Fish Protection at Cooling Water Intakes

Status Report

TR-114013

Final Report, December 1999

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gently rinsed into a collection trough by a low-pressure spraywash system. Once collected, the fish are transported back to a safe release location.

Technology Status

Modified traveling water screens continue to offer an effective method for protecting fish. Survival is highly species- and life-stage dependent. Therefore, to determine the potential biological effectiveness at a given site, the available data presented in this report should be reviewed relative to the representative important species to be protected. With fine-mesh collection screens, the survival of each species/life stage to be protected must be weighed against the survival that would result if that organism were allowed to pass through coarse mesh screens and the circulating water system. For some species/life stages, impingement on fine-mesh screens can result in higher mortality than if the organism were allowed to be entrained through the circulating water system. Therefore, for these species/life stages, impacts will actually increase if fine-mesh screens are used to replace, or used instead of, coarse mesh screens. Information on coarse and fine-mesh modified traveling screens installations and studies is provided in Table 3-1

3
COLLECTION SYSTEMS

Modified Traveling Screens

Concept and General Design

Traveling screens are in common use at most steam electric stations. Modifications for fish protection have been incorporated into the design of through-flow, dual-flow, center-flow and no-well screens. In addition, fine-mesh has been incorporated at some sites (and studied for others) as a means to protect fish eggs, larvae and macroinvertebrates.

The most common type of traveling screen in use in the U.S. is the through-flow design (Figure 3-1). This screen uses the ascending screen face to collect debris. Debris is removed via a high-pressure spraywash system from either the front (ascending) or back (descending) side of the screen. Such screens have been modified to incorporate new design features that improve the survival potential of impinged organisms. Screens modified in this manner are commonly called "Ristroph Screens (Figure 3-2).

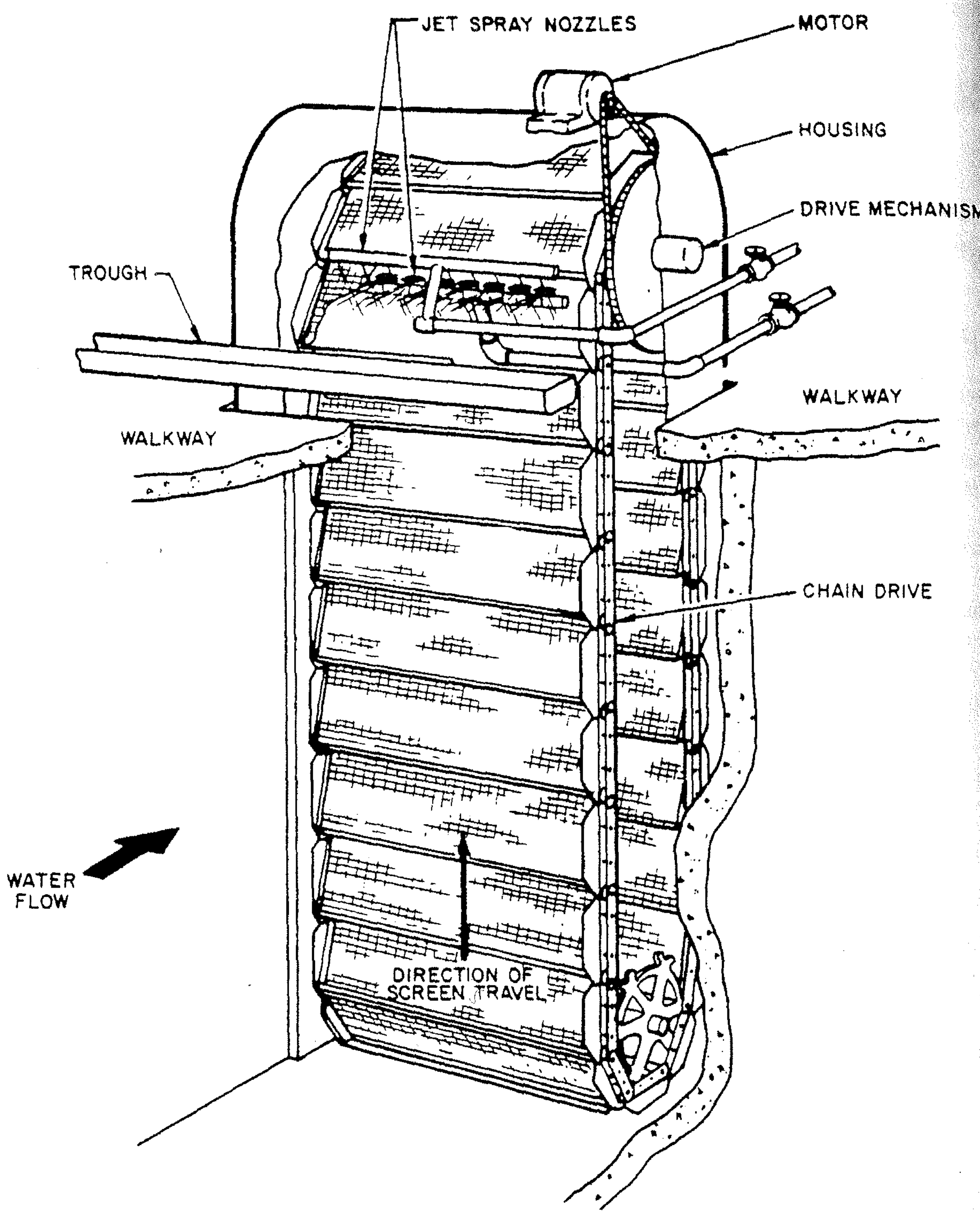


Figure 3-1
Schematic of a Conventional Traveling Water Screen (EPRI 1986)

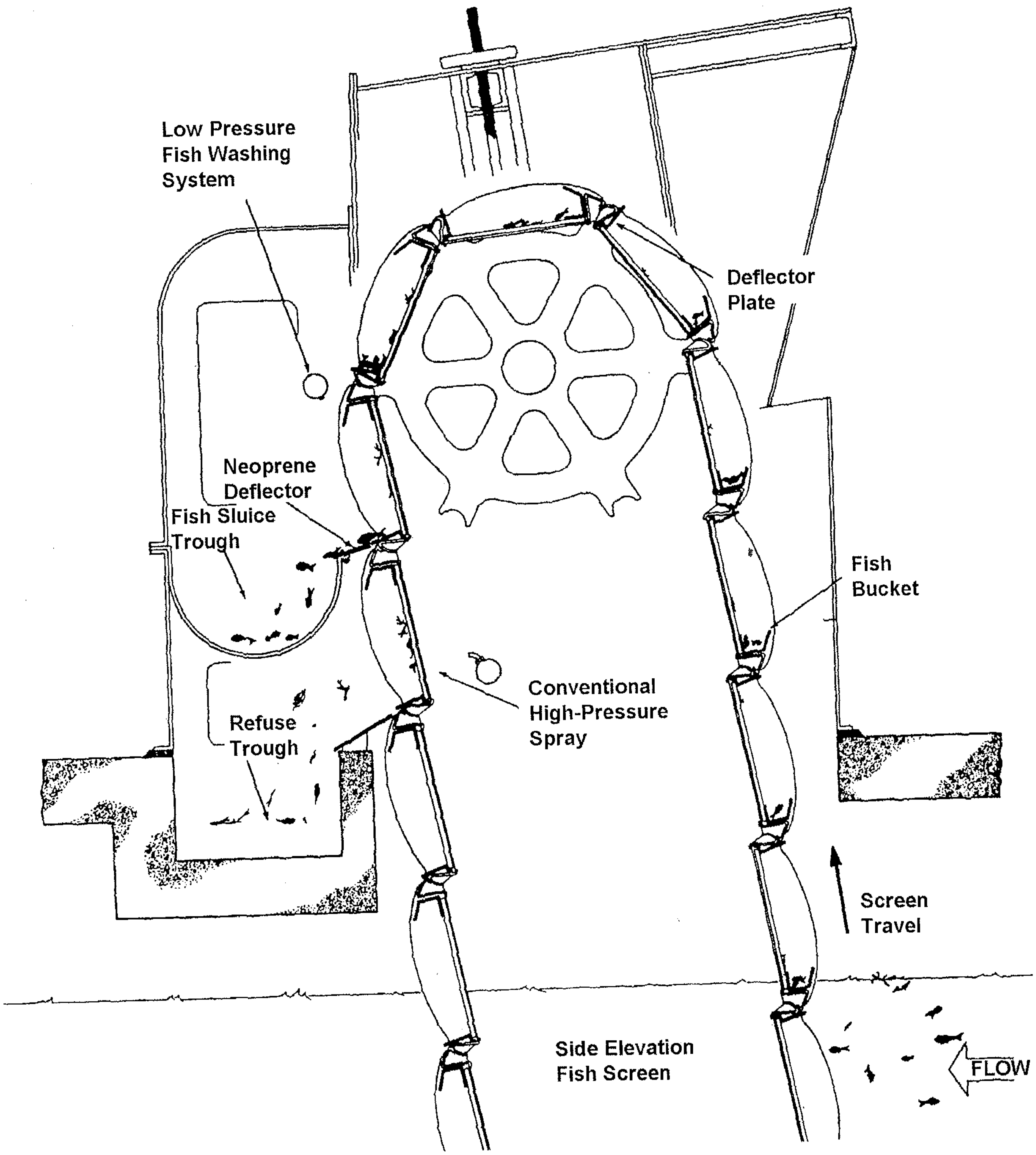


Figure 3-2
Section of a Traveling Water Screen Modified for Fish Protection (EPRI 1986)

Each screen basket is equipped with a water-filled lifting bucket which safely contains collected fish as they are carried upward with the rotation of the screen. The screens operate continuously to minimize impingement time. When each bucket passes over the top of the screen, fish are gently rinsed into a collection trough by a low-pressure spraywash system. Once collected, the fish are transported back to a safe release location.

Technology Status

Modified traveling water screens continue to offer an effective method for protecting fish. Survival is highly species- and life-stage dependent. Therefore, to determine the potential biological effectiveness at a given site, the available data presented in this report should be reviewed relative to the representative important species to be protected. With fine-mesh collection screens, the survival of each species/life stage to be protected must be weighed against the survival that would result if that organism were allowed to pass through coarse mesh screens and the circulating water system. For some species/life stages, impingement on fine-mesh screens can result in higher mortality than if the organism were allowed to be entrained through the circulating water system. Therefore, for these species/life stages, impacts will actually increase if fine-mesh screens are used to replace, or used instead of, coarse mesh screens. Information on coarse and fine-mesh modified traveling screens installations and studies is provided in Table 3-1

Table 3-1
Summary of Information on Modified Coarse and Fine-mesh Traveling Screen Installations and Studies

Plant, Location	Operator	Mesh Size	Screened Flow; Water Source and Debris Type	Screen Type	Predominant Species	Reference
Salem Station, Delaware River	Public Service Electric & Gas Company	6.3 mm by 12.7 mm rectangular mesh	140 m^3/s; brackish water with heavy debris loading	Through-flow with lateral fish passage	weakfish	Ronafalvy et al. (1997), Ronafalvy (1999)
Roseton Station, Hudson River	Central Hudson Electric & Gas Company	3.2 mm by 12.7 mm Smooth-tex	10.3 m^3/s; fresh water with seasonal heavy debris loading	Dual-flow with lateral fish passage	blueback herring, alewife, American shad, white perch, bay anchovy, striped bass	LMS (1991)
Indian Point Unit 2, Hudson River	Consolidated Edison	9.5 mm	133 m^3/s; brackish water with heavy seasonal debris loading	Through-flow	alewife, striped bass, white perch	Con. Ed. (1985)
Danskammer Point, Hudson River	Central Hudson Gas & Electric Company	9.5 mm	Total 4 units – 20 m^3/s; fresh water with heavy seasonal debris loading	Through-flow	alewife, Atlantic tomcod, bay anchovy, blueback herring, shiners, striped bass, weakfish	Ecol. Analysts (1984)
Surry Station, James River	Virginia Electric Power Company	9.5 mm	111 m^3/s; brackish water with moderate debris loading	Through-flow	American shad, alewife, croaker, menhaden, silversides, bay anchovy, spotted seatrout, silver perch, weakfish	White and Brehmer (1984)
Oyster Creek, Barnegat Bay	Jersey Central Power & Light	9.5 mm	116 m^3/s; marine with heavy seasonal debris loading	Through-flow	Atlantic menhaden, bay anchovy, blueback herring, weakfish, bluefish, blue crab	Thomas and Miller (1976)
Oswego Station, Lake Ontario	Niagara Mohawk Power Corporation	9.5 mm	21.5 m^3/s: freshwater with heavy seasonal debris loading	Angled through-flow		

Plant, Location	Operator	Mesh Size	Screened Flow; Water Source and Debris Type	Screen Type	Predominant Species	Reference
Bowline Point Station, Hudson River Estuary	Orange and Rockland Utilities	9.5 mm	Flow not reported; brackish with seasonal heavy debris loading	Through-flow	Striped bass, white perch	King et al. 1978
Belle River Plant, St. Clair	Detroit Edison	9.5 mm	41.7 m^3/s; freshwater with seasonal ice and heavy debris loading	Through-flow with lateral fish passage	alewife, gizzard shad, sculpin, darters, centrarchids, catfish	Freshwater Physicians 1991
Arthur Kill Generating Station, Arthur Kill Tidal Strait	Consolidated Edison Company of New York	6.4 mm x 13 mm and 32 mm	Total Flow 28.6 m^3/s; brackish with heavy seasonal debris loading	Dual-flow	Alewife, Atlantic herring, Atlantic silverside, bay anchovy, blueback herring, weakfish, crabs	ConEd 1996
Dunkirk Station, Lake Erie	Niagara Mohawk Power Company	3.2 mm	Unknown	Dual-flow	alewife, shiners, rainbow smelt, white bass, white perch, yellow perch	Beak Consultants, Inc. (1988)
Indian Point Unit 1, Hudson River	Consolidated Edison	2.5 mm	133 m^3/s; brackish water with heavy seasonal debris loading	Through-flow	Striped bass, white perch, Alosa spp., rainbow smelt	Ecol. Anal. (1977), (1979); TI 1978
Hanford Generating Plant	U. S. D.O.E.	3.2 mm	35.6 m^3/s; freshwater	Through-flow	yellow perch, chinook salmon	Page et al. 1978
100-N Generating Plant	U. S. D.O.E.	3.2 mm	26.4 m^3/s; freshwater	Through-flow	yellow perch, chinook salmon	Page et al. 1978
Calvert Cliffs, Chesapeake Bay	Baltimore Gas & Electric	8 mm	30.5 m^3/s; salt water with light debris loading	Dual-flow	Atlantic menhaden, spot, oyster toadfish, northern searobin, bay anchovy, winter flounder	Ringger 1999; Horwitz 1987
Mystic Station	Boston Edison Company	Smooth-tex	marine with seasonally heavy debris and jellyfish loading	Through flow	alewife, winter flounder	SWEC (1981); Taft and Mussalli

Plant, Location	Operator	Mesh Size	Screened Flow; Water Source and Debris Type	Screen Type	Predominant Species	Reference
Big Bend Station, Tampa Bay, FL	Tampa Electric Company	0.5 mm	30.5m^3/s; salt water with light debris loading	Dual-flow, No-well	bay anchovy, black drum, silver perch, spotted seatrout, scaled sardine, tidewater silverside, stone crab, pink shrimp, American oyster, blue crab	Taft et al. (1981), Bruggemeyer et al. (1987)
Prairie Island Station, Mississippi River, MN	Northern States Power Company	0.5 mm	39.7 m^3/s; fresh water with moderate seasonal debris loading	Through-flow	gizzard shad, carp, shiners, catostomids, channel catfish, white bass, freshwater drum	Kuhl and Mueller (1988)
Brayton Point Station, Mt. Hope Bay, MA	U.S. Generating Company	1.0 mm/ 9.5 mm	16.4m^3/s; salt water with moderate, seasonal debris loading	Angled, through-flow	bay anchovy, Atlantic silversides, winter flounder, northern pipefish	LMS (1985)
Kintigh Station, Lake Ontario, NY	NY State Electric & Gas Company	1.0 mm	12.3 m^3/s; fresh water with light debris loading	Through-flow	alewife, rainbow smelt, shiners	NYSEG (1990)
Brunswick Station	Carolina Power & Light Company	1.0 mm	17.1 m^3/s; salt water with heavy seasonal debris loading	Through-flow	croaker, spot, bay anchovy, shrimp, crabs	Carolina Power & Light (1985)
Barney Davis Station, Laguna Madre, TX	Central Power & Light Company	0.5 mm	21.5 m^3/s; salt water with heavy loading of grasses	Passavant, center-flow	gulf menhaden, bay anchovy, Atlantic croaker, penaeid shrimp	Murray and Jinnette (1978)
Laboratory Study	ESEERCO	0.5 mm	Not applicable	Through-flow	striped bass, winter flounder, alewife, yellow perch, walleye, channel catfish and bluegill	Taft et al. (1981), ESEERCO (1981)

Efforts to optimize the biological effectiveness of modified screens are continuing and should lead to improved survival for even fragile species. Our understanding of fish/screen interactions, important hydraulic conditions, and the contributions of the various screen system components to injury and mortality has improved over the past ten years and are continuing to be investigated.

Review of Permanent Installations and Research Efforts

Ristroph screens have been shown to improve fish survival and have been installed at a wide variety of power plant CWIS (EPRI 1986, 1994a). The most recent advancement in state-of-the-art Ristroph screen design was developed through extensive laboratory and field experimentation. Previously, impingement of fish on the mesh of Ristroph screens had been considered to be the primary cause of most injury and mortality associated with such screens. A series of studies conducted by Fletcher (1990) indicate that substantial injury associated with these traveling screens is due to repeated buffeting of fish inside the fish lifting buckets as a result of undesirable hydraulic conditions. Observations of fish behavior in flume studies demonstrated that fish which entered the standard Ristroph bucket (or were driven down the screen mesh into the bucket) design were caught in a secondary flow, interior to the bucket, that swirled them around in a rapid circular motion (Figure 3-3). Fletcher (1990) noted that fish captured in this manner were injured more by the buffeting they received in the bucket than by movement along the screen mesh.

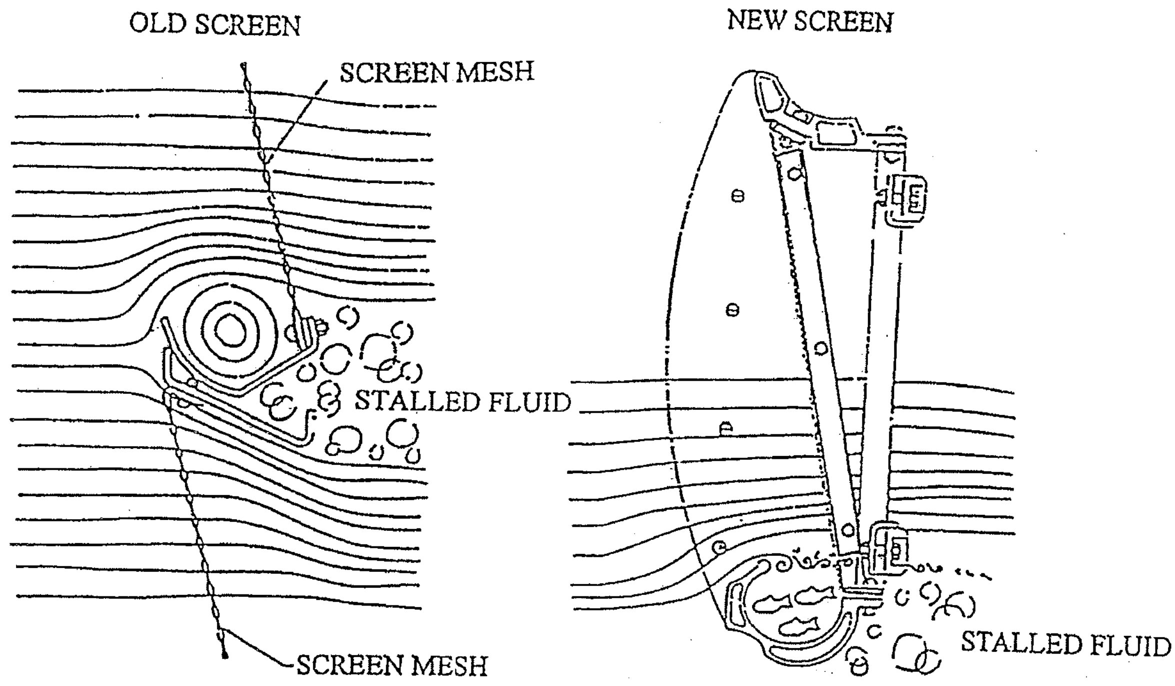
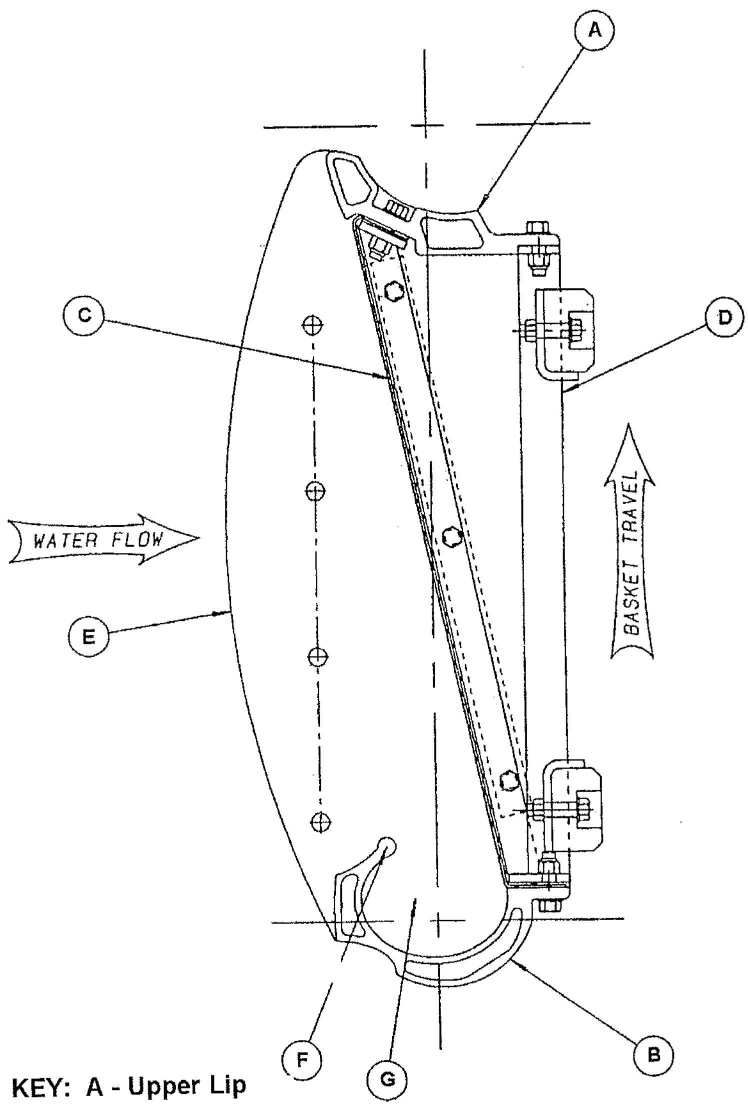


Figure 3-3
Improvements in the Design of Fish Collection Buckets

In an effort to eliminate the observed undesirable hydraulic conditions, a number of alternative bucket configurations were developed to create a sheltered area within the bucket in which fish could safely reside during screen rotation (Envirex 1996). After several attempts, a bucket configuration was developed which achieved the desired conditions. By re-curving the leading edge of the standard bucket (Figure 3-4), this new configuration creates a trail of disordered flow over the bucket of sufficient strength to separate the shearing action of the main flow from the bucket interior. These modifications were applied to the screens in operation at the Salem Generating Station, as described below.



KEY: A - Upper Lip
B - Lower Lip
C - Smooth-Tex Mesh
D - Back-Up Bracket with Wear Pads
E - End Plate
F - Flow Spoiler
G - Fish Sluice

Figure 3-4
Fish Lifting Bucket with Modified Lip Trough (courtesy of U. S. Filter)

Fish Pumps

Concept and General Design

Several pumps have demonstrated an ability to transfer fish with little or no mortality. The pumps by themselves do not represent a technology for protecting fish. However, when coupled with fish bypass systems, such as angled screens and louvers, fish pumps are a biologically acceptable way to transfer fish.

Technology Status

Recent results using new designs indicate that pumps are available that induce little injury and mortality. While they have had limited application at steam electric stations, several designs exist which are biologically effective. The screw-impeller pump appears to offer a potentially effective means of transporting larval, juvenile, and adult fishes with low resultant mortality.

Mechanical problems with larger models, such as those at RBDD, remain to be resolved to the extent that long-term, trouble-free operation can be better assured.

Review of Permanent Installations and Research Efforts

Various types of pumps have been successfully utilized in the past for collecting and transporting fish. For this reason, pumps have been seriously considered for application at power plants to collect entrapped fish from intake screenwells. Detroit Edison (1975) installed a complete fish pump and transportation system in all four units of the **Monroe Power Plant** following an extensive evaluation of the concept in two intake bays of the Unit 2 screenhouse.

The experimental fish pumping system, modeled after an operating system at the Contra Costa Power Plant in California, was installed in August 1973. The system consisted of two barrier screens, two collection pans, piping elements and a volute pump (Figure 3-18). The collecting pans were located near the bottom of the existing skimmer walls directly in front of, and facing, the traveling screens. They were mounted horizontally and measured 3.7 m (12.8 ft) wide by 20.3 cm (8 inches) deep. The barrier screens were installed to prevent fish from penetrating the area above the collecting pans and behind the skimmer wall. The volute pump had a 0.5-m (1.7-ft) diameter impeller with two channels and was rated at a capacity ranging from 0.07 m^3/s to 0.2 m^3/s (2.6 to 8.2 cfs). The piping system consisted of two 20.3-cm (8-inch) pipes, leading from each of the two collecting pans, which transitioned into a common 25.4-cm (10-inch) pipe connecting to the pump.

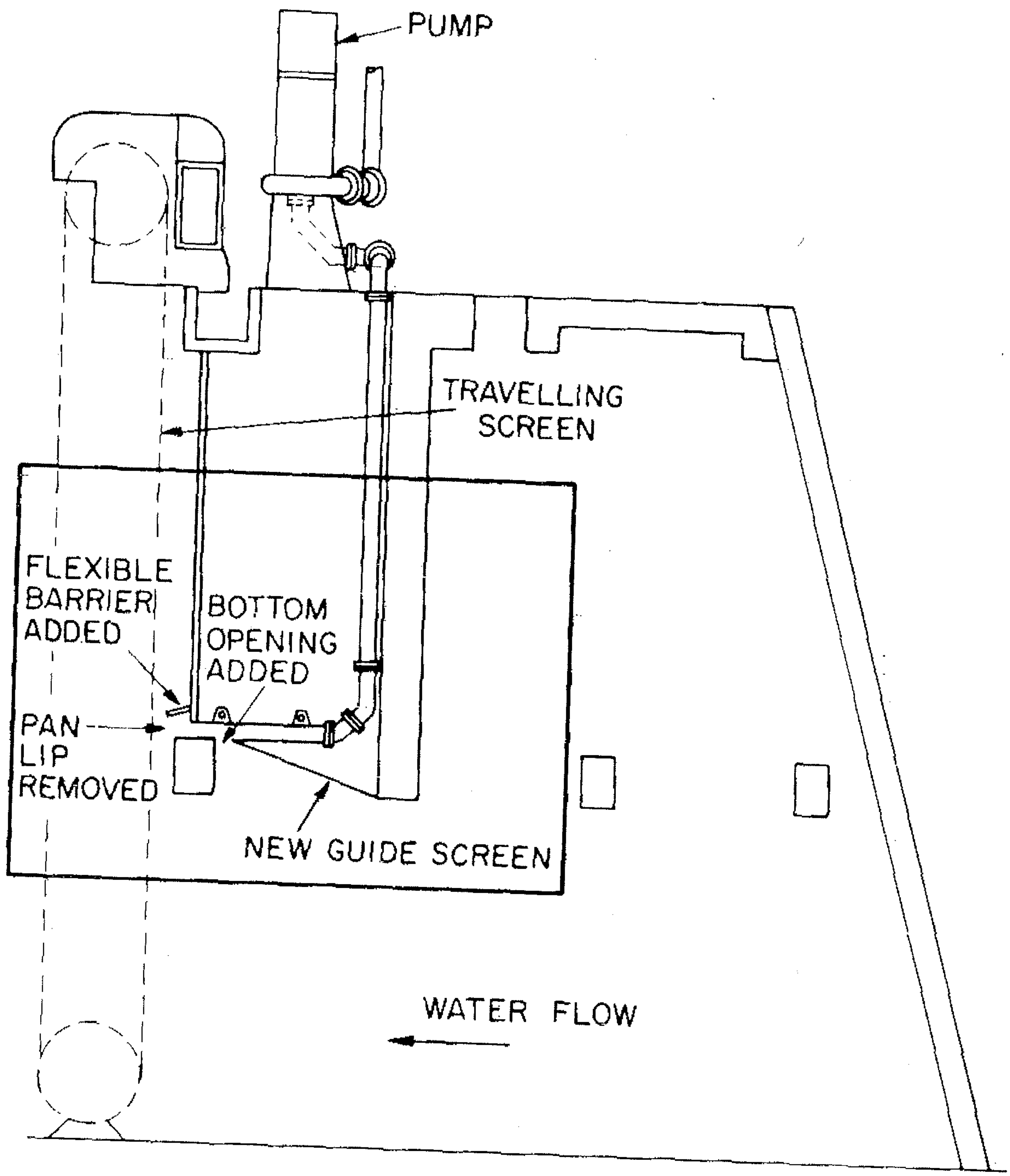


Figure 3-18
Monroe Power Plant Section View of Fish Pump System (Detroit Edison 1975)

During the experimental period, the pump discharged into a holding pool that measured 6.4 m (21 ft) in diameter and 1.2 m (4 ft) in depth (capacity of 37,850 liters [10,000 gallons]). After collection, live fish were transferred to holding tanks for observation and were ultimately transported by truck to Lake Erie for release.

After four months of operation, modifications were made to the pumping system to enhance collection efficiency. The bottom lip of the collecting pan was removed, and a flexible barrier was placed above the pan to guide fish into the collector (see Figure 3-18). To increase the size of the collecting pan opening, the horizontal barrier screens were relocated and holes were cut in the bottom of the pan. In addition, two incandescent underwater lights were installed in the collector cover to help attract fish to the pan. Modifications were also made to the piping system and holding pool in an attempt to reduce mortality in the pumping system.

A complete description of the biological studies conducted with the fish pumping system at Monroe is presented in separate reports (Detroit Edison 1975; Eisele and Malaric 1978). In brief, these studies showed that the pumping system can reduce existing impingement by more than 70 percent and that latent mortality is low.

On the basis of these results, Detroit Edison backfitted all of the screenwell bays at Monroe with fish pumps which return fish to a discharge point in Lake Erie via a 81.2-cm (32-inch) diameter, 1,341-m (4,400-ft) long polyethylene pipe. In addition, the Missouri Department of Natural Resources accepted a fish pump system based on the Monroe design for Union Electric's Sioux Power Plant (letter from R.H. Hentges to J.D. Smith, dated August 19, 1977).

From 1974 to 1976, Stone & Webster Engineering Corporation (SWEC) evaluated the ability of a **jet pump and a screw impeller pump (hydrostal)** to transport fish safely with low resultant mortality at the Alden Research Laboratory. The most pertinent of the jet pump studies involved the evaluation of a system demonstration model, which combined an angled screen model (discussed later) connected to a large-scale, peripheral-type jet pump by a pipe loop (SWEC 1977).

Biological test procedures involved introducing approximately 500 alewives per test into the angled screen model and allowing them to react naturally in the system. Fish which were successfully guided along the screen and which entered the bypass then passed through the pipe loop and the peripheral jet pump before being collected in the secondary bypass. Test fish were held one week for mortality studies. Results of the study are briefly summarized below.

It was anticipated that mortality in the system demonstration model would be higher than mortality with the angled screen alone (as discussed later). This higher mortality would have been due to cumulative stresses from passage through a pipe and jet pump at high velocities and to guidance along a second screen to the collection area. However, such results were not observed. In 11 tests, with screen approach and bypass velocities ranging from 0.3 to 0.6 m/s (1.0 to 2.0 ft/s), pipe velocities from 1.5 to 2.7 m/s (5 to 9 ft/s), and jet nozzle velocities from 9.1 to 15.2 m/s (30 to 50 ft/s), the mean test mortality in the system was 11.8 percent. Mean control mortality was 7.8 percent, thus resulting in a mean differential mortality of 4 percent.

In 1979, Stone & Webster (1979) evaluated the ability of a 12-inch screw impeller centrifugal pump to safely transport fish. The use of a centrifugal pump has two main advantages over the jet pump. A centrifugal pump hydrostal operates more efficiently (hydraulically) and is capable of pumping across greater water level differences. The disadvantage is that the rotating impeller might damage organisms while they are being pumped.

Using juvenile alewives, 40 tests were conducted from September through November 1979. Length of the alewives tested ranged from 9.9 to 10.1 cm (3.9 to 4.0 inches). Approximately 50 fish per test were placed in a specially designed introduction box and passed through the pump, which was operated at a speed of about 430 rpm. Mortality of fish passing through the pump was very low. In the majority of the tests (27 out of 40), 100 percent survival was obtained. Mean test and control mortality were both 1.25 percent.

ESEERCO sponsored additional studies of the **Hidrostal pump** and a **jet pump** to determine their ability to transport striped bass, winter flounder, alewife, and yellow perch with low resultant mortality (ESEERCO 1981). The Hidrostal pump was evaluated with alewife and yellow perch larvae only. Alewife prolarvae could not be successfully tested due to their small size. Postlarvae were tested at mean lengths of 9.6 mm (0.38 inches) (three tests) and 12.4 mm (0.5 inches) (three tests). Mean test and control mortality among the 9.6-mm (0.38-inch) group was 22.4 and 23.1 percent, respectively. Mean test and control mortality among the 12.4 mm (0.5-inch)groups was 46.2 and 32 percent, respectively.

Yellow perch prolarvae (mean length of 6.1 mm [0.24 inches]) were successfully tested in the hidrostal pump. In three tests, mean mortality was 8.3 percent; no control larvae died. Yellow perch postlarvae were tested in four length groups, as presented below:

Mean Length (mm)	Number of Tests	Mean Test Mortality (percent)	Control Mortality (percent)
6.5	3	93.2	72.0
7.3	3	9.7	20.0
7.6	3	52.4	57.7
19.4	2	0.0	0.0

In the jet pump studies, two nozzle velocities of 9.7 m/s and 15.6 m/s (31.8 ft/s and 44.6 ft/s) were evaluated; however, percent mortality did not differ significantly. A total of 126 tests were conducted with striped bass larvae ranging in length from 7.5 to 35.5 mm (0.29 to 1.4 inches). Mean mortality for all tests was 4.7 percent with a 95 percent confidence interval of 3.7 to 6.1 percent. Control larvae experienced a mean mortality of 2.6 percent with a 95 percent confidence interval of 1.4 to 4.4 percent.

Alewife prolarvae (mean length of 6.0 mm [0.24 inches]) were difficult to test due to their small size and transparency; these factors necessitated more extensive handling during collection than with larger larvae. Test mortality in two tests was 40 and 76 percent, while control mortality was 16 percent. Alewife postlarvae were tested at mean lengths of 9.6 and 12.4 mm (0.38 and 0.5 inches). Mean mortality among the two test groups was 80 and 69.5 percent, respectively. Associated control mortalities were 8.3 and 32 percent.

Yellow perch prolarvae were also difficult to recover; however, one test with these 6-mm (0.23-inch) larvae was successfully completed. Test mortality was 32 percent; controls were not held. Postlarvae were tested at four difference mean lengths. Results are given below:

Mean Length (mm)	Number of Tests	Mean Test Mortality (percent)	Control Mortality (percent)
--	3	91.2	65.2
7.3	2	44.8	17.4
8.1	4	86.5	79.2
19.4	2	10.0	0

Ontario Hydro evaluated the effectiveness of a 12.7-cm (5-inch) screw impeller pump and transport system in the laboratory using rainbow trout, alewife, yellow perch, and rainbow smelt (Patrick 1982). Fish ranging in length from 3.1 to 7.9 inches were successfully transported through the pump with minimal damage. Survival varied with pump speeds and generally increased with a decrease in pumping speed. Fewest minor injuries were reported at pump speeds of 438 and 604 rpm. Highest survival after 48 hours was obtained for rainbow trout (99.2 percent), followed by yellow perch (93.6 percent), alewife (91.2 percent), and smelt (90.1 percent). Juvenile gizzard shad, brown bullhead and white sucker ranging from 8.9 to 40 cm (3.5 to 15.7 inches) in length were also passed through the pump at speeds of 604 and 944 rev/s with essentially no mortality after 48 hours (Patrick 1982).

The effectiveness of using a Hidrostal pump for the live transfer of American eels over a hydroelectric dam was evaluated at the **Saunders Generating Station** on the St. Lawrence River near Cornwall, Ontario, in September 1985. A submersible Model 16-F Hidrostal pump was submerged approximately 6.6 ft below water level and operated at a fixed impeller speed of 1,200 rpm. The calculated head of the transport system was over 10 m (33 feet), with a discharge rate of 0.18 m^3/s (6.2 cfs) and velocity of approximately 5.1 m/s (17 ft/s). At the beginning of a test, fish were placed in a wire enclosure leading directly to the pump intake. Fish densities varied from 34 to 547 individuals per liter over a series of 18 tests. Survival was determined immediately following pump passage (time 0 h) and at 24, 48, 72, 96, and 148 hours. In total, 2,300 American eels were passed live through the pump with no latent mortality. Fish injury was minimal, averaging less than 3 percent over all test conditions (Patrick and McKinley 1987).

Evaluations of "fish friendly" pumps for possible use at the **Red Bluff Diversion Dam (RBDD)** have been conducted at the Red Bluff Research Pumping Plant located adjacent to the diversion dam on the Sacramento River (Frizell et al. 1996; Liston et al. 1997; McNabb et al. 1998). The RBDD, which diverts water to the Tehama-Colusa irrigation canal system, affects both the upstream and downstream migrations of several species, including chinook salmon. Three pumps ([two Archimedes and one centrifugal-helical]WEMCO) are being evaluated as part of ongoing research efforts to develop an effective method for protecting outmigrating fish at the diversion (Figure 3-19). The pump studies involve intensive fisheries and engineering evaluations. The design flow of each pump is 2.8 m^3/s (100 cfs) at an operating head of 5.5 m (18 ft). Vertical Vee-shaped screens with wedge-wire panels are used to guide fish to evaluation holding tanks and bypasses (similar to those described under Diversion Systems).

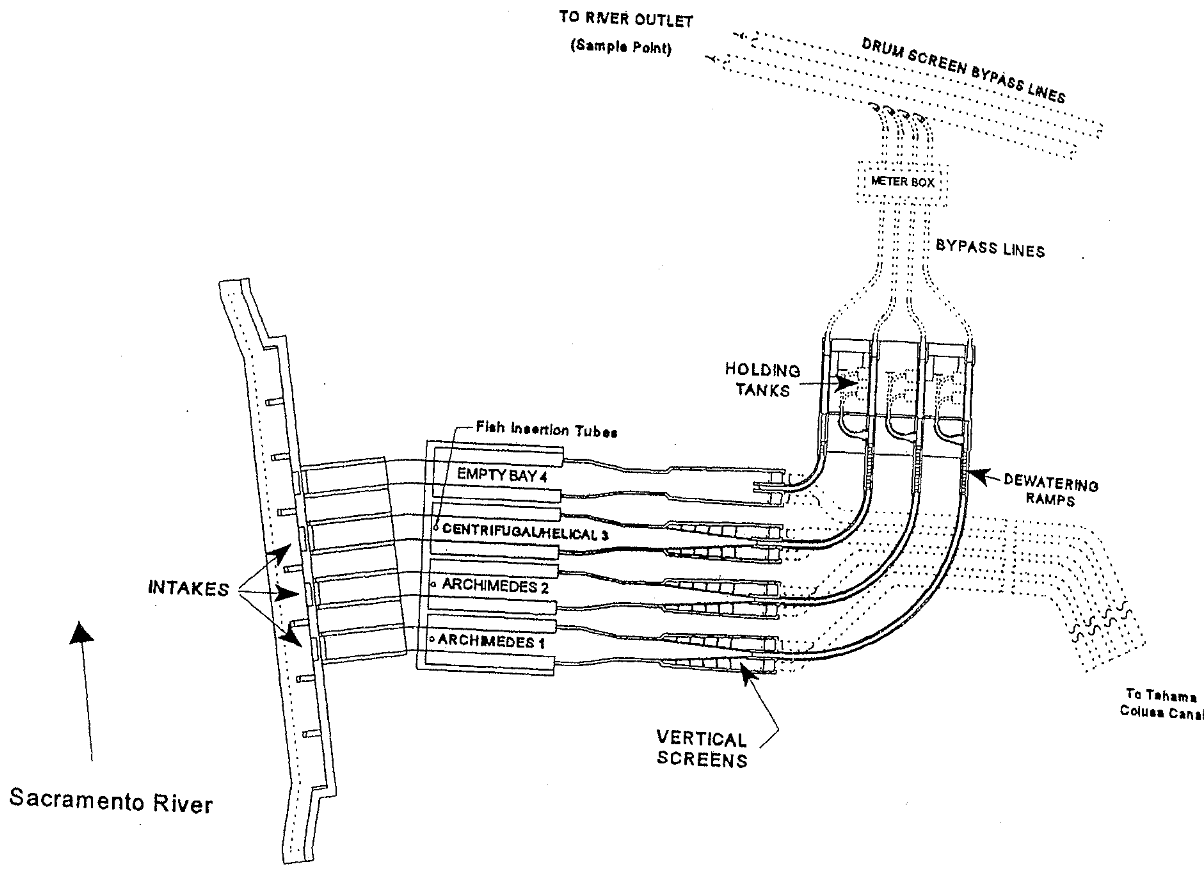


Figure 3-19
Red Bluff Diversion Dam Fish Pumps

Exploratory tests of fish passage through the pumps were conducted in 1995 and 1996. The estimated survival rate for all fish collected was 96.2 percent. Passage survival has been estimated for naturally entrained fish and for fish released during mark-recapture experiments. A total of 2,281 entrained fish representing 20 species were collected during 29 sample events in 1995 and 1996. About half of the fish collected were juvenile chinook salmon. Estimated injury rates for entrained chinook salmon were between 0.6 and 1.2 percent. Mark-recapture experiments were conducted with hatchery-reared juvenile chinook salmon that were almost all greater than 46 mm in length. Survival and injury rates of marked fish passing through the pump facilities was estimated by releasing them at different locations within system (i.e., pump intakes, pump outfalls). A total of 2,080 fish were released into the pump intakes during 65 experimental trials, and 1,725 fish were released into the bypass outfalls during 54 trials. The estimated pump-related direct mortality rate was less than 1 percent, and the estimated 96-hour mortality rate was approximately 1 percent. Estimated external injury rates were less than 1 percent.

Although the preliminary results indicate that the pump facilities are effective, no final recommendations with respect to the overall feasibility of using the pumps on a permanent basis have been made. Other studies associated with predation, adult migration, and survival of fish under a wider range of environmental conditions are ongoing. Also, operational issues accociated with the centrifugal (WEMCO) pump are being addressed. Final study results and recommendations are expected to be released after the year 2000.

Assessment of an Archimedes screw pump was conducted by the California Department of Fish and Game and Pacific Gas Electric Company in March 1989 at the **Don Clausen Fish Hatchery** in Sonoma County (Week et al. 1989). Juvenile steelhead trout and chinook and coho salmon were passed through a prototype Internalift screw fish pump to evaluate the potential of the pump system for raising fish diverted via a fish screen into a bypass channel leading to the mainstem river. The estimated size range of fish tested was 1,000/lb (2,207/kg) to 7.5/lb (16.5/kg). The three flight screw pump was 30 inches (76.2 cm) in diameter and 10 ft (3.0 m) long and was mounted at a 45-degree angle. The fish introduction and recovery system comprised an introduction tank, a transport pipe, a faceplate, and a recovery tank. Five different groups of fish were evaluated at pump settings of 45, 13.75, and 24 rpm. Tests were conducted with and without a shim that was inserted to eliminate a gap between the faceplate and the end of the screw (a possible source for fish injury).

There was no delayed mortality in the test group and two fish died in the control group. Without the shim present, the immediate mortality rate was 1 to 2 percent for 295/kg (134/lb) chinook salmon and 0 percent to 3 percent for 2,207/kg (1000/lb) chinook salmon. Dead fish displayed signs of trauma, e.g., split operculi, dislodged eyes, and descaling. There was no immediate or delayed mortality of test fish during tests with the shim present.

Most fish moved downstream towards the pump when the velocity was 0.67 m/s (2.2 ft/s). However, a few larger fish swam upstream and held position at the upstream end of the tank. A higher proportion of fish introduced in water velocities below 0.67 m/s (2.2 ft/s) did not enter the pump. Fish were exposed to velocities of 2.1 m/s (6.9 ft/s) in the pipe leading to the screw without evidence of trauma. Transit times through the pump ranged from 12 to 25 seconds, depending on the pump revolutions per minute.

The evaluation of the Internalift screw pump demonstrated that it was an acceptable method for moving fish away from the proposed fish screen. Slight modifications were determined to be necessary and it was recommended that the fish bypass pipe be designed to maintain a velocity of at least 0.91 to 1.2 m/s (3 to 4 ft/s) to sweep screened fish through the bypass system to the screw