MOVEMENT OF FALL CHINOOK SALMON FRY *ONCORHYNCHUS TSHAWYTSCHA*:

A Comparison Of Approach Angles For Fish Bypass In A Modular Rotary Drum Fish Screen

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PREFACE

The need to provide passage and protective screens at irrigation diversions has always been a necessary part of the Columbia River Basin Fish and Wildlife Program (NPPC 1984, 1987, 1994). From 1985 through 1990 fish protection facilities in large irrigation diversions throughout the Columbia Basin, especially in the Yakima Basin, were updated. After 1990, fish protection efforts turned to installation of new facilities on unscreened diversions and to repair and upgrade of older facilities. Many of these sites occur in the Lemhi River Basin in east-central Idaho. This study focused on the effectiveness of specific design criteria used for small screens that are longer than 4-ft. According to juvenile fish screening criteria developed by the National Marine Fisheries Society, screens longer than 4-ft must have screen-to- flow angles less than or equal to 45 degrees. Following requests to install screens 6-ft long at some locations where an angled screen added extra costs, the Bonneville Power Administration asked the Pacific Northwest National Laboratory to compare the effectiveness of a 45 degree and a 90 degree angled approach to a screen 6-ft long. Tests were conducted in Richland, Washington with chinook salmon fry, *Oncorhynchus tshawytscha*.

ACKNOWLEDGMENTS

The success of this project depended on the involvement and cooperation of many people. This project was directed by Jodi Stroklund, Bonneville Power Administration (BPA). Tom Clune was manager of the project when the idea of testing modular fish screens in a laboratory was first proposed. John Easterbrooks and Pat Schille, Washington Department of Fish and Wildlife (WDFW), provided the modular fish screen used in the tests, and gave input on screen operation and maintenance. Bill Mavros and Bob Mueller of Pacific Northwest National Laboratory (PNNL) helped monitor the tests and provided technical assistance during the project. A draft of the manuscript was reviewed by Dale Becker and Ted Poston, also of PNNL.

ABSTRACT

The Pacific Northwest National Laboratory (PNNL) performed tests to determine whether a significant difference in fish passage existed between a 6-ft screening facility built perpendicularly to canal flow and an identical screening facility with the screen mounted at a 45-degree angle to the approach channel. A modular drum screen built by the Washington Department of Fish and Wildlife was installed at PNNLs aquatic Ecology research laboratory in Richland, Washington. Fall chinook salmon fry were introduced into the test system, and their movements were monitored. A total of 14 tests (400 fish per test) that lasted 20 hours were completed during April and May, 1996.

There was no significant difference in fish passage rate through the two approach configurations. Attraction flow to the bypass across the face of the screen was more evident for the angled approach, although this did not appear to play a significant role in attracting fish to the bypass. Approach velocities at the face of the screen did not exceed the 0.4 fps criteria for either approach configuration and posed no threat to fish. No fish passed over, around, or through the drum screen during any test.

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INTRODUCTION

Homesteaders arriving in the Pacific Northwest in the mid-1850s were the first people to use water from the Columbia River drainage for irrigation. Early diversion techniques did not provide facilities to prevent fish from being diverted into irrigation canals or to return fish to the stream or river from which they had been diverted. Protection of fish at irrigation diversions in the Pacific Northwest began over 50 years ago. A revolving drum screen was developed by the Oregon Game Commission in 1921 for use in irrigation ditches (Clay 1995). The Mitchell Act, passed in 1938, provided funding to mitigate the impact of federal dams on anadromous fish. Additionally, this funding initiated the current programs to evaluate and screen irrigation diversions in Washington, Oregon, and Idaho.

The Bonneville Power Administration (BPA) and the Northwest Power Planning Council (Council) expanded the screening efforts to protect and enhance fish populations and mitigate adverse effects from hydroelectric development. The Councils Columbia River Fish and Wildlife Program (Program) lists fish protection through effective screening of irrigation diversions as an essential element in their plan to restore declining steelhead and salmon runs (NPPC 1984, 1987, 1994).

The criteria used to measure the effectiveness of fish diversion screens have become more stringent since the first screens were constructed and installed (Bates 1988). The allowable approach velocity at the face of the screens has been reduced, while the permitted sweep velocity that guides fish to the bypass system has been increased. Also, smaller screen mesh sizes are now required to prevent small fish from passing through the screens and becoming entrained in irrigation canals. These new requirements, developed and approved by the National Marine Fisheries Service (NMFS) and fisheries agencies from Washington, Oregon, and Idaho [1], have required development of new screens to replace older, less effective screens. In response to these actions, BPA has established a monitoring and evaluation program to ensure new screening facilities meet fish protection standards.

Fisheries and hydrological evaluations were completed at many large irrigation screening facilities in the Yakima River Basin from 1985 through 1990 (Neitzel et al. 1985, 1986, 1988, 1990abc, Abernethy et al. 1989, 1990). These evaluations relied heavily on release and capture tests with hatchery fish to monitor passage rate, injury rate, and entrainment of fish at each site. Other fish were also monitored during these studies. Problems encountered were usually site-specific but most design, operation, and maintenance problems were common to all sites. Thus, the solution to a problem encountered at one site was generally applicable to similar problems at other sites.

As the region neared the completion of screening the large [2] irrigation diversions (flows of 100 to 3000 cfs), BPA turned its attention to screens on smaller irrigation ditches (flows of 1 to 100 cfs). As part of this effort, BPA asked the Pacific Northwest National Laboratory (PNNL) to evaluate the design, construction, and operation of irrigation diversions and fish screens currently being upgraded in Idaho under the Councils Program. The Salmon River Basin has several hundred irrigation diversions. Most of these diversions are small and supply water to only one irrigator. While most of the diversions are already screened, many were built decades ago and do not comply with current fish protection standards. Over 80 irrigation diversions are found in the lower 50 miles of the Lemhi River, a tributary that enters the Salmon River near Salmon, Idaho. Many of these screening facilities are now being replaced with modular screens designed for small diversions 10-ft wide or less.

The large number of screening facilities involved in the program preclude conducting capture-and-release fisheries tests to evaluate each site. Additionally, the Lemhi River has been classified as a "native stock" river, which excludes planting hatchery-reared fish for research purposes. The low number of native salmonids remaining in the Lemhi River today would make it very difficult to capture enough native fish to make a valid evaluation of an operating screen. Also, Endangered Species Act protection of spring chinook salmon, *Oncorhynchus tshawytscha*, eliminates or severely restricts many collection and sampling methods required to complete an on-site evaluation.

Thus, to evaluate design and operational concerns at these sites, BPA placed a modular screen test facility at the PNNL research hatchery in Richland, Washington to conduct fisheries evaluations under controlled laboratory conditions. Researchers are able to address specific questions about facility design, operation, and maintenance. For example, the test system can be used to monitor injury rates, impingement, entrainment, passage rate, and velocity vectors in front of the screen and in the fish bypass system. Screen submergence, flow through the system, bypass flow, or other operating conditions can be precisely controlled and easily changed. Also, the species, number, and size of fish can be chosen without restrictions mandated by the Endangered Species Act. Replication and standardization of tests in a modular screen system results in increased precision in the evaluation process.

This report describes a series of tests conducted at PNNL to determine the efficacy of two different approach angles to a modular rotary drum screen. The rationale for conducting these tests is discussed in Chapter 2. Chapter 3 describes the methods used for these tests and Chapter 4 describes the results of the tests. In Chapter 5, the results are discussed. References cited are listed in Chapter 6.

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1. Juvenile Fish Screen Criteria, Developed by National Marine Fisheries Service, Environmental & Technical Services Division, Portland, Oregon. Revised Febuary 16, 1995. This criteria document is presented in the Appendix.

2. The designation of large and small screen used here are defined by the authors should not be confussed with the more specific definition used by NMFS in their criteria (see Appendix).

TEST RATIONALE

A small screen and bypass system is defined as "intended for use in streams with flows less than 25 cfs". The NMFS criteria (Appendix, see Section K.2) for small screens vary from the universal criteria. However, NMFS criteria note that some small screens "may be required to apply more universal criteria...while some larger diversions may be allowed to use the small 'screen criteria'..." The provision of the NMFS criteria that provides the rationale for these tests, deals with the approach angle required for small screens.

Diversion screens 4-ft in length or less may have a 90-degree (perpendicular) approach (Figure 1). However, longer screens are required to have an approach angle less than or equal to 45 degrees. The angled approach criteria is intended to increase bypass efficiency (Schuler and Larson 1975, Taft and Mussalli 1977, Mussalli et al. 1977, Taft 1986). With an angled approach, water flows toward the screen at a 30- to 45-degree angle, directing fish to the bypass at one end of the screen. While differences in percent passage and guidance efficiency are expected for angled-approach screens versus perpendicular-approach screens, there is no supporting documentation for restricting this criterion to screens 4 feet long.

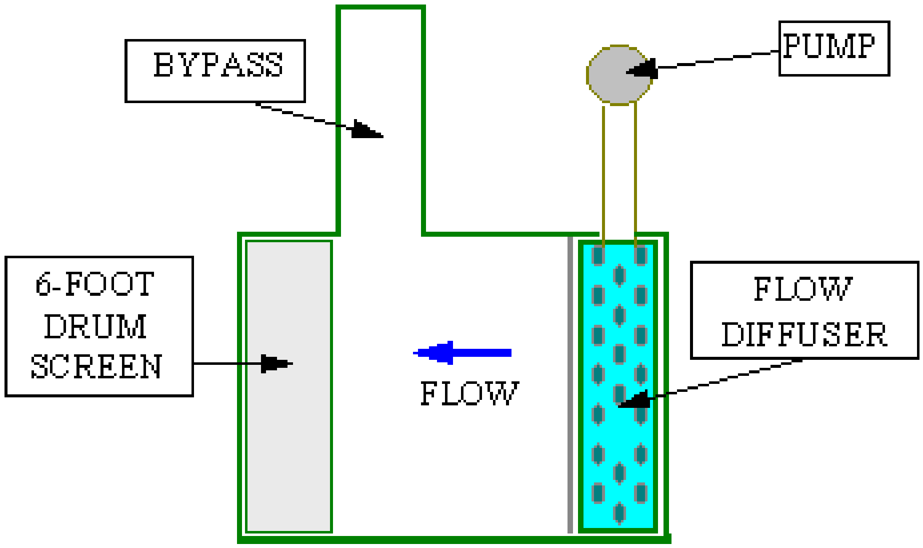

Figure 1(a)

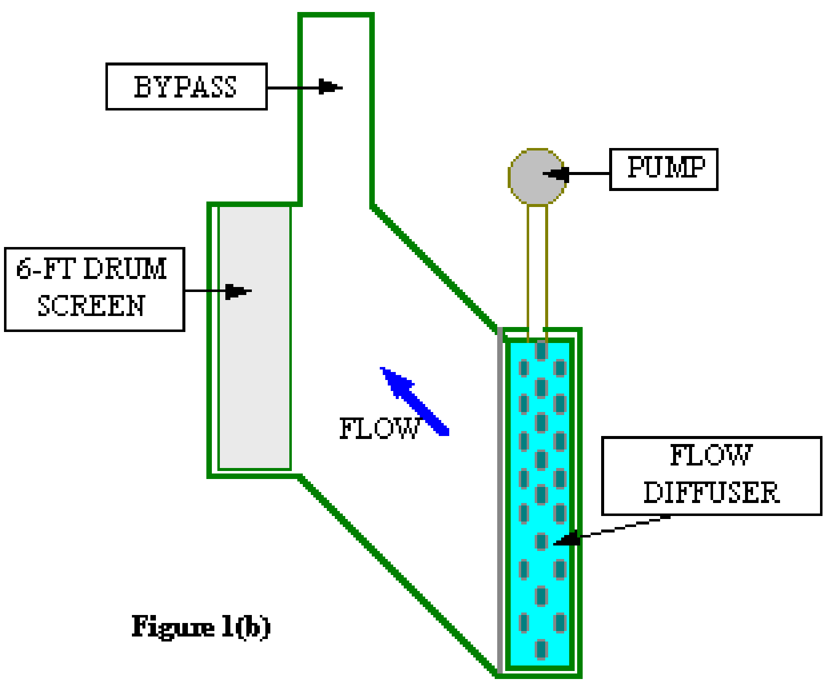

Figure 1(b)

Figure 1.A plan view illustrating a perpendicular (a) and an angled (b) approach to the drum screen

Determining the length of a screen at which an approach angle becomes biologically reasonable can be important from a cost perspective. Angled-approach diversion screens are more costly to construct and usually require more land to install. Should there be no significant difference in fish passage between angled and perpendicular approaches to small screening facilities, costs for new facilities could be decreased by installing perpendicular approaches rather than angled. This study compares the bypass efficiency of perpendicular and angled approaches in a modular 6-ft fish diversion screen.

METHODS

The relative effectiveness between an angled and perpendicular approach to a rotating drum screen was compared in a 6-ft modular fish screen test system at PNNL. We used a modular fish screen in our evaluation designed and built by the WDFW Fish Screen Fabrication Shop in Yakima, Washington. The forebay of the screening facility was modified to allow the placement of dam boards to create flows at either a 90-degree or a 45-degree angle to the screen. There was no difference in the volume of the forebay area between angled and perpendicular configurations. Tests were conducted from April 18 through May 9, 1996.

MODULAR FISH SCREEN TEST SYSTEM

The rotary drum screen was 6-ft long and 1.5-ft in diameter. The drum screen was constructed of stainless steel perforated plate with 1/8-in holes, providing about 28% opening in the material. The screen was mounted within a steel structure that consisted of modular sections (forebay, bypass, diffuser, screen, transition, and paddle wheel sections) bolted together (Figure 2).

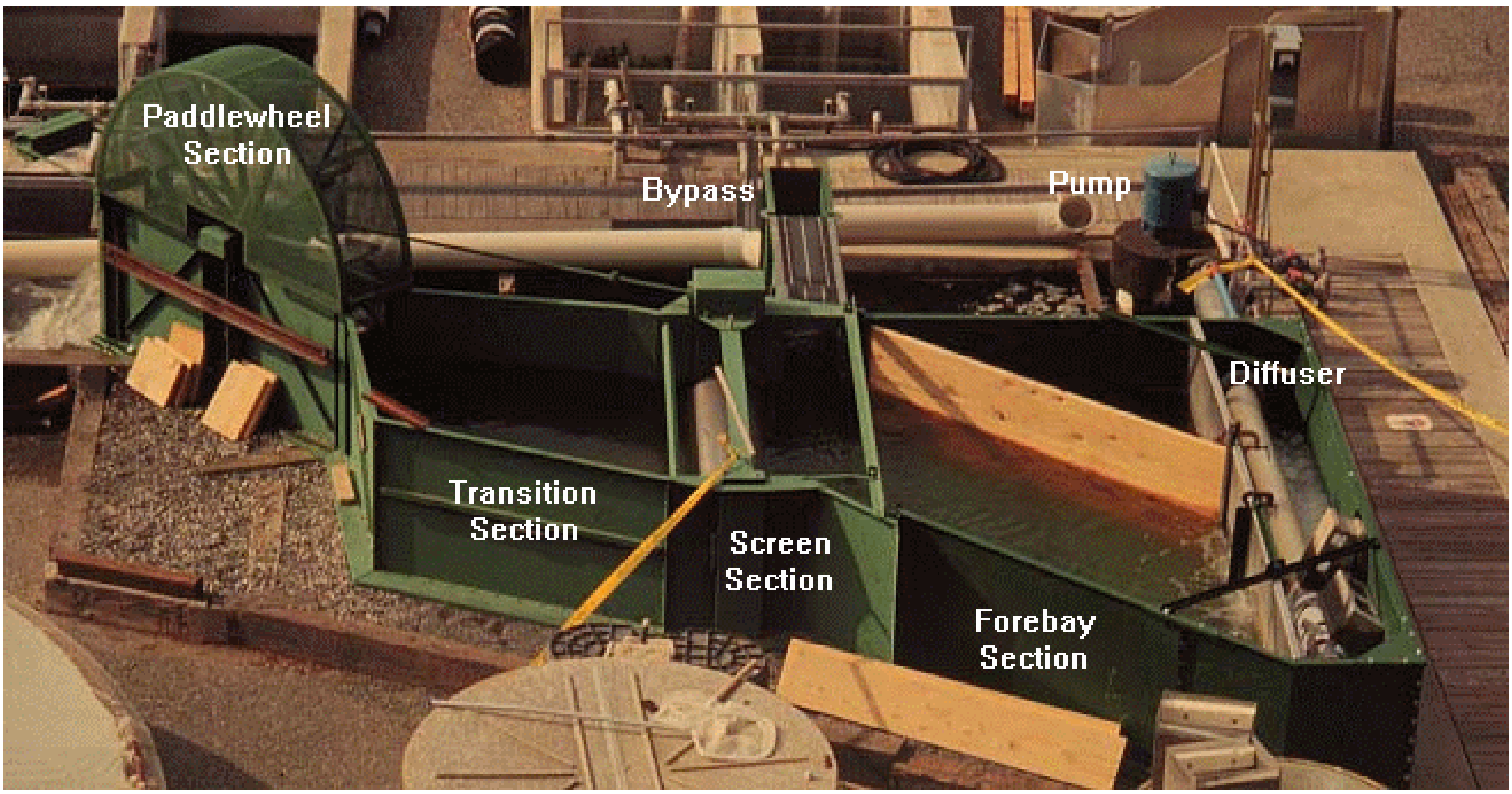

Figure 2. Overhead view of the 6-ft modular fish screen test system installed at the Pacific Northwest National Laboratory in Richland, Washington

The modular screen was positioned on a gravel pad (above ground) next to a concrete raceway serving as a recirculation tank (40-ft long by 4.5-ft wide by 3-ft deep, ~4000 gal volume). The gravel pad was adjusted to make the bottom of the fish screen level with the top of the raceway wall, insuring that water could flow freely through the screen flume and fish bypass. The paddle wheel section was reinforced with I-beams to prevent the sides from spreading when the system was filled with water. No other structural modifications were required to operate the screen above ground level. Water was discharged directly from the paddle-wheel section into the recirculation tank.

A 7.5 horsepower centrifugal pump with a pumping capacity of 3.3 cfs, or ~1500 gpm was installed over the raceway/recirculation tank. Flow through the pump was controlled by a gate valve in the discharge line from the pump. Water was delivered to a head box (~2 -ft wide by 12 -ft long) attached to the forebay of the modular fish screen. The recirculation tank was supplied with ambient Columbia River water that was replaced every 3 hr by the continuous addition of river water at 25 gpm. Test temperatures were 11.4 ± 0.7°C

A diffuser (section of pipe with large [~1.5-in] holes along its length) and concrete blocks were used to reduce water turbulence within the head box. An aluminum perforated plate with 3/32-in holes was installed between the diffuser and the screen forebay section to further reduce turbulence and to prevent fish from moving upstream into the head box area during tests. Water level was maintained at the screen by placing an overflow weir behind the paddle wheel section. The height of the weir was adjusted so that about 1.75 cfs of water passed through the screen at 80% submergence. NMFS design and operation criteria list 65-85% submergence as the accepted operating range.

In the state of Washington, bypass flow is usually maintained and controlled by an overflow weir in the fish bypass. Our test system used the "standard" fish bypass provided by WDFW [3]. The fish bypass section was 6.5-ft long, 1-ft wide, and had a slot for insertion of weir boards about 4.5 ft from the entrance to the fish bypass. The fish bypass section ended with a sleeve that was coupled to an 8-in PVC pipe. We extended the pipe to an overall length of about 30 ft. An inclined plane (surface of stainless steel perforated plate with 1/8-in. holes) with a live box was placed at the terminus of the fish return pipe to capture and hold fish.

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[3]The fish bypass configuration of the modular fish screen differed from typical screening facilities used Idaho, where a submerged orifice is preferred over the weir bypass. Low head differential and fluctuating water levels at most Lemhi River sites make it difficult to maintain a reliable flow over a weir. The weir height in this test series was 4.0-in. lower than the forebay depth to provide about 0.640 cfs of flow when the drum screen was at 80% submergence.

TEST FISH

Because the numbers of spring chinook salmon returning to hatcheries in the Columbia Basin are severely depressed, it was not possible to obtain this race for tests. Instead, we used fall chinook salmon, a race taken at the Priest Rapids Hatchery on the middle Columbia River. Several adult fish were spawned at the laboratory and the young were raised at PNNL hatchery facilities. The 5600 fish used for these tests were 47-mm to 68-mm long and averaged 56.2-mm in length over the test series. Fish increased in weight from an average of 1.39g to 2.69g during the test series. Fish were tested only once to prevent individual fish from "learning" how to migrate through the test system.

EXPERIMENTAL PROCEDURE

Four hundred test fish were introduced in the forebay (in front of the screen) in each test. The number of fish passing through the bypass were counted at 10, 20, 30, 40, 50, 60, 70, 80, 90, and 105 min as well as at 2, 4, 8, and 20 hr. Tests were terminated after 20 hr. At test termination, we determined the number of fish: 1) remaining in front of the screen (residual), 2) exiting the bypass, and 3) missing. We also counted injured and dead fish and calculated the average passage time for fish exiting through the bypass.

FLOW AND VELOCITY MEASUREMENT

Approach and sweep velocity measurements were taken in front of the drum screen and in the entrance to the fish bypass slot with a Marsh McBirney Model 511b(r) bi-directional velocity meter. Flow and velocity were measured at 20% and 80% of forebay depth throughout the forebay and in front of the screens.

(r) The brand and model number are used here for descriptive purposes and not as an endorsement of this produce.

EXPERIMENTAL DESIGN

The purpose of this experiment was to quantitatively compare fish passage rates of angled and perpendicular approaches to a 6-ft fish diversion screen. The treatments for these tests were the perpendicular approach and the angled (45°) approach.

There was no temporal order of preference for selection of treatments (a random number generator was used to determine test order) and there were seven replicates per treatment. The 14 tests were run over a 21-day period. Replications of treatments were used to quantify random error, inherent in variability among experimental units, and chance events

(Snedecor and Cochran 1967).

STATISTICAL ANALYSIS

The difference in fish passage rates was tested statistically by a likelihood ratio test (Lehmann 1991). Fish in the study were faced with one of two bypass approaches; perpendicular or angled. It was hypothesized that the angled approach provided fish with a better bypass entrance queue than the perpendicular approach. We assumed that fish within a test and fish between tests behaved independently. We assumed the probability that a fish that successfully negotiated the passage during a test was equal for all fish in the test. If C represents the count of fish that successfully used the bypass, of the 400 fish tested in one test, then C is a binomial random variable:

$$C \sim \text{Binomial}(400, p)$$

where p is the probability of passage.

To allow for changes in percent fish passed over time, we let the probability of passage vary as a function of study day. Thus, if d denotes the study day and k is a constant multiplier, we assumed the probability of passage for the angled approach is $p_a - kd$, and the probability of passage for the perpendicular approach is $p_s - kd$, where $_a$ is angled and $_s$ is straight (perpendicular). Then, the number C fish in a test that successfully pass on study day d are binomially distributed as either

$$C(ad) \sim \text{Binomial}(400, p_a - kd)$$

or

$$C(sd) \sim \text{Binomial}(400, p_s - kd))$$

depending upon the study day d and the approach $_s$ or $_a$.

To test the hypothesis that the angled approach provides a better bypass entrance queue than the rectangular approach, we tested the following set of hypotheses. If the two approaches equally affect the rate of passage, then the probabilities of passage on any given day are equal. This leads us to the null hypothesis:

$$\text{Ho: } p_s = p_a$$

A difference between the passage rates for the two approaches leads to the alternate hypothesis:

$$\text{H1: } p_s \neq p_a$$

This set of hypotheses can be tested using a likelihood ratio test. Let C_{ad} and C_{sd} denote the number of fish that pass under approach a on study day d and approach s on study day d, respectively. Let L_0 and L_1 denote the likelihoods under the null and alternative hypotheses, respectively. Then, the likelihood that the observed data arose under the null hypothesis is

$$L_1(p = p_s = p_a, k|\text{data}) = \prod_{d=1}^{7} \binom{400}{Csd} (p - kd)^{Csd} \left(1 - (p - kd)\right)^{400-Csd} * \prod_{d=1}^{7} \binom{400}{Cad} (p - kd)^{Cad} \left(1 - (p - kd)\right)^{400-Cad}$$

The likelihood that the observed data arose under the alternative hypothesis is

$$L_1\left(p_s, p_a, k \mid \text{data}\right) = \prod_{d=1}^{7} \binom{400}{Csd} \left(p_s - kd\right)^{Csd} \left(1 - \left(p_s - kd\right)\right)^{400-Csd} * \prod_{d=1}^{7} \binom{400}{Cad} \left(p_a - kd\right)^{Cad} \left(1 - \left(p_a - kd\right)\right)^{400-Cad}$$

The likelihood ratio test compares the maximum of each likelihood via a ratio. If we divide the maximum likelihood under the null hypothesis by the maximum likelihood under the alternative, we would expect the ratio to be near one if there is no difference due to approach because $p = p_s = p_a$. If the alternative fits the data better, then L_1 will be much larger than L_0 and the ratio will be much smaller than one. For our test data, the likelihood ratio can be transformed so that the function is a Chi-squared (χ^2) random variable with one degree of freedom:

$$\lambda = -2 \log\left(\frac{L_0}{L_1}\right) \sim \chi^2(1)$$

RESULTS

A 14-test trial (2 approaches x 7 replicates) was completed. Our results indicate that there is no difference in fish passage rate between the rectangular and angled bypass approaches.

PASSAGE RATE

Passage rates were measured during each test. The passage rate varied greatly between tests within the same treatment (Table 1). The perpendicular-approach fish began the test bypassing very low numbers, but started bypassing between 10 and 15 fish at each sample interval after the first half hour. As expected, numbers increased near dusk, but tapered off for the final 20-hr count. Fish encountering the angled approach bypassed at a moderate rate, generally between 5 and 15 fish per sample interval for the first 2 hr. Passage numbers increased to between 16 and 50 fish for the remaining sample intervals, with the greatest average numbers of fish bypassing between dusk and dawn.

Table 1. Number of fall chinook salmon fry that moved through the bypass during sample intervals in perpendicular and angled approach tests with a modular fish screen, Spring 1996.

	Test Number (PERPENDICULAR)								Test Number (ANGLED)							
Interval	1	2	3	4	5	6	7	Mean	1	2	3	4	5	6	7	Mean
10 min	1	0	1	2	0	0	0	0.57	67	0	5	0	0	2	1	10.71
20 min	0	3	7	1	4	4	1	2.86	6	0	15	0	0	16	1	5.43
30 min	3	36	37	11	3	1	5	13.71	9	0	21	3	6	10	0	7.00
40 min	17	63	23	15	17	2	8	20.71	9	1	20	12	7	6	0	7.86
50 min	6	46	21	29	16	10	8	19.43	10	3	30	9	65	7	7	18.71
60 min	33	42	24	21	3	3	2	18.29	9	6	25	17	16	20	2	13.57
70 min	48	27	3	12	8	7	3	15.43	12	5	14	19	6	11	0	9.57
80 min	44	18	11	22	7	7	3	16.00	1	14	14	20	9	12	12	11.71
90 min	32	10	18	14	10	5	1	12.86	2	17	19	12	20	19	0	12.71
105 min	20	6	17	17	14	4	3	11.57	1	11	26	28	17	2	15	14.29
2 hours	13	7	10	7	9	3	1	7.14	8	3	18	10	11	8	1	8.43
3 hours	14	18	13	39	54	7	42	26.71	19	1	49	12	37	38	58	30.57
4 hours	4	7	24	20	39	12	14	17.14	16	1	11	15	10	20	42	16.43
8 hours	25	14	73	27	57	93	40	47.00	40	69	10	20	35	37	36	35.29
~20 hours	35	4	21	3	9	13	13	14.00	98	201	9	34	4	2	7	50.71
Total Fish	295	301	303	240	250	171	144		307	332	286	211	243	210	182	
Percent Passage	74	75	76	60	63	43	36	60.86	77	83	72	53	61	53	46	63.25

Under ideal conditions we assume that fish act independently of one another when encountering the screening facility. However, random clumping of fish is an uncontrolled factor and there are several instances when large numbers of fish were found in the live box, compared to the adjacent time intervals. Each of these three events occurred with the angled treatment. For example, 67 fish exited the system during the first 10 min of testing during Test 1A. In Test 2A, 201 fish exited the system between dusk and dawn, twice as many fish as were recorded bypassing at any other time interval for any test of either treatment. During test 5A, 65 fish were retrieved from the live box at the 50-min check. This number is nearly two times greater than any other during that test, and is four times greater than either of the number of fish found in the live box within 3 intervals before or after the 50-min count.

The average number of fish passing through the perpendicular approach was greater than the angled approach for 9 of the 15 sample intervals (Figure 3).

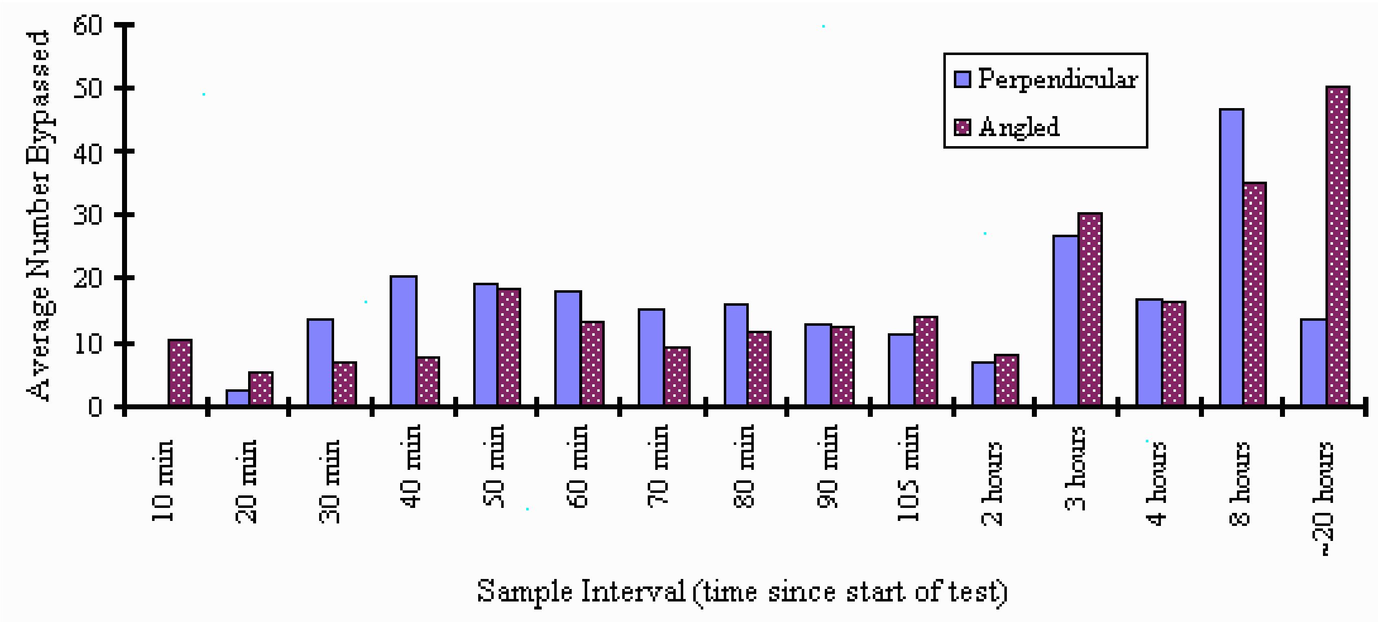

Figure 3. Movement of fall chinook salmon fry by sampling interval during in vivo tests with a modular fish screen, Spring 1996

The cumulative fish passage totals viewed over time (Figure 4) indicate that the fishes rate of passage was greatest during the first 2 hr of testing. Increases in passage were observed at the 8-hr check, which corresponds to fish movement at sundown. Very little fish passage occurred after dusk for fish in the perpendicular approach, but a noticeable increase in passage did occur for fish in the angled approach. While the perpendicular approach had greater cumulative totals for almost the entire 20 hrs, the higher passage rate for angled approach fish between dusk and dawn allowed that group to exceed the perpendicular approach fish in total percent passage.

Fish passage numbers between the two test treatments differed very little from the 1-hr check through the 4-hr check. Outside this time period, passage numbers are more widely distributed. Passage decreases over time for angled approach fish during the first 50 min and increases for perpendicular approach fish. At the end of the test, passage for angled-approach fish increased while passage for perpendicular-approach fish greatly decreased.

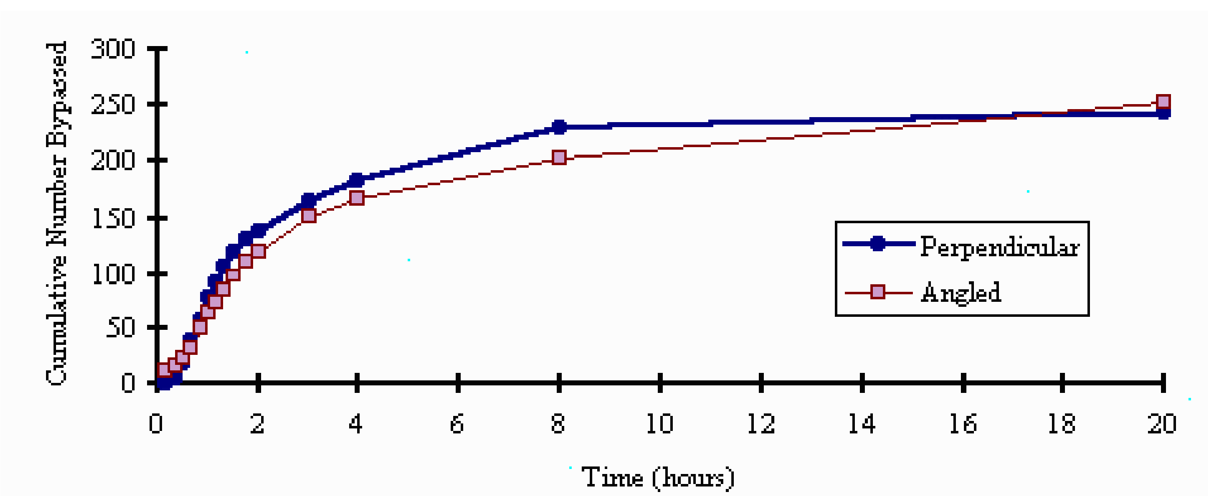

Figure 4. Average cumulative number of fish bypassed over time

ENTRAINMENT, ROLLOVER, PASSAGE

Only one fish died during passage, although several others were injured or killed due to excessive handling and human error. After the fourth angled test a single fish was found wedged under the bottom of the screen where it is attached to the floor of the forebay. No fall chinook salmon passed over, around, or through the drum screen during any test. Of the 5600 fish used, only 19 fish were not accounted for as either successfully bypassed or residual. If fish were missing at the end of a test, a search was conducted. The diffuser box and the ground around the screen were checked and the raceway was drained. No missing fish were found in the raceway or on the ground in a place indicating they may have passed the drum screen undetected. It is likely that fewer than 400 fish were introduced to the forebay at the beginning of the test.

FLOW AND VELOCITY MEASUREMENTS

Water velocity profiles in front of the screen, in the forebay, and in the fish bypass were measured with a bi-directional current meter. Approach (X component) and sweep (Y component) velocities were recorded and the resultant vectors were computed to develop flow maps (Figures 5 and 6). Vector length indicates water velocity. When the perpendicular approach was used (Figure 5), poor sweep velocity conditions occurred in front of the screen opposite the fish bypass. However, approach velocity at the screen face was not excessive and posed no threat to fish. Attraction flow to the bypass was evident in the forebay at 0.8 depth but lacking at 0.2 of the depth, especially near the diffuser screen opposite the fish bypass. Some of the velocity patterns in the forebay were the result of non-uniform flows in the diffuser area. Sweep velocity in the fish bypass slot was 0.8 fps with good velocities at both measured depths. Approach velocity at the face of the screen for the angled approach (Figure 6) was relatively uniform and did not exceed the 0.4 fps criteria. Attraction flow to the fish bypass was more evident at 0.2 depth, but also detectable at 0.8 depth. Again, velocity patterns in the screen forebay were likely affected by flow conditions in the diffuser area. Sweep velocity in the bypass slot reached 0.8 fps and was fairly uniform from top to bottom.

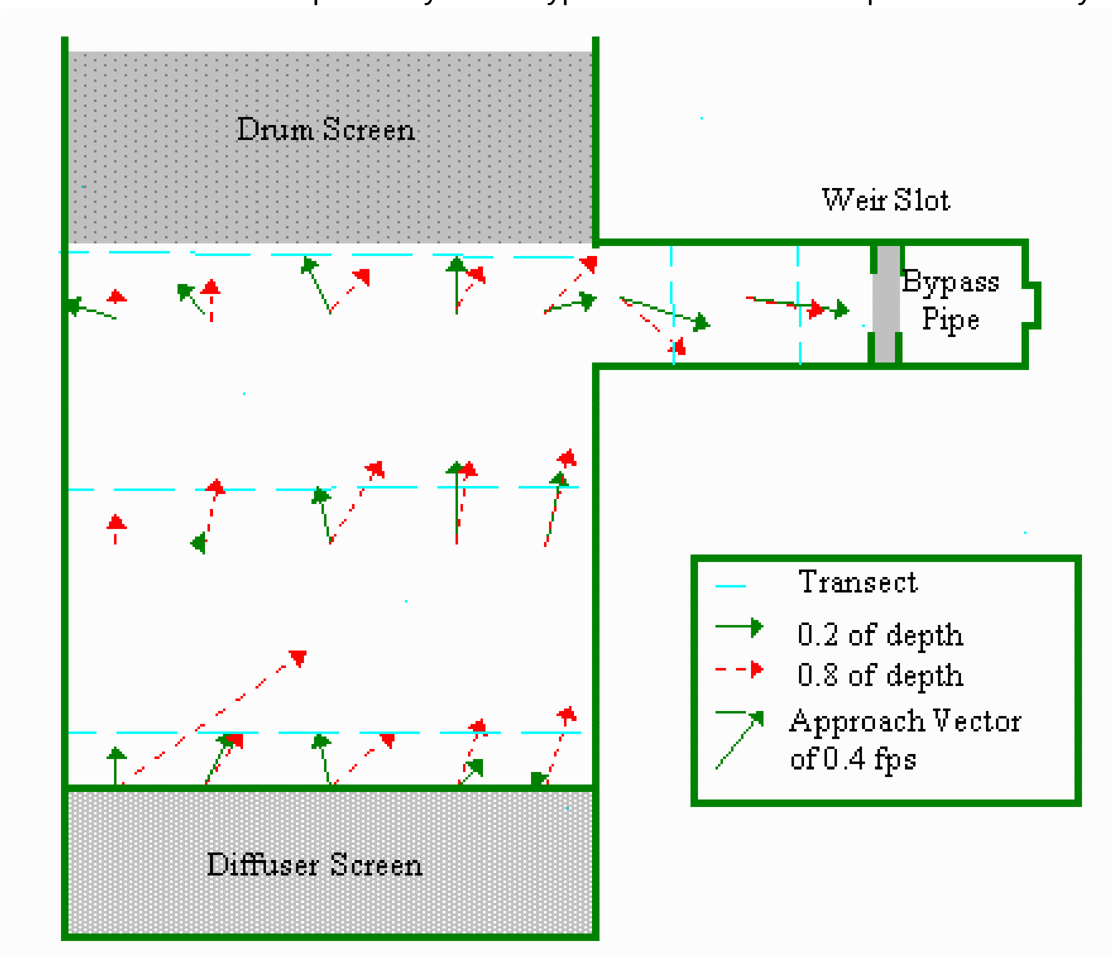

Figure 5. Perpendicular Approach Velocity Profile in Front of the Drum Screen and in the Fish Bypass Slot

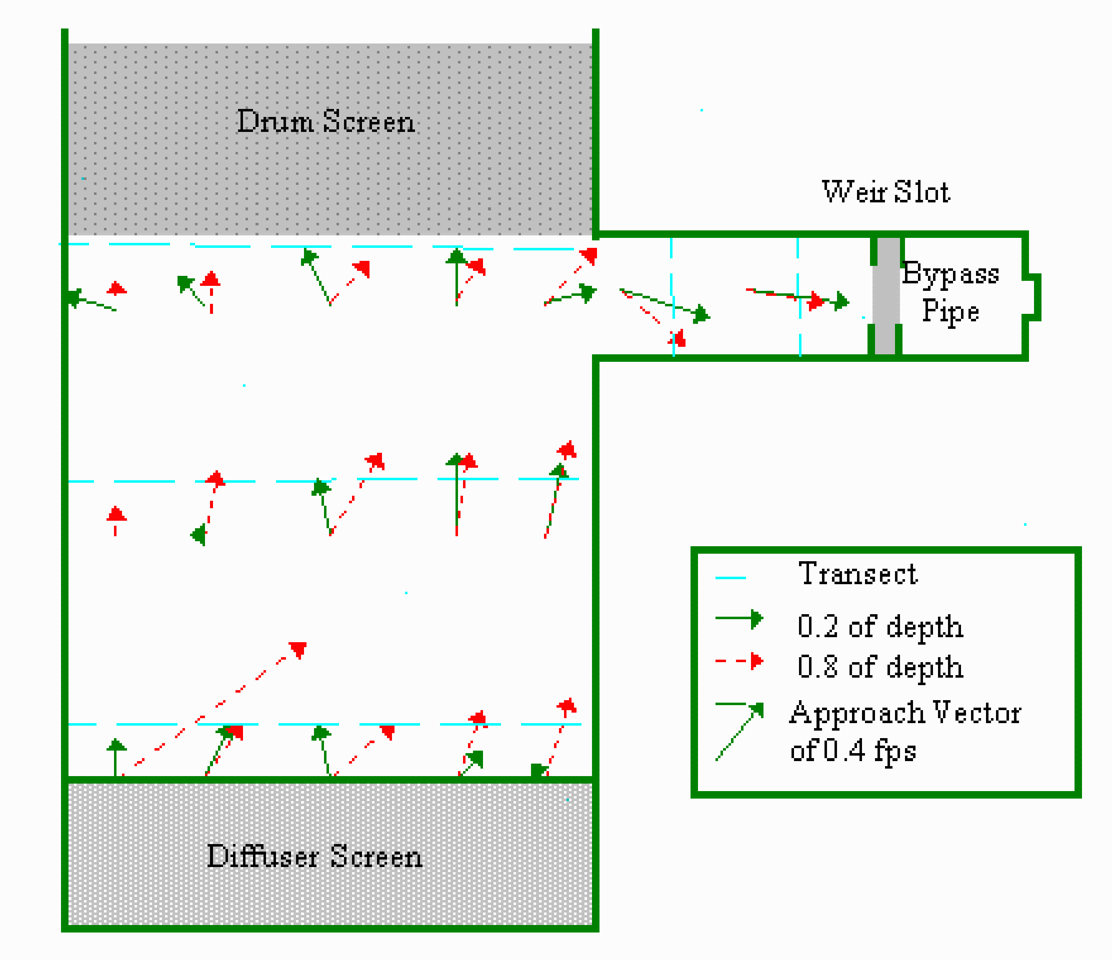

Figure 6. Angled Approach Velocity Profile in Front of the Drum Screen and in the Fish Bypass Slot

STATISTICAL ANALYSIS

With the likelihood ratio test, differences in data collected during the 14 tests were not statistically significant (*p-value* > 0.69). The likelihood ratio statistic is $\lambda = 0.15$.

Figure 7 shows the proportions of passed fish over time by approach configuration. The expected proportions under the accepted null hypothesis are denoted by the dashed line. This line was generated using the maximum likelihood estimates of the two parameters in the null model: $p=p_a=p_r=0.87$ and $kd=-0.022$. For this study, the estimated proportion of passed fish as a function of study day is

$$p_d = p - kd = 0.87 - 0.022d$$

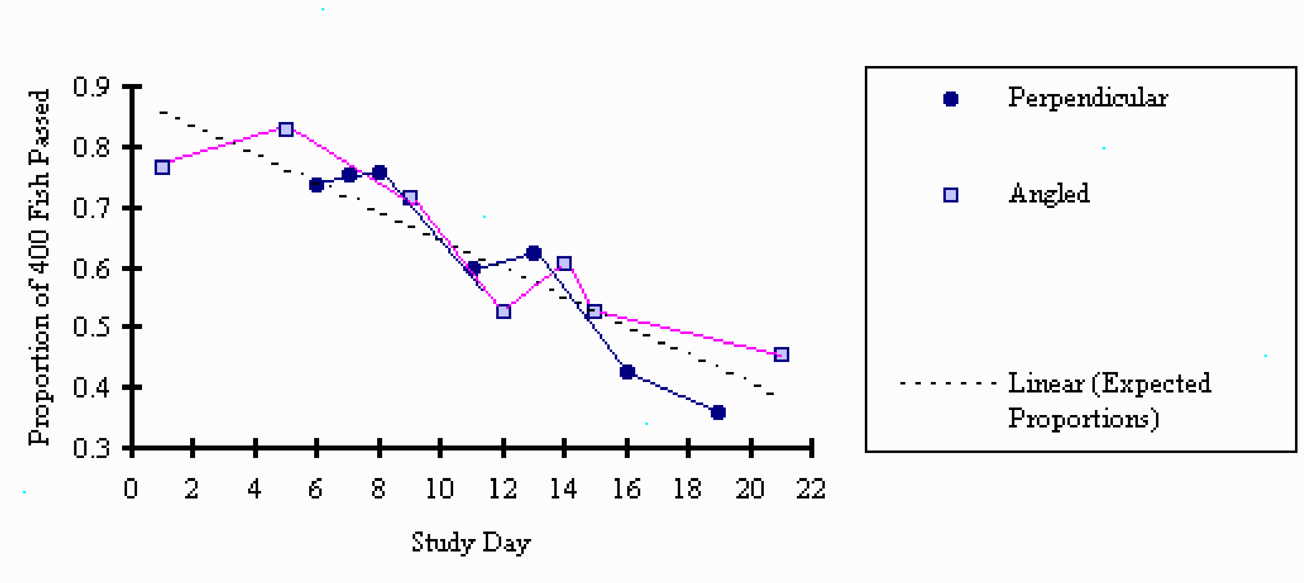

Figure 7. Sample Proportions of 400 Fish Passed by the Perpendicular and Angled Passage Treatments over the 21 Study Days. Points on the Dashed Line Denote the Expected Proportions with no Difference in Passage Approach

DISCUSSION

The purpose of this study was to determine whether a significant difference in total percent passage existed between a 6-ft screening facility built perpendicularly to canal flow (perpendicular) and an identical screening facility with the screen mounted at a 45-degree angle to the approach channel (angled). The NMFS criteria suggest some flexibility in determining whether or not a small screen needs to be "angled or perpendicular relative to flow" (Appendix, see Section K.2.a). Our test data indicate that flexibility is justified and that considerations other than biological can be given equal weight when designing or constructing a screen 6-ft wide.

Changes in movement rate patterns during our test series demonstrate that even slight changes in physiological (i.e., fish behavior, size, age) or environmental conditions (i.e., weather, water temperature, turbidity) can affect the outcome of screen evaluations. Results of one-time evaluations could cause researchers to reach erroneous conclusions. The ability to run repetitive tests under controlled conditions greatly reduces these risks and allows us to quantify the physiological changes and environmental conditions.

The low injury rate observed in fish exposed to both approach angles indicates that small fish can pass safely under test flow conditions. Safe passage of the small chinook salmon used in these tests also indicates that larger fish can safely bypass 6-ft screens with either approach angle.

The benefits of fish passage must be weighed against the costs of constructing and maintaining the screening facility. By virtue of design, a screen with an angled approach is more complex and requires more land than a screen with a perpendicular approach. Time and money needed to prepare this extra land and build the larger facility may be great enough to consider using a less expensive or more maintenance-free design. The results of our tests suggest that a drum screen 6-ft wide and mounted perpendicularly to current flow, when operated within its designed flow range for an adequate fish bypass, provides safe and effective passage conditions for fish.

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APPENDIX - JUVENILE FISH SCREEN CRITERIA[A-1]

Developed by

National Marine Fisheries Service
Environmental & Technical Services Division
Portland, Oregon
Revised February 16, 1995

[A-1] The appendix is a scanned version of the criteria provided to the authors by NMFS staff. Any inconsistencies with NMFSs documentation of these criteria result from the scanning process. Anyone needing to use these criteria should refer to an official communication from NMFS.

I. GENERAL CONSIDERATIONS:

This document provides guidelines and criteria to be used in the development of functional designs of downstream migrant fish passage facilities for hydroelectric, irrigation, and other water withdrawal projects. This material has been prepared by the National Marine Fisheries Service (NMFS) as a direct result of responsibilities for prescribing fishways (including fish screen and bypass systems) under Section 18 of the Federal Power Act, administered by the Federal Energy Regulatory Commission (FERC). This material is also applicable for projects that are undergoing consultation with the NMFS, pursuant to responsibilities for protecting fish under the Endangered Species Act (ESA). Since these guidelines and criteria are general in nature, there may be cases where site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, site- specific criteria may be added. These circumstances will be considered by NMFS on a project-by-project basis.

In designing an effective fish screen facility, the swimming ability of the fish is a primary consideration. Research has shown that swimming ability of fish varies and may depend upon a number of factors relating to the physiology of the fish, including species, size, duration of swimming time required, behavioral aspects, migrational stage, physical condition and others, in addition to water quality parameters such as dissolved oxygen concentrations, water temperature, lighting conditions, and others. For this reason, screen criteria must be expressed in general terms.

To minimize risks to anadromous fish at some locations, the NMFS may require investigation (by the project sponsors) of important and poorly defined site-specific variables that are deemed critical to development of the screen and bypass design. This investigation may include factors such as fish behavioral response to hydraulic conditions, weather conditions (ice, wind, flooding, etc.), river stage-discharge relationships, seasonal operational variability, potential for sediment and debris problems, resident fish populations, potential for creating predation opportunity, and other information. The size of salmonids present at a potential screen site usually is not known, and can change from year to year based on flow and temperature conditions. Thus, adequate data to describe the size-time relationship requires substantial sampling efforts over a number of years. The NMFS will assume that fry-sized salmonids and low water temperatures are present at all sites and apply the appropriate criteria listed below, unless adequate biological investigation proves otherwise. The burden-of-proof is the responsibility of the owner of the screen facility.

Proposed facilities which could have particularly significant impacts on fish, and new unproven juvenile fish protection designs, frequently require: 1) development of a biological basis for the concept; 2) demonstration of favorable fish behavioral response in a laboratory setting; 3) an acceptable plan for evaluating the prototype installation; and 4) an acceptable alternate plan developed concurrently for a screen and bypass system satisfying these criteria, should the prototype not adequately protect fish. Additional information on unproven juvenile fish protection devices can be found in "Experimental Fish Guidance Devices", Position Statement of the National Marine Fisheries Service, Northwest Region, January 6, l995.

Screen and bypass criteria for juvenile salmonids are provided below. Specific exceptions to these criteria occur in the design of small screen and bypass systems (less than 25 cubic feet per second). These are listed in Section K, Modified Criteria for Small Screens. Striped bass, herring, shad, and other anadromous fish species may have eggs and/or very small fry which are moved with any water current (tides, streamflows, etc.). Installations where these species are present may require special screen and/or bypass facilities, including micro-screens and require individual evaluation of the proposed project. In instances where local regulatory agencies require more stringent screening requirements for species of resident or anadromous fish, the NMFS will generally defer to the more conservative criteria.

II. GENERAL PROCEDURAL GUIDELINES

A functional design should be developed that defines type, location, size, hydraulic capacity, method of operation, and other pertinent juvenile fish screen facility characteristics. In the case of applications to be submitted to the FERC and consultations under the ESA, a functional design for juvenile (and adult) fish passage facilities must be developed and submitted as part of the application. It must reflect the NMFS input and design criteria and be acceptable to the NMFS. Functional design drawings must show all pertinent hydraulic information, including water surface elevations and flows through various areas of the structures. Functional design drawings must show general structural sizes, cross-sectional shapes, and elevations. Types of materials must be identified where they will directly affect fish. The final detailed design shall be based on the functional design, unless changes are agreed to by the NMFS.

All juvenile passage facilities shall be designed to function properly through the full range of hydraulic conditions in the lake, tidal area, or stream and in the diversion, and shall account for debris and sedimentation conditions which may occur.

III. SCREEN CRITERIA FOR JUVENILE SALMONIDS

. **Structure Placement**

1. **Stream and Rivers:**

    . **Where physically practical and biologically desirable, the screen shall be constructed at the diversion entrance** with the screen face generally parallel to river flow. Physical factors that may preclude screen construction at the diversion entrance include excess river gradient, potential for damage by large debris, and potential for heavy sedimentation. For screens constructed at the bankline, the screen face shall be aligned with the adjacent bankline and the bankline shall be shaped to smoothly match the face of the screen structure to prevent eddies in front, upstream, and downstream of the screen. If trash racks are used, sufficient hydraulic gradient is required to route juvenile fish from between the trash rack and screens to safety.

    b. **Where installation of fink screens at the diversion entrance is not desirable or impractical**, the screens may be installed in the canal downstream of the entrance at a suitable location. All screens installed downstream from the diversion entrance shall be provided with an effective bypass system approved by NMFS, designed to collect juvenile fish and safely transport them back to the river with minimum delay. The angle of the screen to flow should be adequate to effectively guide fish to the bypass (see Section F, Bypass Layout).

2. **Lakes, Reservoirs and Tidal areas:**

    . **Intakes shall be located offshore** where feasible to minimize fish contact with the facility. Water velocity from any direction toward the screen shall not exceed allowable approach velocities (see Section B, Approach Velocity). When possible, intakes shall be located in areas with sufficient sweeping velocity to minimize sediment accumulation in or around the screen and to facilitate debris removal and fish movement away from the screen face (see Section C, Sweeping Velocity).

    b. If a screened intake is used to route fish past a dam, the intake shall be designed to withdraw water from the most appropriate elevation based on providing the best juvenile fish attraction and appropriate water temperature control downstream of the project. The entire range of fore bay fluctuation shall be accommodated in design, unless otherwise approved by the NMFS.

B. **Approach velocity** - Definition: Approach velocity is the water velocity component perpendicular to and approximately three inches in front of the screen face.

1. **Salmonid fry** [less than 2.36 inches { 60.0 millimeters (mm)} in length]: The approach velocity shall not exceed 0.40 feet per second (fps) {0.12 meters per second (mps)}.
2. **Salmonid fingerling** {2.36 inches (60.0 mm) and longer}: The approach velocity shall not exceed 0.80 fps (0.24 mps)
3. The **total submerged screen area required** (excluding area affected by structural components) is calculated by dividing the maximum diverted flow by the allowable approach velocity (also see Section K, Modified Criteria for Small Screens).
4. The screen design must provide for **uniform flow distribution** over the screen surface, thereby minimizing approach velocity. This may be accomplished by providing adjustable porosity control on the downstream side of screens, unless it can be shown unequivocally (such as with a physical hydraulic model study) that localized areas of high velocity can be avoided at all flows.

C. **Sweeping Velocity**- Definition: Sweeping velocity is the water velocity component parallel and adjacent to the screen face.

1. Sweeping velocity shall **be greater than the approach velocity.** This is accomplished by angling the screen face at less than 45 relative to flow (also see Section K, Modified Criteria for Small Screens). This angle may be dictated by site specific canal geometry, hydraulic, and sediment conditions.

D. **Screen Face Material**

1. **Fry criteria** - If biological justification can not be provided to demonstrate the absence of fry-sized salmonids {less than 2.36 inches (60.0 mm)} in the vicinity of the diversion intake leading to the screen, fry will be assumed present and the following criteria apply for screen material:

    . **Perforated plate:** Screen openings shall not exceed 3/32 or 0.0938 inches (2.38 mm).

    b. **Profile bar screen:** The narrowest dimension in the screen openings, shall not exceed 0.0689 inches (1.75 mm) in the narrow direction.

    c. **Woven wire screen:** Screen openings shall not exceed **3/32 or 0.0938 inches** (2.38 mm) in the narrow direction (example: 6-14 mesh).

    d. Screen material shall provide a minimum of 27% open area.

2. **Fingerling criteria** - If biological justification can be provided to demonstrate the absence of fry-sized salmonids {less than 2.36 inches (60.0 mm)} in the vicinity of the diversion intake leading to the screen, the following criteria apply for screen material:

    . **Perforated plate:** Screen openings shall not exceed 1/4 or 0.25 inches (6.35 mm).

    b. **Profile bar screen:** The narrowest dimension in the screen openings shall not exceed 1/4 or 0.25 inches (6.35 mm) in the narrow direction.

    c. **Woven wire screen:** Screen openings shall not exceed **1/4 or 0.25** inches (6.35 mm) in the narrow direction.

d. Screen material shall provide a minimum of **40% open area**.

3. The screen material shall be corrosion resistant and sufficiently durable to maintain a smooth uniform surface with long term use.

E. **Civil Works and Structural Features**

1. The face of all **screen surfaces shall be placed flush** (to the extent possible) with any adjacent screen bay, pier noses, and walls to allow fish unimpeded movement parallel to the screen face and ready access to bypass routes.
2. Structural features shall be provided to **protect the integrity of the fish screens** from large debris. Provision of a **trash rack, log boom, sediment sluice,** and other measures may be needed. A reliable, ongoing preventative maintenance and repair program is necessary to assure facilities are kept free of debris and that screen mesh, seals, drive unit s, and other components are functioning correctly.
3. Screen surfaces shall be constructed at an angle to the approaching flow, with the downstream end of the **screen terminating at the entrance to the bypass system.**
4. The civil works shall be designed in a manner that **eliminates undesirable hydraulic effects** (such as eddies and stagnant flow zones) that may delay or injure fish or provide predator habitat or predator access. **Upstream training wall(s),** or some acceptable variation thereof, shall be utilized to control hydraulic conditions and define the angle of flow to the screen face. Large facilities **may require hydraulic modeling** to identify and correct areas of concern.

F. **Bypass Layout**

1. The **screen and bypass shall work in tandem** to move out-migrating salmonids (including adults) to the bypass outfall with a minimum of injury or delay. The bypass entrance shall be located so that it can easily be located by out-migrants. Screens placed in diversions shall be constructed with the downstream end of the **screen terminating at a bypass entrance. Multiple bypass entrances** (intermediate bypasses) shall be employed if the sweeping velocity will not move fish to the bypass within 60 seconds, assuming fish are transported at this velocity.
2. The bypass entrance and all components of the bypass system shall be of **sufficient size and hydraulic capacity to minimize the potential for debris blockage**.
3. In order to improve bypass collection efficiency for a single bank of vertically-oriented screens, a **bypass training wall** shall be located at an angle to the screens, with the bypass entrance at the apex and downstream-most point. This will aid fish movement into the bypass by creating hydraulic conditions that conform to observed fish behavior. For single or multiple vee screen configurations, training walls are not required, unless an intermediate bypass is used (see Section F, Bypass Layout, Part 1).
4. In cases where there is insufficient flow available to satisfy hydraulic requirements at the bypass entrance (entrances) for the main screens, a **secondary screen** may be required. This is a screen located in the main screen bypass which allows the prescribed bypass flow to be used to effectively attract fish into the bypass entrance(s) and then allow for all but a reduced residual bypass flow to be routed back (by pump or gravity) for the primary diversion use. The residual bypass flow (not passing through the secondary screen) would then convey fish to the bypass outfall location or other destination.
5. **Access is required** at locations in the bypass system where debris accumulations may occur.
6. The **screen civil works** floor shall be designed to allow fish to be routed back to the river safely, if the canal is dewatered. This may entail a sumped drain with a small gate and drain pipe, or similar provisions.

G. **Bypass Entrance**

1. Each bypass entrance shall be provided with **independent flow-control capability,** acceptable to NMFS.

2. The **minimum bypass entrance flow velocity** must be greater than or equal to the maximum flow velocity vector resultant upstream of the screens. A gradual and efficient acceleration of flow into the bypass entrance is required to minimize delay by out- migrants.
3. **Ambient lighting conditions** are required at, and inside of, the bypass entrance and should extend downstream to the bypass flow control.
4. The **bypass entrance** must extend from the floor to the canal water surface.

H. **Bypass Conduit Design**

1. Bypass pipes shall have **smooth surfaces** and be designed to provide conditions that minimize turbulence. Bypass conduits shall have a **smooth joint design** to minimize turbulence and the potential for fish injury and shall be satisfactory to the NMFS.
2. Fish shall **not be pumped** within the bypass system.
3. Fish shall **not be allowed to free-fall within a confined shaft** in a bypass system.
4. **Pressures in the bypass pipe** shall be equal to or above atmospheric pressures.
5. **Bends shall be avoided** in the layout of bypass pipes due to the potential for debris clogging. **Bypass pipe center-line** radius of curvature (R/D) shall be greater than or equal to 5. Greater R/D may be required for super-critical velocities.
6. Bypass pipes or open channels shall be designed to **minimize debris clogging and sediment deposition** and to facilitate cleaning as necessary. Therefore, the required pipe diameter shall be greater than or equal to 24 inches {0.610 meters (m)}, and pipe velocity shall be greater than 2.0 fps (0.610 mps), unless otherwise approved by the NMFS, for the entire operational range (also see Section K, Modified Criteria for Small Screens, Part 4).
7. **Closure valves** of any type are not allowed within the bypass pipe, unless approved by NMFS.
8. The **minimum depth** of open-channel flow in a bypass conduit shall be greater than or equal to 0.75 feet (0.23 m), unless otherwise approved by the NMFS (also see Section K, Modified Criteria for Small Screens. Part 5).
9. **Sampling facilities** installed in the bypass conduit shall not impair normal operation of the facility.
10. The bypass pipe hydraulics should not produce a **hydraulic jump** within the pipe.

I. **Bypass Outfall**

1. Bypass outfalls should be located such that **ambient river velocities** are greater than 4.0 fps (1.2 mps).
2. Bypass outfalls shall be **located to minimize avian and aquatic predation** in areas free of eddies, reverse flow, or known predator habitat.
3. Bypass outfalls shall be **located where the receiving water is of sufficient depth** (depending on the **impact velocity** and quantity of bypass flow) to ensure that fish injuries are avoided at all river and bypass flows.
4. Maximum bypass outfall impact velocity (including vertical and horizontal velocity components) shall be less than 25.0 fps 7.6 mps).
5. The bypass outfall discharge into tail race shall be designed to **avoid adult attraction or jumping injuries**.

J. **Operations and Maintenance**

1. Fish screens shall be **automatically cleaned** as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol must be effective, reliable, and satisfactory to the NMFS. Proven cleaning technologies are preferred.
2. Open channel intakes shall include a trash rack in the screen facility design which shall be kept free of debris. In certain cases, a satisfactory profile bar screen design can substitute for a trash rack.
3. The head differential to trigger screen cleaning for intermittent type cleaning systems shall be a

maximum of 0.1 feet (O.03 m) or as agreed to by the NMFS.

4. The completed screen and bypass facility shall be made available for inspection by NMFS, to verify compliance with the design and operational criteria.
5. Screen and bypass facilities shall be evaluated for biological effectiveness and to verify that hydraulic design objectives are achieved.

K. **Modified Criteria for Small Screens (Diversion flow less than 25 cfs)**

The following criteria vary from the criteria listed above and apply to smaller screens. Twenty-five cfs is an approximate cutoff; however, some smaller diversions may be required to apply more universal criteria listed above, while some larger diversions may be allowed to use the "small screen" criteria listed below. This will depend on site constraints.

1. The **screen area required** is shown in Section B, Approach velocity, Parts 1, 2 and 3. Note that "maximum applies to the greatest flow diverted, not necessarily the waver right.
2. **Screen orientation:**
   . For **screen lengths less than or equal to 4 feet**, screen orientation may be angled or perpendicular relative to flow.
   b. For **screen lengths greater than 4 feet**, screen-to-flow angles must be **less than or equal to 45 degrees** (see Section C, Sweeping velocity, Part 1).
   c. For drum screens, the **design submergence shall be 75%** of drum diameter. Submergence shall not exceed 85%, nor be less than 65% of drum diameter.
3. The **minimum bypass pipe diameter shall be 10 inches**, unless otherwise approved by NMFS.
4. The **minimum allowable pipe depth is 0.15 feet** (1.8 inches or 4.6 cm) and is controlled by designing the pipe gradient for minimum bypass flow. Questions concerning this document can be directed to NMFS Environmental and Technical Services Division Engineering staff, at 503-230-5400.

Adopted,
(original on file)
William Stelle, Jr.
Date 3-23-95
Regional Director

ADDENDUM
JUVENILE FISH SCREEN CRITERIA FOR PUMP INTAKES

Developed by
National Marine Fisheries Service
Environmental & Technical Services Division
Portland, Oregon
May 9, 1996

The following criteria serve as an addendum to current National Marine Fisheries Service gravity intake juvenile fish screen criteria. These criteria apply to new pump intake screens and existing inadequate pump intake screens, as determined by fisheries agencies with project jurisdiction.

Definitions used in Pump intake screen criteria

Pump intake screens are defined as screening devices attached directly to a pressurized diversion intake pipe. Effective screen area is calculated by subtracting screen area occluded by structural members from the total screen area. Screen mesh opening is the narrowest opening in screen mesh. Approach velocity is the calculated velocity component perpendicular to the screen face. Sweeping velocity is the flow velocity component parallel to the screen face with the pump turned off. Active pump intake screens are equipped with a cleaning system with proven cleaning capability, and are cleaned as frequently as necessary to keep the screens clean. Passive pump intake screens have no cleaning system and should only be used when the debris load is expected to be low, and

1. if a small screen (less than 1 CFS pump) is over-sized to eliminate debris impingement, and
2. where sufficient sweeping velocity exists to eliminate debris build-up on the screen surface, and
3. if the maximum diverted flow is less than .01% of the total minimum streamflow, or
4. the intake is deep in a reservoir, away from the shoreline.

Pump Intake Screen Flow Criteria

The minimum effective screen area in square feet for an active pump intake screen is calculated by dividing the maximum flow rate in cubic feet per second (CFS) by an approach velocity of 0.4 feet per second (FPS). The minimum effective screen area in square feet for a passive pump intake screen is calculated by dividing the maximum flow rate in CFS by an approach velocity of 0.2 FPS. Certain site conditions may allow for a waiver of the 0.2 UPS approach velocity criteria and allow a passive screen to be installed using 0.4 FPS as design criteria. These cases will be considered on a site-by-site basis by the fisheries agencies.

If fry-sized salmonids (i.e. less than 60 millimeter fork length) are not ever present at the site and larger juvenile salmonids are present (as determined by agency biologists), approach velocity shall not exceed 0.8 FPS for active pump intake screens, or 0.4 FPS for passive pump intake screens. The allowable flow should be distributed to achieve uniform approach velocity (plus or minus 10%) over the entire screen area. Additional screen area or flow baffling may be required to account for designs with non-uniform approach velocity.

Pump intake Screen Mesh Material

Screen mesh openings shall not exceed 3/32 inch (2.38 mm) for woven wire or perforated plate screens, or 0.0689 inch (1.75 mm) for profile wire screens, with a minimum 27% open area. If fry-sized salmonids are never present at the site (by determination of agency biologists) screen mesh openings shall not exceed 1/4 inch (6.35 mm) for woven wire, perforated plate screens, or profile wire screens, with a minimum of 40% open area.

Screen mesh material and support structure shall work in tandem to be sufficiently durable to withstand the rigors of the installation site. No gaps greater than 3/32 inch shall exist in any type screen mesh or at points of mesh attachment. Special mesh materials that inhibit aquatic growth may be required at some sites.

Pump Intake Screen Location

When possible, pump intake screens shall be placed in locations with sufficient sweeping velocity to sweep away debris removed from the screen face. Pump intake screens shall be submerged to a depth of at least one screen radius below the minimum water surface, with a minimum of one screen radius clearance between screen surfaces and adjacent natural or constructed features. A clear escape route should exist for fish that approach the intake volitionally or otherwise. For example, if a pump intake is located off of the river (such as in an intake lagoon), a conventional open channel screen should be considered, placed in the channel or at the edge of the river. Intakes in reservoirs should be as deep as practical, to reduce the numbers of juvenile salmonids that approach the intake. Adverse alterations to riverine habitat shall be minimized.

Pump Intake Screen Protection

Pump intake screens shall be protected from heavy debris, icing and other conditions that may compromise screen integrity. Protection can be provided by using log booms, trash racks or mechanisms for removing the intake from the river during adverse conditions. An inspection and maintenance plan for the pump intake screen is required, to ensure that the screen is operating as designed per these criteria.