Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen—The Farmers Screen

By Matthew G. Mesa, Brien P. Rose, and Elizabeth S. Copeland

Open-File Report 2010–1042

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2010

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit *http://www.usgs.gov* or call 1-888-ASK-USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit *http://www.usgs.gov/pubprod*

To order this and other USGS information products, visit *http://store.usgs.gov*

Suggested citation:
Mesa, M.G., Rose, B.P., and Copeland, E.S., 2010, Biological evaluations of an off-stream channel, horizontal flat-plate fish screen—The Farmers Screen: U.S. Geological Survey Open-File Report 2010–1042, 16 p.

Contents

Figures

Tables

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
	Flow rate	
centimeter per second (cm/s)	30.48	feet per second
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)

Abbreviations and Symbols

Abbreviation and Symbol	Meaning
AV	approach velocity
CRRL	Columbia River Research Laboratory
FID	Farmers Irrigation District
FL	fork length
h	hour
mg/L	milligram per liter
NMFS	National Marine Fisheries Service
NV	normal velocity

s	second
SV	sweeping velocity
UV	ultraviolet
Z	water depth
<	less than
>	greater than

Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen—The Farmers Screen

By Matthew G. Mesa, Brien P. Rose, and Elizabeth S. Copeland

Abstract

Screens are commonly installed at water diversion sites to reduce entrainment of fish. Recently, the Farmers Irrigation District (Oregon) developed a flat-plate screen design that offers passive operation and may result in reduced installation and operation costs to irrigators. To evaluate the performance (its biological effect on fish) of this type of screen, two size classes of juvenile coho salmon (*Oncorhynchus kistuch*) were released over a small version of this screen in the field. The screen was evaluated over a range of inflow [0.02 to 0.42 m^3/s (cubic meters per second)] and diversion flows (0.02 to 0.34 m^3/s) at different weir wall heights. The mean approach velocities ranged from 0 to 5 cm/s (centimeters per second) and mean sweeping velocities ranged from 36 to 178 cm/s. Water depths over the screen surface ranged from 1 to 25 centimeters and were directly related to weir wall height and inflow. Passage of juvenile coho salmon over the screen under a variety of hydraulic conditions did not severely injure them or cause delayed mortality. This occurred even though many fish contacted the screen surface during passage. No fish were observed becoming impinged on the screen surface. To determine whether fish would refuse to pass over the screen and swim back upstream upon encountering the leading edge of the screen under different hydraulic conditions, smolting coho salmon and steelhead trout (*O. mykiss*) were released over a modular screen apparatus that had 34 m of wooden flume connected to a 3.5-m long section of the Farmers Screen. Overall, 81% and 91% of the fish volitionally traversed the apparatus within 5 and 25 minutes from their release and only one of the 275 fish released

swam back upstream after encountering the screen. When operated within its design criteria (diversion flows of about 0.28 m^3/s), the screen provided safe and efficient downstream passage of juvenile salmonids under a variety of hydraulic conditions. However, we do not recommend operating the screen at inflows less than 0.14 m^3/s (5 ft^3/s) because water depth can get quite shallow and the screen can completely dewater, particularly at very low flows.

Introduction

Diversions from natural or manmade waterways are common in the United States and the water is used for many purposes. Many diversion structures are fitted with screens meant to prevent fish and other aquatic life from becoming entrained in the diversion, injured, or killed. However, many thousands of water diversions remain unscreened. Some screening technology (for example, submersible traveling screens or rotary drum screens) and design criteria meant to protect fish (National Marine Fisheries Service [NMFS] 2008)are relatively expensive and require frequent maintenance to operate properly (McMichael and others, 2004), which can limit the installation of screens in areas where they are needed. Recently, however, the development of unique horizontal flat plate fish screens offer designs that may be less expensive to install, offer simpler, more passive operation, and may have fewer detrimental effects on aquatic communities. Research on the hydraulic characteristics and biological effects of some flat plate screens has been promising (Beyers and Bestgen 2001; Frizell and Mefford 2001; and Rose and Mesa, 2008), but more work is needed to fully evaluate their performance. Evaluating different designs and sizes of horizontal flat plate screens, both in the laboratory and in the field, would allow further verification of their performance, provide data for comparison with criteria for more traditional fish screens, and perhaps facilitate their installation.

We evaluated the hydraulic and biological performance of a newly developed, off-stream channel horizontal flat plate fish screen, also known as the Farmers Screen. These screens, designed over a 10-year period by personnel from the Farmers Irrigation District in Hood River, Oregon, have a higher rate of horizontal movement of water across the screen (sweeping velocity, SV) relative to the rate of movement of water through the screen (approach velocity, AV), good self-cleaning characteristics, the potential for reduced impingement, injury, and entrainment of fish, and may provide lower installation and maintenance costs. The screens are manufactured in various sizes; a large version, designed to accommodate flows as large as 2.3 m^3/s (80 ft^3/s), has been subjected to hydraulic, debris-loading, and biological tests to evaluate injury and mortality to juvenile salmonids, including Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*). The test results showed that the large Farmers Screen did not cause injury or mortality to fish when operated in accordance with its design parameters (Farmers Irrigation District 2003). Smaller versions of this screen have not been tested, however, and such evaluations would help to more fully evaluate the performance of these alternative technology screens.

The U.S. Geological Survey's Columbia River Research Laboratory (CRRL) conducted field experiments to assess (1) the hydraulic performance of a small version of the Farmers Screen under various environmental conditions, (2) the effects of downstream passage of fish over the screen on injury and delayed mortality, and (3) whether fish would refuse to pass over the screen under different hydraulic conditions. This paper describes the study methods and the results of those experiments.

Study Methods

The screen evaluated was located at the Oxbow Fish Hatchery in Cascade Locks, Oregon (fig. 1). The screen is on a side-channel of Herman Creek, a tributary of the Columbia River, and is designed to divert 0.28 m^3/s (10 ft^3/s) of water. The installation is similar to other Farmers Screens that have already been installed in the Pacific Northwest. For a complete description of this screen and of the Farmers Screen in general, see *http://www.farmerscreen.org/*. For purposes of this report, we refer to the screen as the Herman Creek screen.

To assess the hydraulic performance of the Herman Creek screen, we adjusted the inflow entering the screen, measured the inflow and water depth (Z), diversion discharge, and bypass discharge, and calculated mean SV, AV, and normal velocity (NV, which is the AV multiplied by the percent open area of the screen, or AV × 0.5) under different weir wall heights. After most of these measurements, we experimentally released fish over the screen (see below). We evaluated the screen under four weir wall heights (that is, 4, 11, 13, and 20 cm; or 1.6, 4.3, 5.1, and 7.8 in.) and at inflows ranging from 0.02 to 0.42 m^3/s (0.71 to 14.8 ft^3/s).

To assess the biological performance of the Herman Creek screen, we experimentally released groups of juvenile coho salmon (*O. kistuch*) over the screen under different hydraulic conditions and quantified any injuries to the integument of the fish and documented short-term delayed mortality. Our test fish were from the Oxbow Hatchery and we evaluated two size groups, large [85–145 mm FL (fork length)] and small (54–78 mm FL), in two separate sets of trials. Fish that passed over the screen (treatment fish) were released in groups of 10, at a distance of 1–2 m above the upper edge of the screen, and were recaptured in a net below the bypass outfall. Control fish were released into the bypass outfall and captured in a net and held for several minutes to simulate the time it took most treatment fish to pass over the screen. We used a fluorescein dye method described by Noga and Udomkusonsri (2002) to determine the extent of ulceration on the skin, eyes, and fins of each fish. After capture, both groups of fish were euthanized in a lethal dose of MS-222 (200 mg/L), rinsed in a freshwater bath for 1 minute, and then placed in a solution of fluorescein dye (fluorescein disodium salt at 20 mg/L). After 6 minutes, fish were removed from the dye and rinsed in three separate freshwater baths over 3 minutes to remove excess dye. Images were taken of both sides of each fish in a dark box under ultraviolet (UV) light using a digital camera with a 200-mm macro lens. The UV lights were placed at 45° angles to the side of the fish and a yellow barrier filter was used to eliminate the blue auto-fluorescence. Images were imported into Adobe Photoshop® CS3 and the body surface area and area of fluorescence was measured on each side of a fish. The percent body surface area of a fish that was injured was derived by dividing the total area of fluorescence by the total body surface area. This included the two sides and most, but not all, of the dorsal and ventral surfaces of the fish. We calculated the mean (and SD) body surface area that was injured for each release group and compared control and treatment fish using two-sample, one-tailed *t*-tests. We were interested in whether the mean level of injury in treatment fish was significantly higher than background levels of control fish. The level of significance was set at $P < 0.05$.

To assess delayed mortality after passage, additional fish were released in the same manner as described above but were transported to holding tanks after being collected in the bypass outfall. Fish were monitored for 24–48 h after passage and handling and the number of fish that died was compared between treatment and control groups. Mortality tests were conducted for most, but not all, of the same hydraulic conditions as injury tests.

The treatment fish passing over the screen were videotaped using three underwater cameras mounted to one edge of the screen. The system was not designed to cover the entire screen area, and each camera provided only a partial, upstream view of the screen. Video files were reviewed in slow motion, and the approximate number of times fish contacted the screen, their orientation to the current during passage, and their general depth of passage were recorded. Control fish were not videotaped.

To evaluate whether fish would refuse to pass over the screen upon encountering the leading edge under different hydraulic conditions, we constructed a modular screen apparatus that had 34 m (112 ft) of wooden flume (46 cm wide by 36 cm deep) connected to a 3.5 m (10 ft) long section of the Farmers Screen (Fig. 2). The purpose of the long flume was to provide fish with plenty of distance between their release point (at the upstream end of the flume) and the upstream edge of the screen so they could orient themselves and move downstream somewhat naturally. The flume received water from the outflow of the Herman Creek Screen and was designed so that water velocities were slower in the upstream half of the flume than in the downstream half. We installed a trap on the downstream end of the screen to capture the fish.

We used yearling coho salmon (113 – 161 mm FL) from the Oxbow State Fish Hatchery (Oregon) and Skamania-stock steelhead (134 – 260 mm FL) from the Bonneville Fish hatchery (Oregon) for tests. We used fish presumably undergoing the process of smoltification to maximize the probability that they would have a strong desire to migrate downstream. All of our test fish were large and silvery with faint or non-existent parr marks. These fish should have had a relatively strong swimming ability (compared to smaller fish) and thus would be most likely to reject the screen if conditions posed a behavioral obstacle. Normally, these fish would have been released from the hatcheries during mid-April to early May. Prior to testing, all fish were held in large tanks at the Oxbow State Fish Hatchery and water temperatures were monitored daily.

On the day of testing, we first established the hydraulic conditions for the test, including inflow volume, water depth, AV, and SV over the screen, and water velocity and depths at several locations throughout the flume. Our intent was to test fish under a variety of hydraulic conditions over the screen.

We then removed ten fish from their holding tank, placed them in a 19-L bucket with water, transported them from the hatchery to the test facility (about 2 km), and gently released them at the upstream end of the flume. Fish were allowed 20 minutes to volitionally migrate down the flume and pass over the screen. After 20 minutes, we gently prodded any fish that remained in the upper 3 m of the flume until they moved downstream. We conducted three to four releases of about 10 fish each, for a total of 20 – 40 fish released for each species under the different hydraulic conditions.

An observer was stationed on an elevated platform slightly upstream of the fish screen to record the behavior and passage timing of fish as they approached the screen. For each of five consecutive 5-minute periods, we recorded the number of fish that encountered the screen and whether they passed over the screen or refused to (i.e., they turned and swam back upstream). For our analysis, we pooled data from the release groups for each species and hydraulic scenario and determined the proportion of fish that passed over or rejected the screen for each time period. We also tallied data from each time period and determined the proportion of fish that passed over the screen within 25 minutes of their release.

Results of Field Experiments

Hydraulic conditions measured at the Herman Creek screen and the numbers of coho salmon released for injury and delayed mortality assessments are summarized in table 1. Diversion discharges (the volume of water collected from the screen and sent to the hatchery) comprised from 65 to 100% of the inflow rates. Mean AVs estimated for the entire screen ranged from 0 to 5 cm/s (0 to 0.16 ft/s) and for individual sections of the screen never exceeded 6 cm/s (0.20 ft/s). Mean NVs ranged from 0 to 10 cm/s (0 to 0.33 ft/s) and varied along the length of the screen (fig. 3). Mean SVs ranged from 36 to 178 cm/s (1.2 to 5.8 ft/s) and generally were faster at the upstream edge and slower at the downstream edge of the screening panels. Mean SVs were usually at least 32 times higher than AVs for all conditions tested. The mean Z ranged from 1 to 25 cm (0.39 to 9.8 in.) and generally was deeper at the upstream than at the downstream end of the screen. Mean depths were directly related to weir wall height and inflow and were inversely related to diversion discharge, mean SVs were inversely related to weir wall height and diversion discharge and were directly related to inflow, and diversion discharge was related to several variables (table 2). “Hot spots”, or localized areas of high AV with spiraling flow, were not observed during any of our tests.

Overall, the injury rates of fish after passage over the Herman Creek screen were low, and severe injuries to the skin, eyes, and fins of both size cohorts were not observed. For large fish, the mean percentage of body surface area that was injured varied by release group and ranged from about 0.5 to 2.5% (fig. 4). The mean percentage of body surface area that was injured in treatment fish was significantly higher than that of control fish for two test conditions (*t*-tests, $P < 0.05$; fig. 4), but the magnitude of these differences was small (< 1%). For small fish, the mean percentage of body surface area that was injured ranged from about 0.4 to 3.0% (fig. 5). The mean percentage of body surface area that was injured in treatment fish was significantly higher than that in control fish for one test condition (fig. 5), but again, the magnitude of this difference was small. One small fish, shown as an outlier in figure 5 with about 60% of its body surface area injured, probably was injured by something other than passage over the screen. For delayed mortality after passage, we tested 849 fish in total and none died within 24–48 h of passage or handling and only one control fish died.

For large fish, the mean number of times fish contacted the screen surface ranged from 0.15 to 0.72 per fish observed (table 3). During passage, most fish remained low in the water column near the screen surface (table 3). Fish were oriented either upstream or downstream during passage, with no clear relation to the hydraulic conditions (table 3). For small fish, the mean number of times fish contacted the screen surface ranged from 0.26 to 0.62 per fish observed (table 4). Again, most fish remained low in the water column and near the screen surface during passage. Most fish were oriented upstream during passage.

To evaluate the behavioral responses and travel time of juvenile salmonids approaching and passing over the screen, we released a total of 173 coho salmon and 102 steelhead trout in the modular screen apparatus under a variety of hydraulic conditions (table 5). In general, the hydraulic conditions in the modular screen system were similar to those recorded in the Herman Creek screen. For example, mean AVs estimated for the entire screen ranged from 1 to 3 cm/s (0.03 to 0.10 ft/s) and Z ranged from 15 to 25 cm (0.5 to 0.8 ft). Mean SVs ranged from 102 to 150 cm/s (3.3 to 4.9 ft/s) and were at least 32 times higher than AVs for all of our tests. In the flume, mean water velocities ranged from 60 to 79 cm/s^2 (2.0 to 2.6 ft/s) in the upstream half of the flume and from 85 to 104 cm/s^2 (2.8 to 3.4 ft/s) in the downstream half of the flume. Mean values of Z in the flume ranged from 23 to 31 cm (0.8 to 1.0 ft). For coho salmon, from 75 – 95% of the fish approached and passed over the screen within 5 minutes of their release, depending on hydraulic conditions (Table 5). Within 20 minutes, the percentages of fish that quickly passed over the screen increased to 82 – 98%. After 20 minutes, 12 fish remained upstream in the flume and were gently prodded to move downstream; all of these fish passed over the screen without hesitation. For steelhead trout, from 47 – 90% of the fish approached and passed over the screen within 5 minutes of their release, depending on hydraulic conditions (Table 5). Within 20 minutes, the percentages of fish that quickly passed over the screen increased to 79 – 95%. After 20 minutes, 11 fish (11%) were coerced downstream from the upper 3 m of the flume and one fish turned and swam back upstream after it encountered the screen. However, this fish returned to the screen within ten minutes and successfully passed. Overall, 99.6% of the fish we observed passed over the screen without hesitation or delay.

Biological Evaluation of Experimental Results

The results of our experiments indicate that passage of juvenile coho salmon over the Herman Creek screen under a variety of hydraulic conditions did not severely injure them, cause delayed mortality, or delay their migration. This occurred even though most fish passed over the screen near the screen surface, many contacted the screen during passage, and they were oriented to the current in a variety of directions. However, we never observed fish becoming impinged on the screen surface (that is, >1 s contact with the screen). The screen showed good self-cleaning performance and never had problems with debris loading. Our results are similar to those of Rose and Mesa (2008), who also reported minimal injuries and low mortality of rainbow trout after passage over backwatered and inverted-weir horizontal flat plate screens in Oregon. Other studies evaluated various designs of vertically oriented screens and reported results similar to ours (Danley and others, 2002; Zydlewski and Johnson 2002).

The injuries observed in our fish—both treatment and control groups—were minor and indicate that fish had some trauma to the integument prior to testing and that our holding and handling procedures probably caused more trauma. The fluorescein dye method was effective for detecting injuries to the integument of fish and revealed that all of them had some level of injury after testing. As stated previously, however, all injuries were minor and any differences in mean injury rates between treatment and control groups were small, which makes it difficult to ascribe any biological significance to the injuries we observed. Further, and perhaps more importantly, none of our tests would have exceeded the performance standards for safe passage of fish over conventional screen systems as established by NMFS. For example, performance standards set by NMFS include less than 0.5% mortality and 2% injury rate (that is, the percent of a sample that is injured) for salmonid smolts, and that at least 90% of salmonids that encounter a screened water diversion are bypassed within 24 h

(Bryan Nordlund, NMFS, written communication, 2010). The agency defines injury as visual trauma (including but not limited to hemorrhaging, open wounds without fungus growth, gill damage, bruising greater than 0.5 cm in diameter), loss of equilibrium, or greater than 20% descaling on one side (Bryan Nordlund, NMFS, written communication., 2009). Because none of our fish showed such injuries, mortality was lower than 0.5%, and virtually all fish traveled over the screen without hesitation or delay, the Herman Creek screen would surpass these NMFS standards. Although the performance standards discussed here are for other types of screens, they do indicate that screens like the one at Herman Creek probably would, at a minimum, meet federal regulatory standards.

The ability of the Herman Creek screen to safely and efficiently pass fish at water depths ranging from 7 to 25 cm was largely due to achieving a high ratio of SV to AV (30:1–60:1) under a variety of diversion scenarios. These ratios were substantially higher than the SV criteria established by NMFS for horizontal screens, which only require that downstream SVs be higher than AVs for the entire length of the screen (NMFS 2008). The combination of high SVs and low AVs facilitated quick downstream fish passage and eliminated impingements, results similar to Beyers and Bestgen (2001). That most fish passed over the screen near the screen surface—regardless of water depth—suggests that the 30 cm water depth criteria established for horizontal screens (NMFS 2008) could be relaxed for smaller screens like the one at Herman Creek. Although we safely passed fish over the screen at a depth of only 7 cm, the number of screen contacts per fish increased at this shallow depth for large, but not small, fish. Even though the screen contact rate was not related to the extent or severity of injuries, operating the screen at water depths near 7 cm seems too shallow, particularly under high flow conditions. Thus, although our results suggest that the Herman Creek screen can be operated effectively at water depths less than 30 cm, we cannot unequivocally recommend a single, specific minimum depth for this screen.

Rather, a range of minimum depths, perhaps from 15–20 cm, would probably provide safe passage of fish under most circumstances.

Despite the advantages of the Herman Creek screen for protecting fish populations, there are some things to consider when interpreting our results. First, we were unable to evaluate all possible hydraulic conditions on screen performance, fish injury, and mortality. Although we believe our evaluations were realistic because they encompassed typical diversion scenarios, there may be other flow conditions we missed that are relevant to fish passage and safety. Second, only one species of fish was tested for the screen evaluations and our results may not be applicable to other species. The two size groups of juvenile coho salmon used in our experiments probably were good surrogates for other salmonids of similar size. Extrapolation of our results to other fishes, such as juvenile lampreys or salmonids undergoing smoltification, seems inappropriate and would require further testing. Next, our video analyses were not rigorous and our camera installation was meant to provide qualitative information on the behavior of fish as they passed over the screen. Even though we used three cameras, we had limited fields of view and it was often difficult to see because of water turbidity, sunlight, or other factors. Although we are confident that the data we did collect were representative of fish behavior during passage, more detailed analyses will require further work. Finally, we evaluated only the effects of downstream passage on juvenile fish. Further testing would be required to assess the effects of this screen type on fish migrating upstream across the screen surface.

Conclusions

When operated within its design criteria—diversion flows of about 0.28 m^3/s or 10 ft^3/s— the Herman Creek screen provided safe and effective downstream passage of juvenile coho salmon under a variety of hydraulic conditions. We do not recommend operating the Herman Creek screen at inflows lower than 5 ft^3/s because water depth can get quite shallow and the screen can completely dewater, particularly at very low flows. If the screen is operated at inflows lower than 5 ft^3/s, caution must be used to avoid diverting an excessive amount of water, which can lead to shallow depths, insufficient bypass flow, and perhaps screen dewatering. Finally, we do not know the fate of fish that pass over the screen, enter the bypass channel, and are diverted back to the Columbia River. It is possible that passage through these areas is a stressful and disorienting event for fish, which could make them vulnerable to hazards that exist downstream, such as predation by fish or birds. This idea is not unique to the Herman Creek screen, but is relevant for many types of diversions and obstacles fish may encounter in the wild. Further research would be necessary to address this issue.

Acknowledgments

We thank Les Perkins, Julie Davies O'Shea, and Daniel Kleinsmith of The Farmers Conservation Alliance for financial and technical support; Jerry Bryan for his expertise on the Farmers Screen and advice; Duane Banks and his staff from the Oxbow Fish Hatchery for use of their facility and technical assistance; Michelle Day and Larry Swenson of NMFS for early discussions and advice on our study; and staff from the Columbia River Research Laboratory for their assistance in the field.

References

Beyers, D.W., and Bestgen, K.R., 2001, Bull trout performance in a horizontal flat plate screen: Final report to the Bureau of Reclamation, Water Resources Research Group, Denver, Colorado.

Danley, M.L., Mayr, S.D., Young, P.S., and Cech, J.J., Jr., 2002, Swimming performance and physiological stress responses of splittail exposed to a fish screen: North American Journal of Fisheries Management, v. 22, p. 1241–1249.

Farmers Irrigation District (FID), 2003, Draft data report of the evaluation of overshot horizontal flat plate fish screen, Farmers Canal, Hood River, Oregon.

Frizell, K., and Mefford, B., 2001, Hydraulic performance of a horizontal flat plate screen: Final report to the Bureau of Reclamation, Water Resources Research Group, Denver, Colorado.

McMichael, G.A., Vucelick, J.A., Albernathy, C.S., and Neitzel D.A., 2004, Comparing fish screen performance to physical design criteria: Fisheries, v. 29, chap. 7, p. 10–16.

National Marine Fisheries Service (NMFS). 2008. Anadromous salmonid passage facility design:

NMFS, Northwest Region, Portland, Oregon.

Noga, E.J., and Udomkusonsri, P., 2002, Fluorescein: a rapid, sensitive, nonlethal method for detecting skin ulceration in fish: Veterinary Pathology, v. 39, p. 726–731.

Rose, B.P., and Mesa, M.G., 2008, Field-base evaluations of horizontal flat plate fish screens: North American Journal of Fisheries Management, v. 28, p. 1702–1713.

Zydlewski, G.B., and Johnson, J.R., 2002, Response of bull trout fry to four types of water diversion screens: North American Journal of Fisheries Management, v. 22, p. 1276–1282.

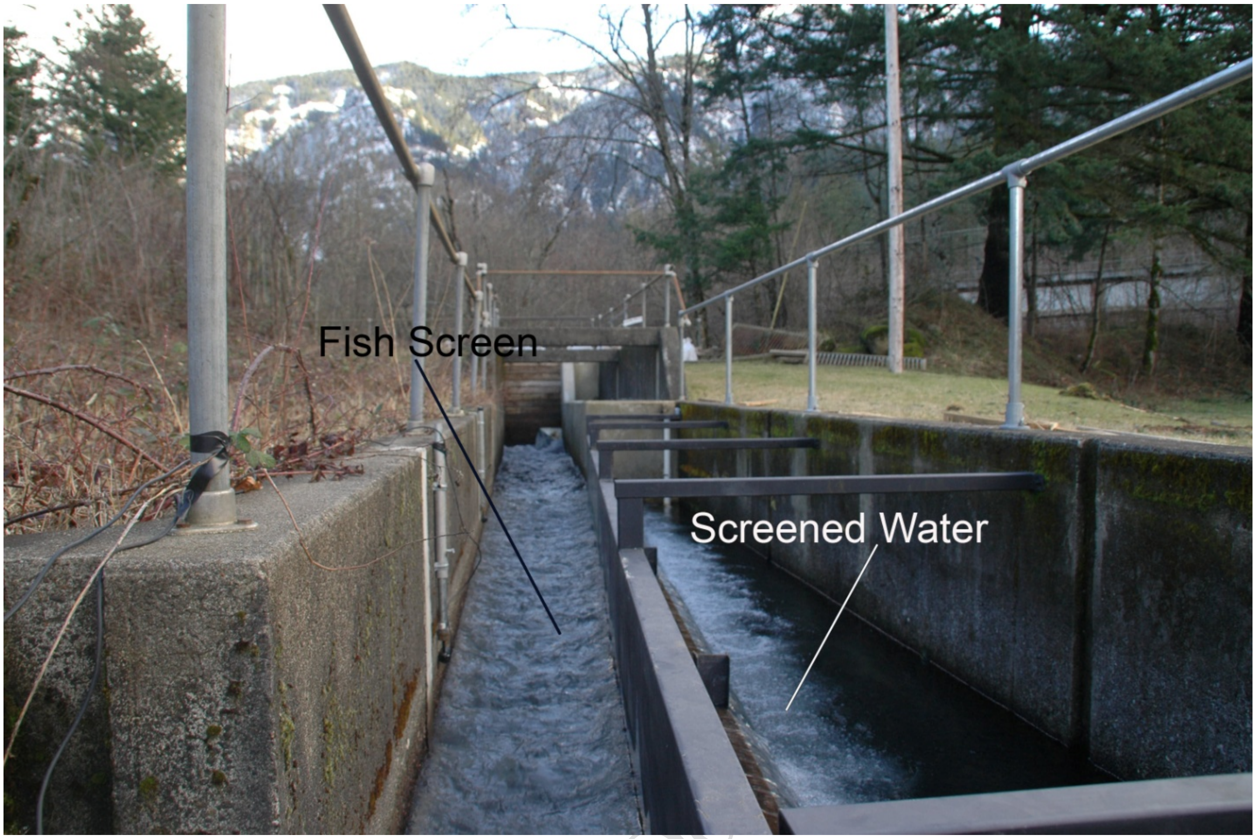

Figure 1. Photograph of the Herman Creek Screen, looking upstream, at the Oxbow Fish Hatchery, Cascade Locks, Oregon. Photograph taken by Brien P. Rose.

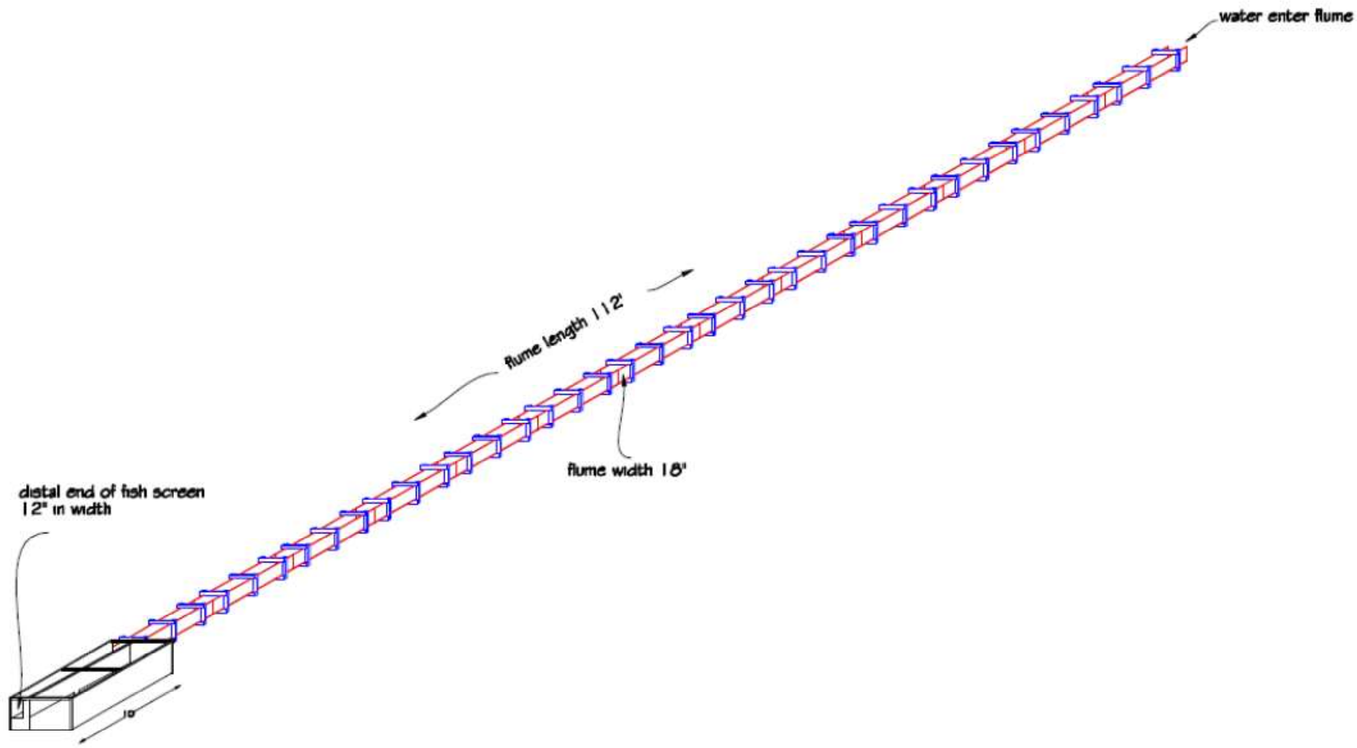

Figure 2. Schematic of the modular screen apparatus used to evaluate the behavioral responses and travel time of juvenile salmonids passing over the screen. The modular screen apparatus consisted of a 34 m (112 ft) of wooden flume connected to a 3.5-m (10 ft) long section of the Farmers Screen.

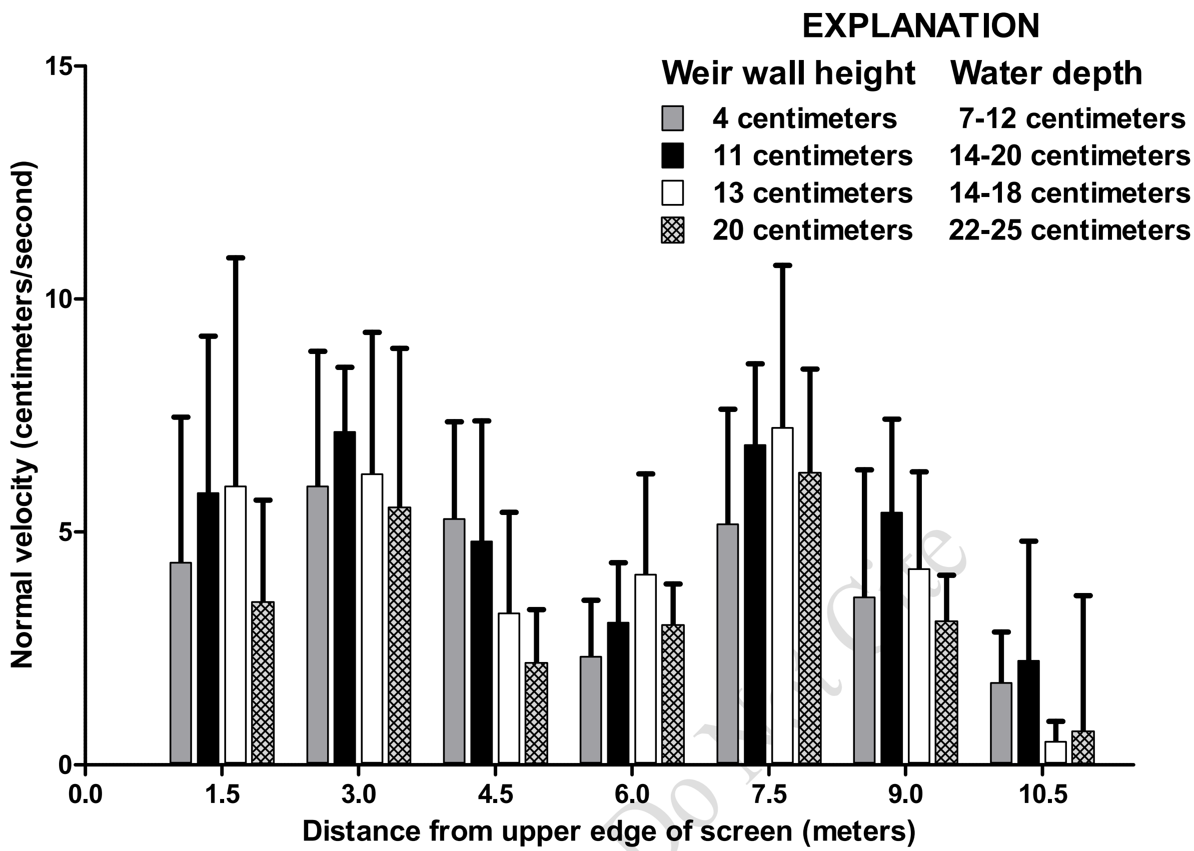

Figure3. Mean normal velocities (approach velocities corrected for the net open area of the screen) estimated for different sections of the Herman Creek screen relative to weir wall height and water depth (in parentheses), 2009. The whiskers represent the standard deviations of the estimates.

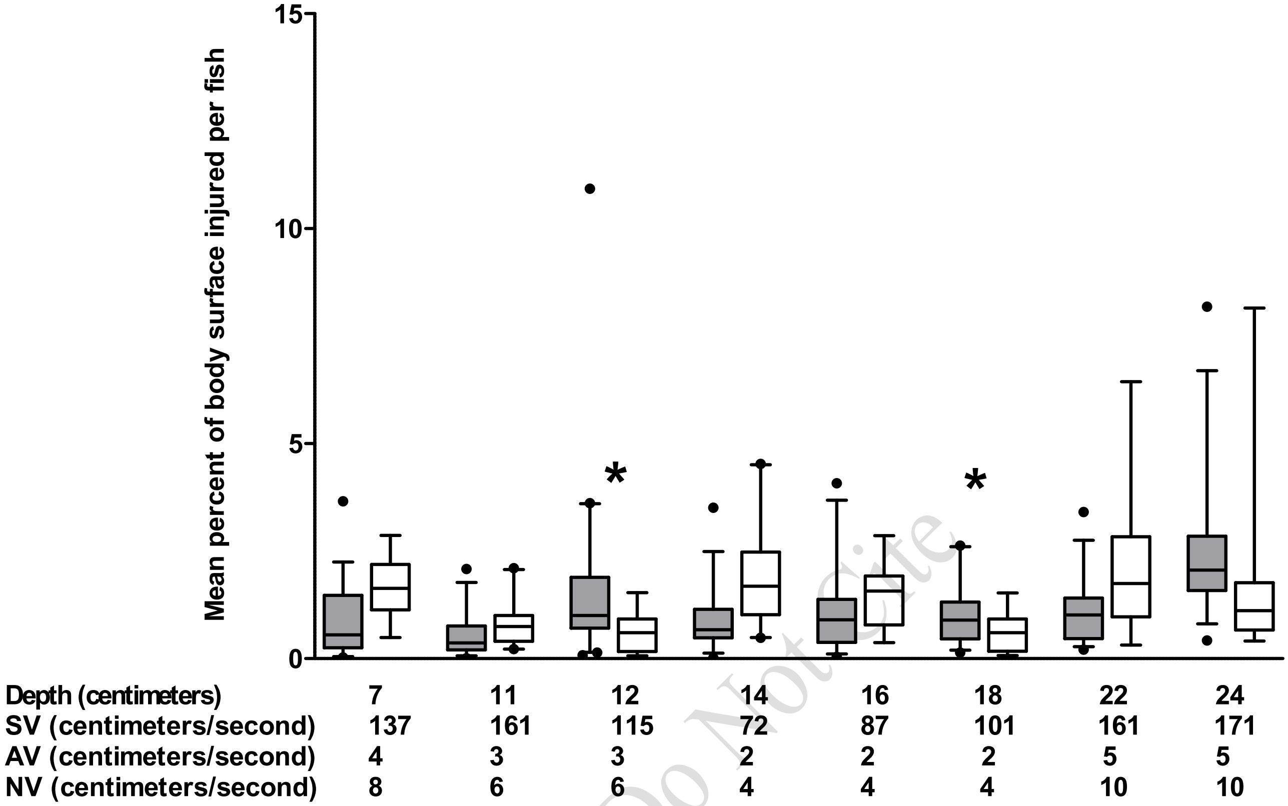

Figure 4. Distribution of the percent body surface area of large juvenile coho salmon injured when released over the Herman Creek screen (grey boxes) under different hydraulic conditions relative to control fish (white boxes). The upper and lower boundaries of the box represent the 25th and 75th quartiles, the line inside the box is the mean, the whiskers represent the 5% and 95% confidence intervals, and outliers are shown by solid points. The X-axis shows the water depth over the screen, the mean sweeping velocity (SV), the approach velocity (AV), and the normal velocity (NV) during each trial. Asterisks denote a significant difference between means within a group (one-tailed *t*-test, $P < 0.05$).

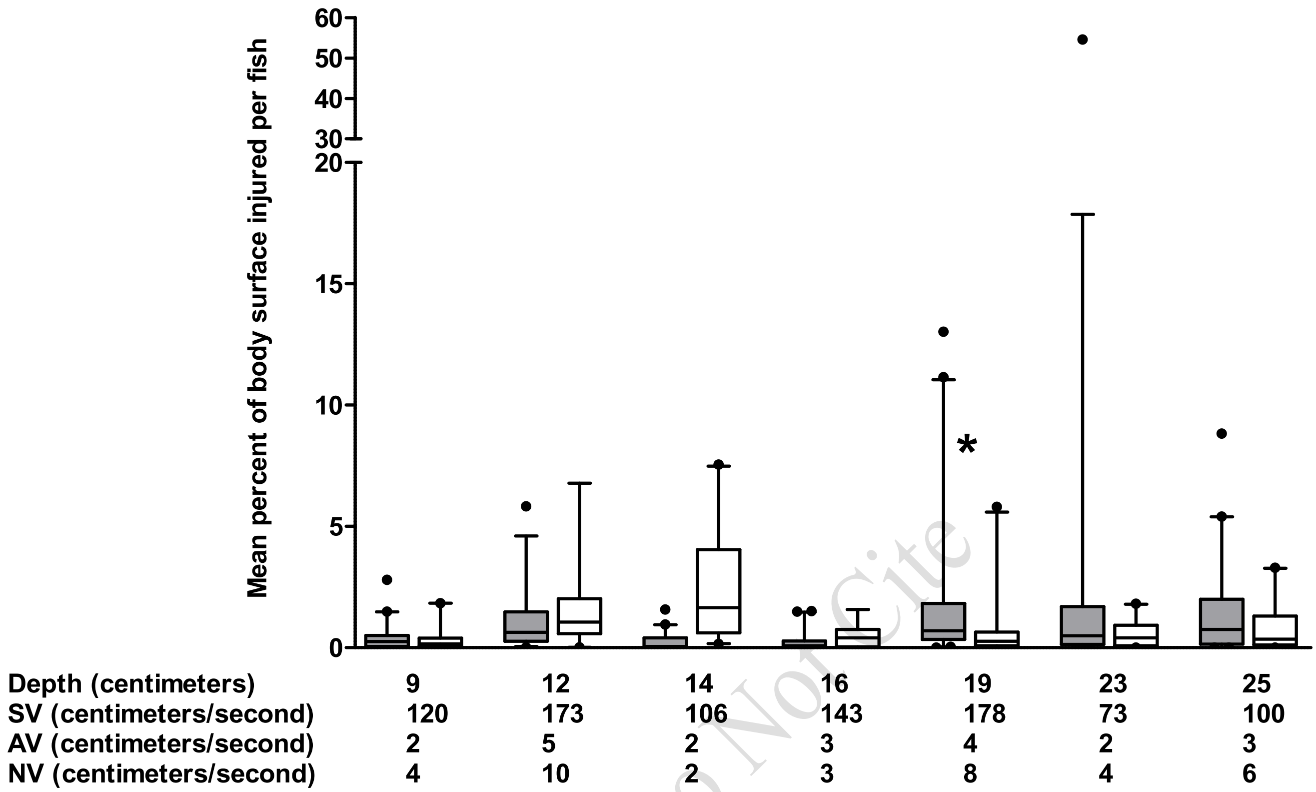

Figure 5. Distribution of the percent body surface area of small juvenile coho salmon injured when released over the Herman Creek screen (grey boxes) under different hydraulic conditions relative to control fish (white boxes). The upper and lower boundaries of the box represent the 25th and 75th quartiles, the line inside the box is the mean, the whiskers represent the 5% and 95% confidence intervals, and outliers are shown by solid points. The X-axis shows the water depth over the screen, the mean sweeping velocity (SV), the approach velocity (AV), and the normal velocity (NV) during each trial. Asterisks denote a significant difference between means within a group (one-tailed *t*-test, $P < 0.05$).

Table 1. Summary of hydraulic conditions at the Herman Creek screen and the numbers of two size groups of juvenile coho salmon used during injury assessments and delayed mortality tests.

[Trials were conducted on different days during February through May 2009. *Q*, discharge; *SV*, sweeping velocity; *AV*, approach velocity; *Z*, water depth over the screen; T, treatment fish; C, control fish; m^3/s, cubic meters per second. Values in parentheses are data for delayed mortality tests]

Inflow *Q* (m^3/s)	Diversion *Q* (m^3/s)	Bypass *Q* (m^3/s)	*SV* (cm/s; mean [SD])	*AV* (cm/s)	*Z* (cm; mean [SD])	Large fish		Small fish	
						T	C	T	C
4-cm weir wall height									
0.10	0.10	0.00	67 (34)	1	7 (1)				
0.14	0.13	0.01	87 (41)	2	7 (1)	37	17		
0.15	0.14	0.01	120 (50)	2	9 (1)			40 (44)	19 (15)
0.26	0.23	0.03	166 (52)	3	12 (1)				
0.27	0.25	0.02	137 (49)	4	11 (3)	38 (65)	20		
0.29	0.26	0.02	138 (73)	4	10 (1)				
0.31	0.28	0.02	130 (46)	4	12 (2)				
0.34	0.31	0.03	173 (45)	5	12 (1)			39 (51)	19 (17)
0.36	0.33	0.03	171 (41)	5	12 (1)	41 (60)	15 (30)		
11-cm weir wall height									
0.14	0.11	0.03	101 (30)	2	14 (1)	39	20		
0.15	0.12	0.03	106 (30)	2	14 (1)			40 (45)	20 (18)
0.29	0.23	0.05	161 (23)	3	16 (2)	40	20		
0.29	0.23	0.06	143 (30)	3	16 (1)			40 (45)	14 (15)
0.34	0.26	0.08	178 (32)	4	19 (1)			41 (36)	20 (15)
0.42	0.34	0.07	161 (30)	5	18 (1)	38 (61)	15 (42)		
13-cm weir wall height									
0.10	0.09	0.02	61 (20)	1	14 (0)				
0.20	0.13	0.07	170 (36)	2	16 (2)				
0.31	0.24	0.06	127 (25)	4	20 (1)				
20-cm weir wall height									
0.02	0.02	0.00	na	0	1 (1)				
0.04	0.03	0.01	36 (15)	0	8 (0 [a])				
0.15	0.10	0.05	72 (12)	2	22 (1)	38	14		
0.15	0.10	0.05	73 (12)	2	23 (0 [a])			36 (44)	20 (15)
0.27	0.20	0.07	100 (15)	3	25 (1)			35 (45)	20 (15)
0.28	0.22	0.06	115 (17)	3	24 (1)	39 (60)	15 (52)		
0.29	0.21	0.08	101 (25)	3	25 (1)				

Table 2. General linear models describing the relation between hydraulic variables measured at the Herman Creek screen, 2009.

[All coefficients are significant ($P < 0.05$) unless noted. *SV*, sweeping velocity*;* *Z*, depth of water over screen; *SQ*, inflow discharge; *DQ*, diversion discharge; *WW*, weir wall height; *SEE*, standard error of estimate; cm, centimeters; m^3/s, cubic meters per second]

Dependent variable	Equation
Depth	$Z = 2.592^{a} + 0.572\ (WW) + 89.673\ (SQ) – 75.712\ (DQ)$
	$N = 24$, $R^2 = 0.84$, $SEE = 2.27$
Diversion discharge	$WQ = 0.056 – 0.003\ (WW) + 0.902\ (SQ) + 0.000\ (SV)$
	$N = 24$, $R^2 = 0.99$, $SEE = 0.01$
Sweeping velocity	$SV = 105.007 – 4.863\ (WW) + 1{,}166.178\ (SQ) - 1{,}063.394\ (DQ)$
	$N = 24$ $R^2 = 0.81$, $SEE = 17.82$

[a]P=0.25

Table 3. Mean number of fish contacts with the screen, their relative depth of travel during passage, and their general orientation to the water flow during passage for large juvenile coho salmon experimentally released over the Herman Creek screen, 2009.

[*AV*, approach velocity; *SV*, sweeping velocity; SD, standard deviation; cm, centimeter; cm/s, centimeter per second]

Date	Water depth (cm; mean [SD]))	*AV* (cm/s)	*SV* (cm/s; mean [SD])	Mean (SD) number of screen contacts per fish	Depth in water column (% of observed)			Orientation (% of observed)		
					low	mid	high	up stream	down stream	other
2/27	7	2	87 (41)	0.72 (0.58)	69	25	6	44	56	0
2/17	11	4	137 (49)	0.45 (0.23)	41	54	5	36	60	4
3/4	12	5	171 (41)	0.47(0.24)	53	35	12	55	45	0
3/2	14	2	101 (30)	0.26 (0.18)	58	35	6	35	65	0
2/18	16	3	161 (23)	0.41(0.23)	44	43	13	58	42	0
3/3	18	5	161 (30)	0.15(0.18)	66	28	5	33	67	0
2/24	22	2	72 (12)	0.41 (0.34)	69	25	5	53	47	0
2/19	24	3	115 (17)	0.41 (0.33)	60	32	8	46	54	0

Table 4. Mean number of fish contacts with the screen, their relative depth of travel during passage, and their general orientation to the water flow during passage for small juvenile coho salmon experimentally released over the Herman Creek screen, 2009.

[*AV*, approach velocity; *SV*, sweeping velocity; SD, standard deviation; cm, centimeter; cm/s, centimeter per second]

Date	Water depth (cm; mean [SD])	*AV* (cm/s)	*SV* (cm/s; mean [SD])	Mean (SD) number of contact per fish	Depth in water column (% of observed)			Orientation (% of observed)		
					low	mid	high	up stream	down stream	other
5/19	9 (1)	2	120 (50)	0.32 (0.14)	57	40	3	56	40	4
5/20	12 (1)	5	173 (45)	0.50 (0.30)	63	33	4	61	15	24
5/15	14 (1)	2	106 (30)	0.56 (0.26)	58	32	10	55	41	4
5/13	16 (1)	3	143 (30)	0.42 (0.25)	49	37	14	44	38	18
5/14	19 (1)	4	178 (32)	0.62 (0.35)	65	23	12	53	35	12
5/8	23 (0)	2	73 (12)	0.26 (0.22)	69	24	7	70	30	0
5/12	25 (1)	3	100 (15)	0.35 (0.21)	53	28	19	61	37	2

Table 5. Summary of hydraulic conditions at the modular screen, the number and species of fish used for testing, and the percentage of fish that successfully passed over the screen for each time period. Only one steelhead refused to pass over the screen initially, but eventually did so within 10 minutes.

[*Q*, discharge; *AV*, approach velocity; *SV,* sweeping velocity; SD, standard deviation; cm, centimeter; cm/s, centimeter per second; STH, Steelhead trout; Coho, coho salmon]

Inflow*Q* (m^3/s)	Water depth (cm; mean [SD])	AV (cm/s)	SV (cm/s; mean [SD])	*N* of fish released	Percent of observations where fish passed over the screen				
					0 – 5 min	5 – 10 min	10 – 15 min	15 – 20 min	>20[1] min
Coho Salmon									
0.06	15 (1)	2	111 (6)	40	91	0	0	0	9
0.09	15 (1)	3	150 (8)	20	75	10	10	0	5
0.09	19 (1)	2	132 (7)	33	82	0	0	0	18
0.07	20 (0)	1	102 (10)	40	88	0	0	0	12
0.08	25 (1)	1	102 (13)	40	95	3	0	0	3
Steelhead Trout									
0.06	15 (1)	2	111 (6)	40	90	3	0	0	8
0.09	15 (1)	3	150 (8)	22	62	5	0	29	5
0.08	25 (1)	1	102 (13)	40	47	12	0	21	21

[1]Values include fish that were prodded from the upper 3 m of the flume.

This page left intentionally blank

H:\WORK\FSOC\2010_0722\DRAFT_ FCA_Screen_Evaluation_06082010.doc