIA provided initial costs to convert from seawater cooling to air cooling with a radiator on a platform rig. In this case, a cantilevered deck was installed onto the side of the pipe rack. The radiator was rated at about 15 MM Btu/hr, and the cost for the installation was about $150,000. The weight of the addition was about 15,000 pounds. The cost of space and payload on an offshore platform is about $5/pound; therefore, the added weight cost about $75,000 bringing the total cost to about $225,000.

EPA agrees with industry that dry cooling systems are most easily installed during planning and construction, but some can be retrofitted with additional costs. IADC believes that it is already difficult to justify such conversions of jack-ups and that it would be far more difficult to justify conversion of drillships or semi-submersibles. EPA will also look at the net gain or loss in the energy efficiency of conversions from wet to dry cooling.

6.3.4 Description of Benefits for Potential 316(b) Controls on Offshore and Coastal Oil and Gas Extraction Facilities

EPA was only able to identify one case where potential impacts to aquatic communities from OCOGEF CWIS were described (MMS Liberty Draft Environmental Impact Statement).[6] MMS estimated that less than 1% of the arctic cisco in the Liberty area are likely to be harmed or killed by the intake structure but that the intake structure is not expected to have a measurable effect on young-of-the-year arctic cisco in the migration corridor or on other fishes populations.

OOC submitted a video tape of three different OCOGEF CWIS as part of their public comments. These CWIS have an intake of 5.9 to 6.3 MGD with a intake velocity of 2.6 to 2.9 ft/s. The intake has a passive screen (strainer) with 1 inch diameter slots. EPA will use this documentation in determining potential impacts on aquatic communities from OCOGEF CWIS.

6.4 Phase III Activities Related to Offshore and Coastal Oil and Gas Extraction Facilities

Numerous researchers and State and Federal regulatory agencies have studied and controlled the discharges from these facilities for decades. The technology-based standards for the discharges from these facilities are located in 40 CFR 435. Conversely, there has been extremely little work done to investigate the environmental impacts or evaluation of the location, design, construction, and capacity characteristics of OCOGEF CWIS that reduce impingement and entrainment of aquatic organisms.

EPA discussions with two main regulatory entities of OCOGEF (i.e., MMS, USCG) identified no regulatory requirements on these OCOGEF CWIS with respect to environmental impacts. MMS generally does not regulate or consider the potential environmental impacts of these OCOGEF CWIS. MMS could only identify one case where the environmental impacts of a OCOGEF CWIS were considered.[6] Moreover, MMS does not collect information on CWI rates, velocities and durations for any OCOGEF CWIS. The U.S. Coast Guard does not investigate potential environmental impacts of MODU CWIS but does require operators to inspect sea chests twice in five years with at least one cleaning to prevent blockages of firewater lines.

EPA will work with industry and other stakeholders to identify all major issues associated with OCOGEF CWIS and potential Phase III 316(b) requirements. EPA will also collect additional data to identify the costs and benefits associated with any regulatory alternative.

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