Studies to establish biological design criteria for wet separators, 1996

Fish Ecology Division

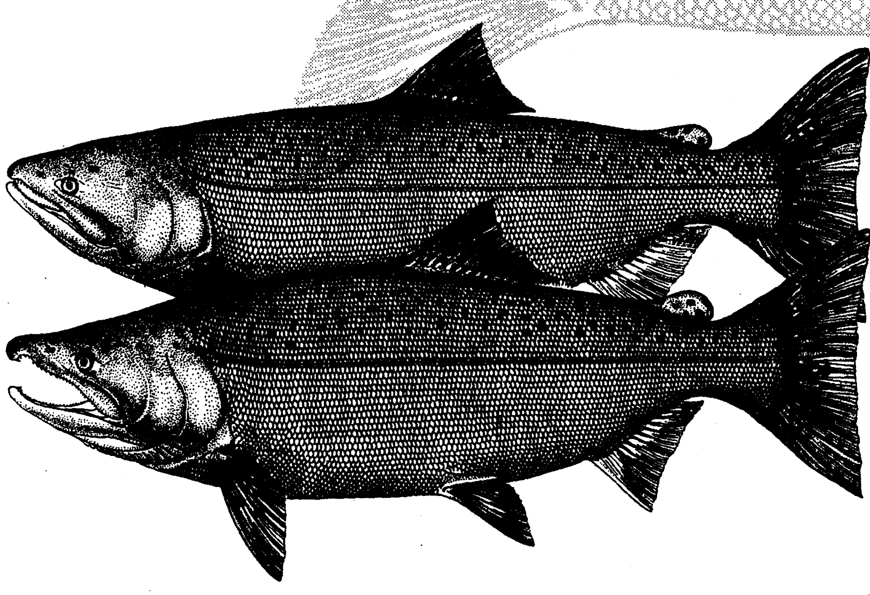
Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
R. Lynn McComas, Michael H. Gessel,
Benjamin P. Sandford, and
Douglas B. Dey

December 1998



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R. Lynn McComas
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Report of Research

Funded by

U.S. Army Corps of Engineers
Walla Walla District
Delivery Order E86910060

and

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

December 1998

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EXECUTIVE SUMMARY

Separation of juvenile salmonid species is important for the effective management of the Columbia and Snake River Systems and the fish transportation program. Thus, separation of smolts by size has been incorporated into all the new juvenile fish bypass systems at hydroelectric dams on the Columbia and Snake Rivers. However, results using wet-separator designs currently available have been less than adequate for separating smolts into large (≥180 mm) and small (<180 mm) size classes. In addition to poor separation, there is evidence that smolts hold in separator units, resulting in increased stress and migration timing delays. In 1996, the National Marine Fisheries Service and the U. S. Army Corps of Engineers initiated a project to provide biological design criteria to aid in the development of an improved wet separator planned for installation at the new Lower Granite Dam Fish Passage Facility. This study evaluated a new approach to separation, in addition to evaluating methods for improving the traditional wet-separator concept to reduce holding times and stress in fish during the separation process.

Two identical evaluation separator systems were built, and suspended over the juvenile fish bypass channel at McNary Dam to collect and test river-run smolts from Gatewell 6B. This facilitated comparison of different conditions that influenced passage of fish through the evaluation systems. Six test series were completed over the spring and summer outmigration periods to evaluate the effects of orifice depth, attraction flow around the orifice (attraction jets), and orifice placement, on fish passage through the separator (exit efficiency).

There was no statistical difference between orifice exit efficiency values for shallow (15.2 cm) and deep (66 cm) orifices for yearling chinook salmon or steelhead using 15.2-cm circular orifices oriented 90° to inflow. Similarly, the orifice attraction jet configuration used in this study did not improve mean exit efficiency over the non-jetted orifice condition for either subyearling or yearling chinook salmon.

Mean subyearling chinook salmon orifice exit efficiency was evaluated using 7.6-cm X 25.4-cm rectangular orifices 23 cm and 61 cm deep and in line with the evaluation unit inflow, and using a 15.2-cm circular orifice oriented 90° to inflow. Exit efficiency using the 23-cm deep rectangular orifice (97%) was significantly higher than with the rectangular orifice at 61-cm depth (93%), or the circular orifice (83%).

Near the end of the summer outmigration period, a prototype high velocity flume was constructed in the McNary Dam collection channel and evaluated as an alternative method for separating salmonid smolts. Three discharge rates (high, medium, and low) were considered at each of four separation-bar lengths (3.68, 2.92, 2.18, and 1.43 m). There was no difference in least squares mean separation efficiency values (81, 74, and 74%) among the three discharge treatments at any of the bar lengths tested and no interaction between discharge and separation-bar array length. Combined over all three discharges, differences among mean subyearling chinook salmon separation efficiency values (79, 84, 73, and 72%) were significant ($F = 5.12$, $df = 3,43$, $P = 0.0041$) for the four respective separation-bar lengths.

INTRODUCTION

Juvenile fish bypass facilities at hydroelectric dams on the Snake and Columbia Rivers collect outmigrating juvenile salmonids (*Oncorhynchus* spp.) for subsequent transport and/or release downriver. Because juvenile chinook salmon (*O. tshawytscha*) that are transported with juvenile steelhead (*O. mykiss*, which are generally larger than chinook salmon smolts) may experience higher levels of stress than those transported with other chinook salmon (McCabe et al. 1979, Schreck et al. in prep., Congleton et al. in prep.). Separation of smolts by size is an important objective of juvenile fish bypass systems not only for stress reduction, but also for providing management options based on different size classes.

The first separation systems were used at Lower Granite and Little Goose Dams on the Snake River and at McNary Dam on the Columbia River. Separation was achieved with a dry separator where fish dropped through gaps between pipes. The pipes were contained in an inclined array, and spaces between the pipes increased toward the downstream end of the array. Separation occurred as fish slid along the array; small fish dropped through first, and larger fish were carried farther down the pipes prior to dropping through. Collection flumes were provided for transporting size classes to separate holding areas. The system separated fish, but fish were out of water for most of the process. A study in 1981 (Gessel et al. 1985) led to the installation of wet separators at collection/bypass sites, which keep fish submerged throughout the sorting process.

Wet separators currently in use at juvenile fish collection facilities at Snake and Columbia River dams utilize a three-stage separation strategy to segregate smolts into two size classes and remove larger incidental and adult salmonids (Fig. 1). Though the separator for each facility

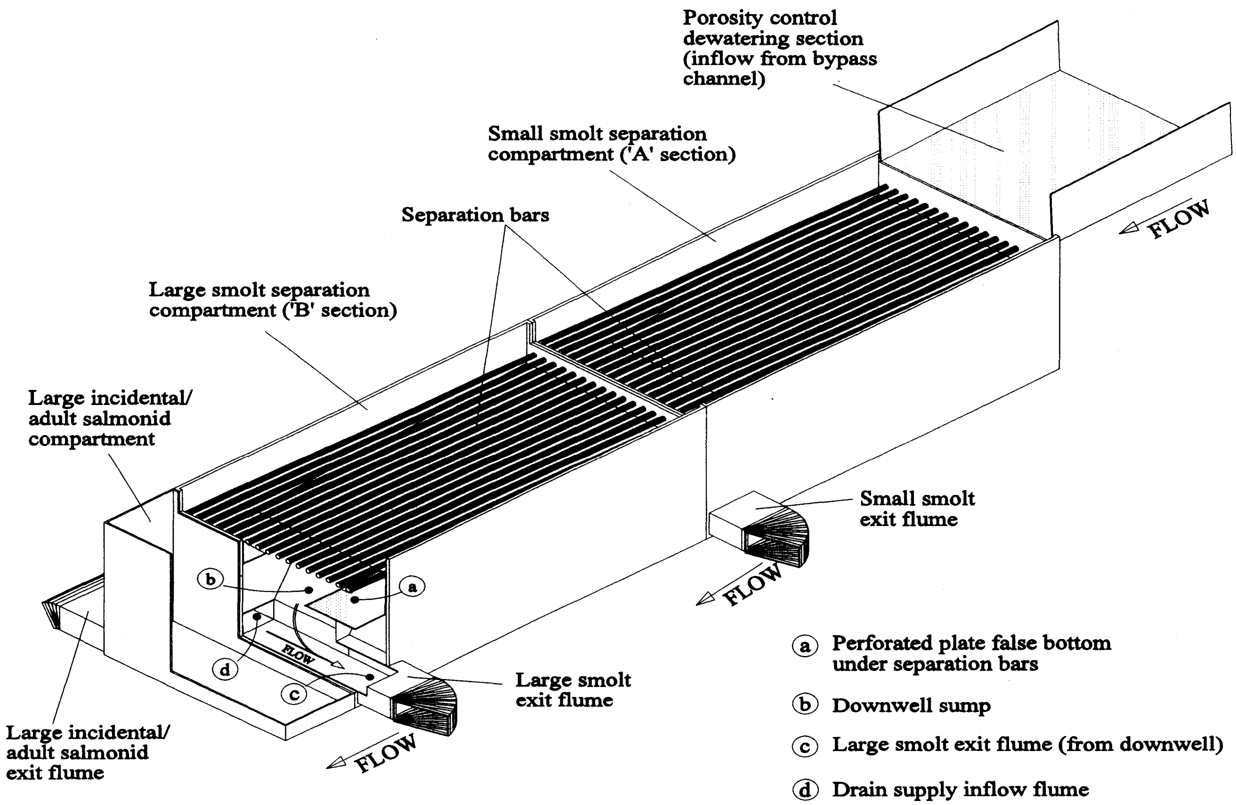

Figure 1. Generic wet-separator unit similar to those in use at existing juvenile fish bypass facilities for size separation of juvenile salmonids. Fish are delivered to the porosity control structure through a pipe leading from the collection channel. Separation bar spacing is adjusted to allow only smaller smolts to pass between the bars in the upstream (A) section. Larger smolts pass between the more widely spaced bars in the second (B) section, with large incidentals and adult salmonids being deposited in the last compartment for return to the river. The cutaway portion of the large smolt section shows the fish and flow path leading from the separator, and a similar path is provided in the small fish section. Fish passing between the bars are confined to the upper portion of the separator by a sloped, false bottom made of perforated aluminum plate (a), until they eventually exit the respective section through a downwell sump (b) and exit flumes (c). Makeup water is supplied to each section by upwelling forced through the false bottom and through the drain supply flumes (d).

is unique to that site, all units have a basically generic structure and operate similarly. A generalized wet separator consists of a rectangular box partitioned into two tandem sections. Each section is approximately 1.5 m (5 ft) wide, 4 m (13 ft) long and 1.2 m (4 ft) deep. Following partial dewatering, all fish from the bypass channel are deposited in the upstream section (A section) of the separator. Separation bars just under the water surface are spaced widely enough to allow smaller fish to pass through the gap between the bars to a fish collection area under the bars. Larger fish continue on to the second section (B section), where the next size class is removed in a similar manner. Fish too large to negotiate the gap between the bars in the B section pass through the length of the separator, into a flume at the end, for return to the river. For salmonids, under ideal conditions, the A section is intended to segregate smaller smolts such as chinook, coho (*O. kisutch*), and sockeye (*O. nerka*) salmon from the larger, predominantly steelhead smolts that are sorted through the B section. Larger fish eliminated during this process are adult salmonid fall-backs and nonsalmonid incidental species.

Wet separation relies on volitional sounding between submerged separation bars. Separators are designed to induce a sounding response by forcing makeup water through a perforated plate false bottom under the separation bars, relying on the assumption that salmonids tend to orient and swim into the predominant flow. Fish which have sounded between the bars of either the A or B sections exit through a 60-cm square downwell sump centered on the downstream end of each section. The outlet orifice from the sump to transport flumes is 1 to 1.2 m (3 to 4 ft) below the water surface. This increased head results in sharply accelerated flows through the sump and exit orifice, which is supplied by the makeup water augmented by a separate supply directly to the sump.

In practice, there are several problems with existing wet separators. For example, the McNary Dam separator exhibits poor performance in the A section, resulting in 1994 separator efficiency values of 32.2, 24.1, and 27.7% for yearling chinook, coho, and sockeye salmon, respectively (Brad Eby, U.S. Army Corps of Engineers, McNary Dam Juvenile Fish Passage Facility, Umatilla, OR 97882). Possible reasons for the low separation efficiencies included flow surges that carried small fish through the first section with insufficient time to sound between the separation bars, and a sounding response stimulus that was inadequate to cause fish to dive between the bars.

Video monitoring associated with behavior and physiology studies has indicated that fish also hold under the bars for extended periods, rather than exiting expeditiously from the separator unit (Schreck et al. in prep). Fish appear to eventually exit due to fatigue caused by resistance to hydraulic conditions within the unit, particularly in the area of rapidly increasing flow gradients near the downwell sump. The resulting fatigue would probably increase overall stress which in turn could ultimately affect survival.

During the 1996 spring and summer outmigration periods, the National Marine Fisheries Service (NMFS), in cooperation with the Idaho Cooperative Fish and Wildlife Research Unit of the University of Idaho and the U.S. Army Corps of Engineers (COE), initiated studies to establish biological design criteria (BDC) that could be used to increase separation efficiency and reduce residence time for salmonid smolts in wet separators. Because of the lack of available information concerning separation, interagency brainstorming sessions were also initiated at this time to address changes for improving wet-separator efficiency and to explore possible alternatives to the conventional wet-separator design. As a result of these meetings, objectives for this study were modified, deleted, or added in response to emerging research data and to accommodate prioritized direction from the committee. This interaction helped concentrate resources by eliminating or postponing marginal objectives. Specific research objectives in 1996 were the following:

1) Evaluate the effects of exit-orifice depth on juvenile salmonid orifice exit efficiency.
2) Evaluate the effects of exit-orifice attraction flows on juvenile salmonid orifice exit efficiency.
3) Evaluate the effects of reduced separator volume and orifices placed in line with inflow on juvenile salmonid orifice exit efficiency.
4) Evaluate the potential of a high-velocity flume separator for size separation of juvenile salmonid smolts.

OBJECTIVE 1: EVALUATE THE EFFECTS OF EXIT-ORIFICE DEPTH ON JUVENILE SALMONID ORIFICE EXIT EFFICIENCY

Approach

Two identical BDC evaluation separators were constructed to simulate the hydraulic conditions in the A section of an operating wet separator (Fig. 2). Evaluation separator units measured 1 m (39 in) wide, 2.1 m (7 ft) long, and 1.2 m (4 ft) high, with a maximum water depth of 84 cm (33 in). Main water supply was furnished by two valve-regulated, 15-cm-diameter (6-in) siphons drawing water directly from the forebay. Flow from the siphons was injected near

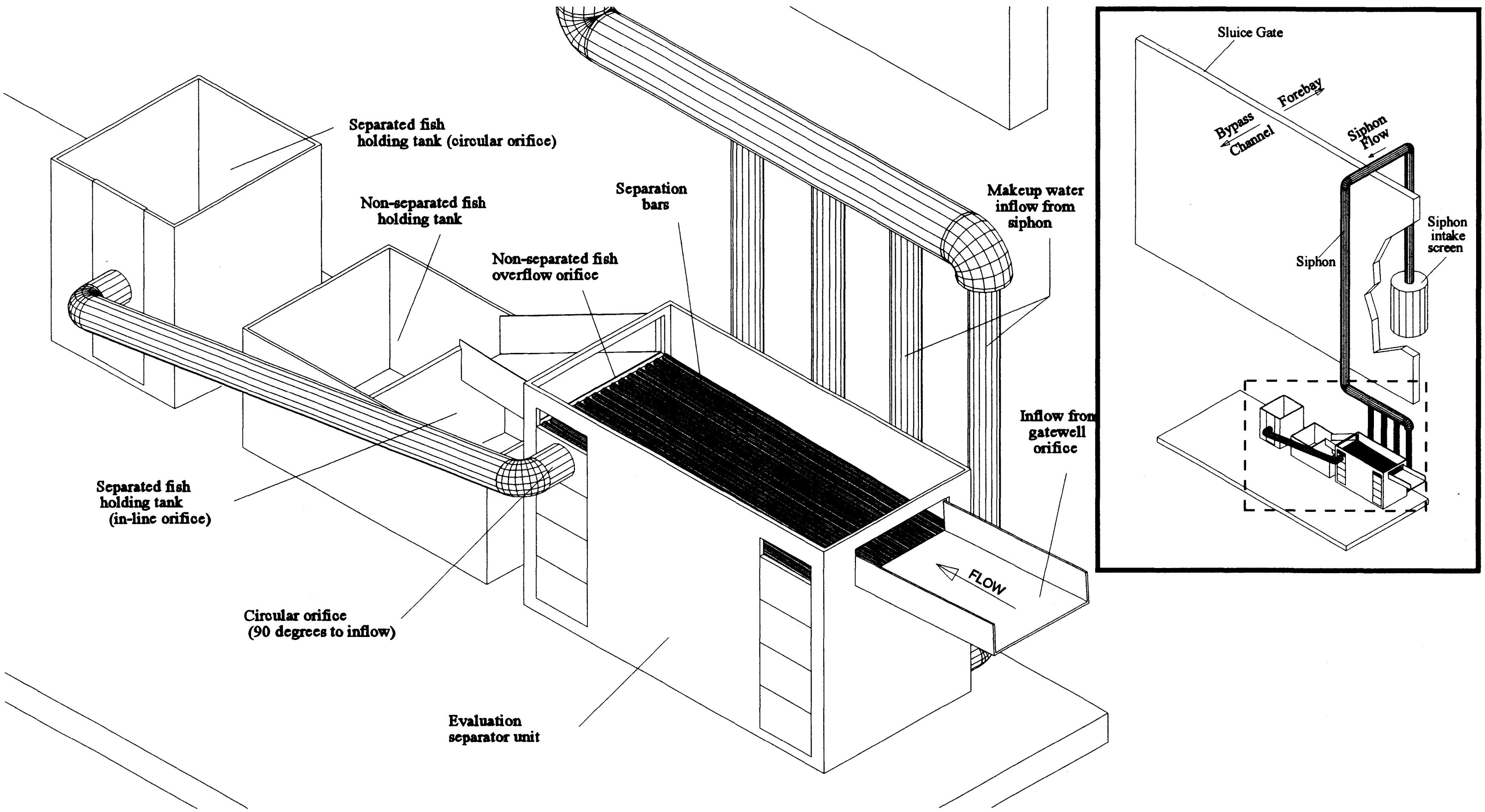

Figure 2. Major research components during separation efficiency testing at McNary Dam, 1996. Inset shows relationship among components on the platform suspended over the juvenile fish bypass channel, the forebay siphon, and the sluice gate for Gatewell 6B separating the forebay from the bypass channel.

the floor of the evaluation unit and diffused through sloped, perforated-plate false bottoms within the separator. This arrangement paralleled conditions in operating wet separators, serving to reduce volume under the separation bars and to disperse makeup water inflows through the false bottom evenly across the separator floor. Evaluation units also contained a downwell sump at the downstream end of the separator, similar to those currently in use in operating wet separators.

The evaluation units were placed on separate (north and south) platforms suspended above flows in the juvenile fish bypass channel (Fig. 3). River-run fish were collected by dewatering flows from pipe sweeps (orifice traps) connecting the north and south orifices of Gatewell 6B to the evaluation units (McComas et al. 1997), and introduced into the upstream end of the evaluation separator units. Fish sounding between and remaining below the separation bars (separated fish) were afforded egress through a submerged orifice. A rectangular 81-cm-wide (32-in) rectangular overflow orifice at the downstream end of the separator provided an exit for fish that remained above the separator bars (non-separated fish). All orifices were set flush with the inside of the evaluation units to reduce the likelihood of unintended visual or hydraulic cues, and to reduce the potential for injury to the fish.

To gain access to the submerged orifice, fish had to negotiate between the bars of a single-plane, separation-bar array. The array was submerged approximately 7.6 cm (3 in) at the inflow (upstream) end of the evaluation unit and angled upward to 2 cm (0.75 in) below the surface at the overflow orifice outfall (downstream). Individual separation bars were 2.54-cm (1-in) Schedule 80 polyvinyl chloride (PVC) tubing with a 3.2-cm (1.25-in) outside diameter. Gray pipe was used to minimize the likelihood of visual stimuli (positive or negative) which

Figure 3. McNary Dam juvenile fish bypass channel, looking north. Gatewell orifices drain into the channel from under the walkway to the left side of the photograph, with the forebay behind the sluice gates along the right side. Flow in the channel is toward the foreground. Separator design criteria evaluation units are on platforms suspended over the channel near the upper center.

may have resulted from using white bars. Spacing between bars was maintained by lengths of 0.95-cm plastic tubing between the bars. The separation bar arrays were held together by lengths of 0.64-cm (0.25 in) threaded rod passing through holes through the horizontal centerline of the bars at three points along their 2.1-m (7-ft) length.

Test Series 1, 2, and 6 were conducted to evaluate the effects of orifice depth on orifice exit efficiency (Table 1). Though orifice treatment and outmigration timing were different, fish handling and test procedures were similar for all three series of tests. Before beginning a replicate, flow through the evaluation unit was stabilized using the siphons to fill the unit with water to the bottom of the surface overflow (non-separated fish) orifice. Gatewell orifices were then opened, and fish were recruited into the unit along with enough additional water to raise the water surface in the unit by approximately 2 cm (0.75 in). This additional depth was necessary to produce adequate flow over the overflow orifice for the non-separated fish group to exit. Because separation was not under consideration during orifice exit efficiency testing, the overflow orifice for non-separated fish was screened so that the only exit was through the submerged orifice. Separation bars were spaced 3.8 cm (1.5 in) apart to allow unrestricted passage between the bars for all juvenile salmonids, while still providing the impression of an array with narrower spacing.

Due to fabrication and installation delays, only one evaluation unit was available for orifice exit efficiency testing during Test Series 1 and 2. Replicates were therefore run consecutively on the same day, alternating between deep and shallow orifice treatments.

Table 1. Schedule for wet-separator biological design criteria testing using the evaluation separator at McNary Dam, 1996.

Test series	Test dates	Test type	Submerged orifice type	Submerged orifice size (cm)	Orifice submergence (cm)	Submerged orifice exit velocity (m/s)	Treatment comparisons
1	2 - 10 May	OEE[a]	Circular	15	15	1.6	Orifice submergence, deep vs.
			Circular	15	66	1.6	shallow orifice exit efficiency.
2	13 - 17 May	OEE	Circular	15	15	1.6	Orifice submergence, deep vs.
			Circular	15	66	1.6	shallow orifice exit efficiency.
3	30 - 31 May	OEE	Circular	15	15	1.6	Orifice jets, jetted vs.
	4 - 6 June		Circular	15	15	1.6	non-jetted orifice exit efficiency.
4	12 - 28 June	OEE	Circular	15	15	2.1	Orifice placement; orifice
			Rectangular	7.6 x 25.4	23	2.1	perpendicular to inflow vs.
							orifice in line with inflow orifice
							exit efficiency.
5	28 - 29 June	OEE	Circular	15	23	2.1	Orifice placement; orifice
	1 - 3 July		Rectangular	7.6 x 25.4	23	2.1	perpendicular to inflow vs.
							orifice in line with inflow orifice
							exit efficiency.
6	16 - 17 July	OEE	Rectangular	7.6 x 25.4	23	2.1	Orifice submergence, deep vs.
			Rectangular	7.6 x 25.4	61	3.0	shallow orifice exit efficiency.

[a] Orifice exit efficiency.

The submerged orifice for separated fish used during the first two test series was a 15-cm (6-in) circular opening through the side of the unit near the downstream end. The orifice exited perpendicular to inflow from the dewatering system, a configuration similar to conditions in operating wet separators. Fish exiting the submerged orifice were routed to a holding tank through an enclosed pipe. Orifice exit velocity was measured at 1.6 m/s (5.2 fps) for both series, and held at that velocity regardless of orifice depth, by maintaining a standard water depth in the holding tank.

To allow equal time for fish to find the submerged orifice and exit the evaluation unit, test duration for each pair of replicates was kept as similar as possible, with secondary regard for the numbers of animals entering the unit during the test interval. At the end of the test interval, each replicate test was concluded by blocking the submerged orifice with a perforated plate panel to prevent further egress from the unit. Recruitment to the unit was halted by closing the gatewell orifice at the same time.

Fish remaining in the evaluation separator were removed using a dip net, anesthetized with tricaine methane sulfonate (MS-222), measured to fork length, and enumerated by species. Fish condition was also noted as percent descaling for each species using current Fish Transportation Oversight Team descaling criteria (Ceballos et al. 1992). Fish having exited through the submerged orifice during the test were then removed from a holding tank and enumerated by the same procedure. Orifice exit efficiency (OEE) was calculated by species as the portion of fish that exited the evaluation separator through the submerged orifice relative to the total number of fish that entered the evaluation separator during the test interval:

$$OEE = \frac{A}{T} \times 100\%$$

where: OEE = orifice exit efficiency
A = portion exiting orifice
T = total number entering the evaluation unit

Following recovery from anesthetic, all fish were released directly into the juvenile fish bypass channel. Fish were handled and released in a similar manner for all test series.

During Series 1, the shallow orifice was located in the wall of the evaluation unit centered approximately 60 cm (23.5 in) above the floor of the downwell. By contrast, the deep orifice was only about 6 cm (2.5 in) above the floor of the downwell. To test whether proximity to the floor of the unit had an effect on OEE, a removable aluminum floor was installed about 6 cm under the shallow orifice during the second test series. Deep orifice treatment conditions were the same as for Series 1.

Procedures for Test Series 6 were similar to those used during the first two series, except that both evaluation units were available, allowing paired testing of orifice depth treatments. Submerged orifices used during this series were rectangular (7.6-cm high by 25.4-cm long) and centered in the downstream end of the unit under the overflow orifice. Orifice submergence was 23 cm (9 in) for the shallow orifice and 61 cm (24 in) for the deep orifice. Both treatments were set 1 cm (0.4 in) above the floor of the unit. Also, during Series 6 both orifices had unrestricted discharge directly into holding tanks, resulting in exit velocities of 2.1 m/s (7 fps) and 3 m/s (10 fps) for the shallow and deep conditions, respectively.

Results and Discussion

Orifice exit efficiency testing for Test Series 1 and 2 was completed during the spring outmigration period. Yearling chinook, coho, and sockeye salmon and steelhead composed 97 and 99% of the catch for these two series, respectively. Test Series 6 was conducted during the summer outmigration, with subyearling chinook salmon constituting 99% of the total catch. Catch data for all three series are presented by replicate for each species in Appendix Table 1. Results of statistical comparisons are summarized in Appendix Table 2.

Seven replicates of each orifice treatment were conducted for Test Series 1, five for Series 2, and six for Series 6 (Table 2).

For statistical comparison purposes, data from replicates with fewer than 25 fish were pooled with data from adjacent replicates. Too few coho or sockeye salmon were captured during any of these three test series to conduct comparisons between treatments for these species. A two-sample t-test revealed no significant difference in OEE between deep and shallow circular orifice treatments for yearling chinook salmon, steelhead, or for all species combined (total catch). There was no significant difference regardless of the presence (Test Series 2) or absence (Test Series 1) of the removable floor under the shallow orifice. Although OEE for subyearling chinook salmon using the rectangular orifice was high for both treatments (Test Series 6), it was significantly higher with the shallow orifice treatment than with a similar orifice deeper in the water column ($t = 5.01$, $df = 5$, $P = 0.0041$).

Table 2. Percent orifice exit efficiency for juvenile salmonid migrants using shallow (15 cm) and deep (61 cm) orifices during orifice exit efficiency (OEE) evaluations in an evaluation wet separator, McNary Dam, 1996. Standard error terms are in parenthesis.

		Percent orifice exit efficiency (SE)					
Series	Orifice treatment	Subyearling chinook	Yearling chinook	Steelhead	Coho	Sockeye	Total catch
1	deep	100 (0)	40 (6)	39 (11)		86 (6)	46 (5)
	shallow	63 (24)	45 (11)	51 (8)		70 (14)	51 (8)
2	deep		42 (10)	57 (15)	28 (8)	55 (22)	68 (3)
	shallow		67 (5)	77 (6)	38 (8)	63 (15)	45 (9)
6	deep	93 (2)					
	shallow	98 (1)					

Fish condition, measured by percent descaling, was consistent with values obtained during orifice passage efficiency testing using the same orifice trap arrangement in previous studies (McComas et al. 1997), indicating that passage through the traps, dewatering system, and evaluation separator units was relatively benign. Descaling values are presented by species in Table 3 for Test Series 1 and 2. Subyearling chinook salmon descaling was less than 1% for all treatment groups during Series 6.

Table 3. Percent descaling for juvenile salmonid migrants using shallow (15 cm) and deep (61 cm) orifices during orifice exit efficiency (OEE) evaluations in an evaluation wet separator, McNary Dam, 1996. Standard error terms are in parenthesis.

		Percent descaling (SE)				
Series	Orifice treatment	Yearling chinook	Steelhead	Coho	Sockeye	Total catch
1	deep	3.6 (1.8)	13.0 (6.1)		1.5 (1.4)	4.9 (0.04)
	shallow	4.0 (2.0)	5.1 (3.7)		5.1 (3.6)	4.3 (0.02)
2	deep	7.0 (1.8)	14.3 (4.7)	3.9 (1.2)	6.3 (1.6)	8.9 (0.04)
	shallow	8.9 (5.1)	14.2 (6.0)	4.5 (0.3)	8.7 (3.5)	7.5 (0.05)

OBJECTIVE 2: EVALUATE THE EFFECTS OF EXIT ORIFICE ATTRACTION FLOWS ON JUVENILE SALMONID ORIFICE EXIT EFFICIENCY

Approach

Video camera observations of juvenile salmonids in operating wet separators have indicated that smolts may hold for long periods of time oriented toward inflow or makeup flow through the floor of the unit rather than exit expeditiously from the separator through the exit orifice (Schreck et al. in prep). Regardless of the flow source, fish generally orient facing upstream to a detectable current. One solution to this problem may be to furnish an attraction flow near the exit orifice. Jetting water into the separator around the circumference of the opening may cause fish within the unit to orient into this attraction flow and swim towards and through the orifice.

To evaluate the effect of orifice attraction flows on exit efficiency, both the north and south evaluation units were equipped with 15-cm (6-in) circular orifices similar to those used in Objective 1. The submerged orifice on the south evaluation unit was also provided with orifice attraction jets consisting of 8 equally spaced 1.27-cm (0.5-in) holes through the end of a 15-cm-long (6-in) pressurized jacket surrounding the orifice pipe (Fig. 4). Jets were directed into the separator through the wall of the separator unit and parallel with outflow. A 1-hp pump supplied pressure to the jacket through two 5-cm (2-in) tubes coupled to opposite sides of the jacket, producing individual jet flows of approximately 2 m/s (6.7 fps).

Test procedure, fish handling, and data collection followed methods similar to those used for Objective 1, except that the availability of both evaluation units allowed simultaneous (paired) testing of treatments under this objective.

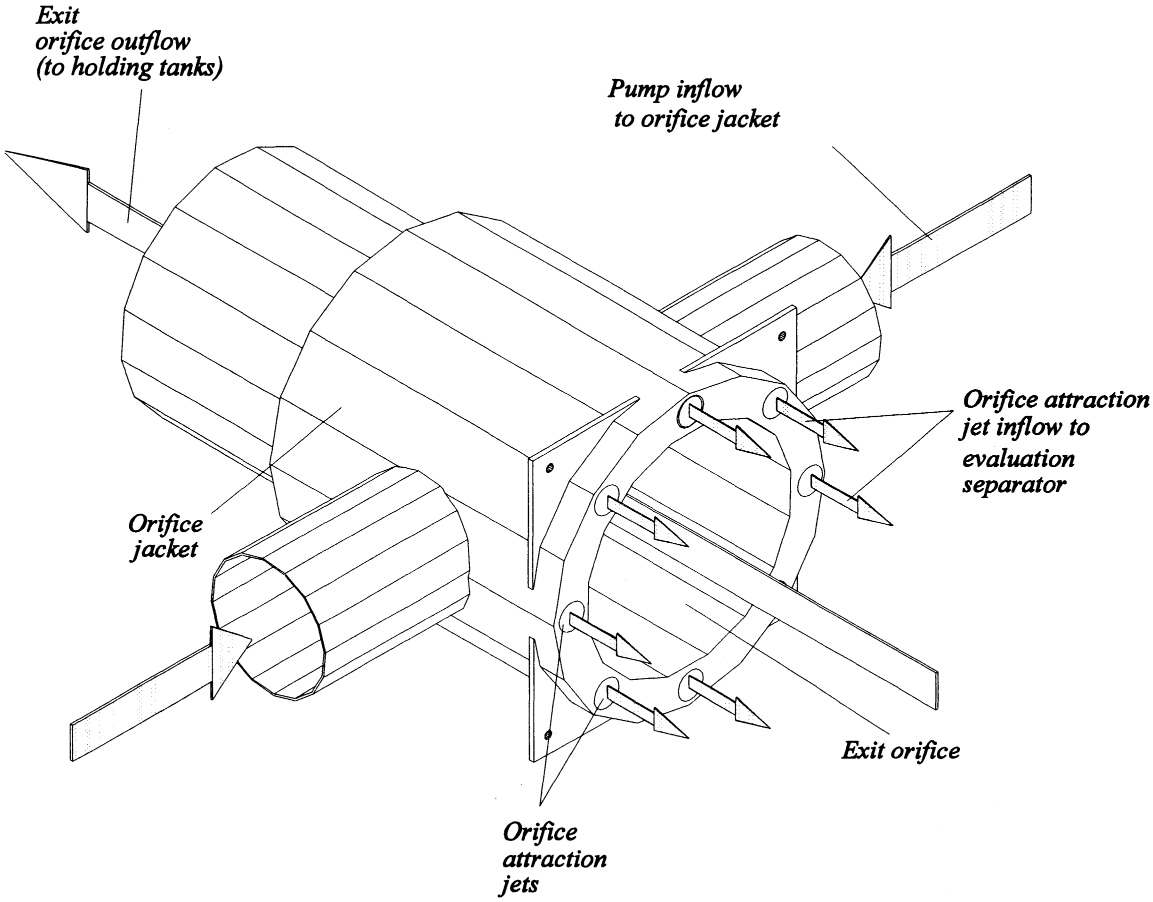

Figure 4. Configuration of orifice attraction jets in relation to the 15-cm (6-in) submerged exit orifice used during orifice exit efficiency studies at McNary Dam, 1996. Arrows indicate direction of major flow components.

Results and Discussion

A total of six pairs of replicates were completed using orifice attraction jets. Subyearling chinook and yearling chinook salmon and steelhead constituted 47, 36, and 15%, respectively, of the total catch from all replicates. Coho and sockeye salmon, combined, accounted for 2% of the catch. Mean OEE values for Test Series 3 are presented in Table 4.

Only sufficient numbers of yearling and subyearling chinook salmon were captured for statistical evaluation. Using a two-sample t-test, we found no significant difference between mean OEE values obtained using orifices with and without attraction-flow jets for subyearling chinook salmon ($t = 1.14$, $df = 7$, $P = 0.2908$), yearling chinook salmon ($t = 1.32$, $df = 6$, $P = 0.2336$), or for the total catch ($t = 0.34$, $df = 10$, $P = 0.7385$).

Descaling of subyearling chinook salmon was less than 1% for both treatments. Descaling of yearling chinook salmon was 10.6% (SE = 3.8) and 5.5% (SE = 3.1) for jetted and non-jetted orifice conditions, respectively.

Evaluation was halted after only six pairs of replicates because there was no evident increase in OEE using the jetted orifice and because fish descaling appeared to increase using this treatment. However, this result does not necessarily indicate that the jetted orifice concept has no merit. Though there was no detectable difference in exit efficiency between the two conditions tested, only one combination of orifice attraction-jet angle and pressure was used during this evaluation. The evaluation of other combinations was precluded by the substantial fabrication time required for reoutfitting the jetted orifice for each iteration. Future evaluation of this concept would benefit from a system with adjustable-angle jets for comparison of several angle/pressure combinations.

Table 4. Percent orifice exit efficiency for juvenile salmonid migrants with jetted and non-jetted orifices during orifice exit efficiency (OEE) evaluations using an evaluation wet separator, McNary Dam, 1996. Standard error terms are in parenthesis.

		Percent orifice exit efficiency (SE)				
Series	Orifice treatment	Yearling chinook	Steelhead	Coho	Sockeye	Total catch
3	jetted	75 (7)	38 (5)	1 (1)	100 (0)	58 (4)
	non-jetted	84 (2)	27 (6)	2 (2)	60 (20)	61 (8)

In addition, there may be means of accomplishing the same purpose without using jets around the orifice. For example, an attraction flow could be provided to induce fish to swim over an overflow weir or through an orifice under the attraction flow. Another proposed solution was to develop attraction flows by creating back pressure through the exit orifice opening (Scott Ross, U.S. Army Corps of Engineers, 201 N. Third Ave., Walla Walla, WA 99362-1876, pers. commun., October 13, 1995). In either scenario, fish would swim voluntarily into the attraction flow, to the point where outflow would force them forward through the orifice opening.

OBJECTIVE 3: EVALUATE THE EFFECTS OF REDUCED SEPARATOR VOLUME AND ORIFICES PLACED IN LINE WITH INFLOW ON JUVENILE SALMONID ORIFICE EXIT EFFICIENCY

Approach

Several concepts related to improving orifice exit efficiency emerged from the interagency brainstorming sessions mentioned above (Introduction). One of the concepts to help improve orifice exit efficiency was to reduce hydraulic complexity within the separator. This was tested by placing the submerged exit orifice aligned with the flows carrying fish into the separator. This configuration eliminated the change in direction of the flow between the inflow and the exit orifice, thus streamlining the hydraulic conditions within the separator. Ideally, the space under the separation bars would also be configured to transition into the shape and size of the submerged orifice in order to reduce the amount of hydraulic dead space where fish might hold. The orifice shape would approximate the space under the bars, which is essentially a shallow rectangle.

The effect of using an orifice aligned with flows entering the separator units was evaluated during Test Series 4 and 5. For both series, the south evaluation unit was equipped with a 7.6-cm (3-in) by 25.4-cm (10-in) rectangular orifice submerged 23 cm (9 in). The orifice was centered in the end of the evaluation separator opposite inflow from the gatewell dewaterer so that flow through the submerged orifice was in line with inflow. An aluminum floor was placed in the unit approximately 1 cm (0.4 in) below the bottom of the submerged orifice, covering the downwell sump. Volume in the separator was further reduced by placing angled perforated plate panels along the sides of the unit to block access to corners along the entire length of the bottom. Flow through the rectangular orifice was unrestricted, resulting in a discharge of 2.1 m/s (7 fps).

The north evaluation separator retained the 15-cm (6-in) circular orifice used in Objectives 2 and 3 (oriented perpendicular to inflow through the side of the unit) during both the fourth and fifth test series. During Series 4, the orifice was also maintained 6 cm above the removable floor as described in Objective 1 for the second test series. However, for Series 5, the orifice was lowered to approximately 1 cm (0.4 in) above the floor (61 cm deep from the water surface to the top of the orifice) to match the relationship between floor and orifice used with the rectangular orifice treatment. Exit velocities through the circular orifice were increased to 2.1 m/s (7 fps) to match those through the rectangular orifice for both series.

Comparison replicates of the two treatments were run concurrently for both series, with test procedures and data collection following methods similar to those described for Objective 1.

Results and Discussion

A total of 35 replicate tests were conducted for Test Series 4, resulting in 31 statistically valid comparisons. Only subyearling chinook salmon, representing 94% of the total catch, were captured in sufficient numbers for statistical analysis. There was a significant difference between mean OEE values of 85% (SE = 2.0) for the circular orifice and 97% (SE = 1.0) for the rectangular orifice ($t = 5.18$, $df = 28$, $P < 0.0001$).

Subyearling chinook salmon represented over 99% of the catch for the 13 replicates in Series 5. Respective mean OEE values for the lowered circular orifice and rectangular orifices were 83 (SE = 2) and 96% (SE = 2). The difference was statistically significant ($t = 5.01$, $df = 12$, $P = .0003$).

Mean subyearling chinook salmon OEE values were statistically similar for Series 4 and 5 for both circular orifice treatments ($t = 0.46$, $df = 42$, $P = 0.6501$). Grouped mean values over all 42 valid replicates in both series were 97 (SE = 1) and 84% (SE = 2) for the rectangular and circular conditions, respectively.

Subyearling chinook salmon descaling was less than 1% of the total catch for all but one group during Series 4 and 5. Two of 58 fish (3.4%) not exiting the rectangular in-line orifice were found descaled during Series 5, but this may have resulted from the small sample size considered.

The size of the rectangular orifice for this study was chosen to present a square area (193 cm^2) similar to the circular orifice (182 cm^2) so that the two could reasonably be compared. Ideally, the rectangular orifice would have been as wide as possible, or about 61 cm (24 in) for the evaluation unit used during this evaluation. Also, though OEE with the rectangular orifice was higher than with the lowered circular orifice for subyearling chinook salmon, there was not enough data for other salmonid species to make similar comparisons.

OBJECTIVE 4: EVALUATE THE POTENTIAL OF A HIGH-VELOCITY FLUME SEPARATOR FOR SIZE SEPARATION OF JUVENILE SALMONID SMOLTS

Approach

In general, juvenile fish bypass systems at Columbia and Snake River hydroelectric dams operate in a similar manner. Migrants that accumulate in the collection channel are transported through a large-diameter pipe or flume to the separator where they are sorted by size and then transferred through flumes to holding areas or back to the river. The current separation method, which requires low velocities to be effective, is a bottleneck that impedes movement of fish through the system. This method not only requires slowing the water, dewatering, and then reintroducing the velocity, but creates the possibility of migration delay and increased stress within the separator unit. A more efficient method would be to have sorting occur during in-flume transport to holding areas, so that the process is not interrupted. The concept of using high-velocity flume separation was advanced during interagency brainstorming sessions as an alternative to the wet separator.

In its most rudimentary form, a high-velocity flume separator is a channel with appropriately spaced separation bars in a single-plane array that reaches from side to side across the width of the flume. Since velocities would be greater than those in a wet separator, separation bars would also be longer to facilitate adequate separation. However, beyond conceptualization, there was no reference for the range of parameters from which to begin investigating the implementation of a prototype system. The purpose of this objective was to evaluate the practicality of the high-velocity flume as a separation technique, and to begin to define the relationship between separation-bar array length and discharge in order to build a working prototype.

An aluminum evaluation flume 4.5 m (15 ft) in length was fabricated in 0.75-m (2.5 ft) segments with a cross section 61 cm (24 in) square. The inflow end was connected to the dewatering unit on the south evaluation unit platform, with water supplied from gatewell orifice dewatering. Fish were introduced at the upstream end of the flume in the same manner as for evaluation separators. Discharge through the unit was controlled by an adjustable leaf gate built into the last segment at the outfall end of the flume. A solid plate above the leaf gate served to divide separated and non-separated groups of fish, which were then routed to separate holding tanks. Smolts sounding between the separation bars (separated) exited beneath this plate, while non-separated fish passed above the plate.

Separation bars were constructed of the same PVC tubing used for Objective 1, with a 19-mm spacing between bars. Separation-bar array lengths of 3.7 m (12.3 ft), 2.9 m (9.8 ft), 2.2 m (7.3 ft), and 1.4 m (4.8 ft) were used for estimates of separation efficiency. At each length, discharges of 0.5 m^3/s (5.5 ft^3/s), 0.47 m^3/s (5.25 ft^3/s), and 0.42 m^3/s (4.7 ft^3/s) were evaluated, corresponding to relatively high, medium, and low mean velocities through the flume, respectively.

Testing for separation efficiency using the evaluation high-velocity flume was carried out near the end of the subyearling chinook salmon outmigration (Table 5). Beginning with the longest separation-bar array length, at least three replicates were conducted at each discharge.

Table 5. Schedule for biological design criteria testing using an evaluation high-velocity flume, McNary Dam, 1996.

Test series	Test dates	Number of replicates	Separation-bar array length (m)	Separation-bar array angle (°)	Discharge (m^3/s)
7	5 - 6 Aug	5	3.7	4.5	0.47
	6 - 7 Aug	5	3.7	4.5	0.42
	7 Aug	6	3.7	4.5	0.50
8	8 Aug	3	2.9	5.4	0.42
	8 Aug	3	2.9	5.4	0.47
	8 - 9 Aug	4	2.9	5.4	0.50
9	9 Aug	3	2.2	7.3	0.50
	9 - 10 Aug	4	2.2	7.3	0.42
	10 Aug	3	2.2	7.3	0.47
10	12 Aug	10	1.4	11.1	0.42
	12 - 13 Aug	5	1.4	11.1	0.47
	12 - 13 Aug	4	1.4	11.1	0.50

The array and flume were then shortened by 0.75 m (2.5 ft) and the process was repeated until all four length/discharge treatments had been evaluated. Separation efficiency of the flume (SE_F) was recorded by species for each treatment as the number sounding between the separation bars relative to the total number entering the evaluation flume:

$$SE_F = \frac{E}{T} \times 100\%$$

where: E = number sounding between the separation bars
T = total number entering the evaluation flume

Fish handling and data recording were carried out in the same manner as for Objective 1.

Results and Discussion

Catch data, test conditions, and separation efficiency results are presented by replicate in Appendix Table 3. Only subyearling chinook salmon, constituting over 99% of the total catch, were captured in sufficient numbers for statistical analysis.

A two-factor analysis of variance revealed no significant interaction between separation-bar array length and discharge for subyearling chinook salmon separation efficiency during this study (F = 0.80, df = 6,43, P = 0.5781). No significant differences were found among mean separation efficiency values based on discharge among any of the four bar lengths tested (F = 2.73, df = 2,43, P = 0.0768). However, differences in mean separation efficiency among the four length treatments were significant (F = 5.12, df = 3,43, P = 0.0041). There was a general decrease in separation efficiency with decreasing separation-bar array length (Fig. 5).

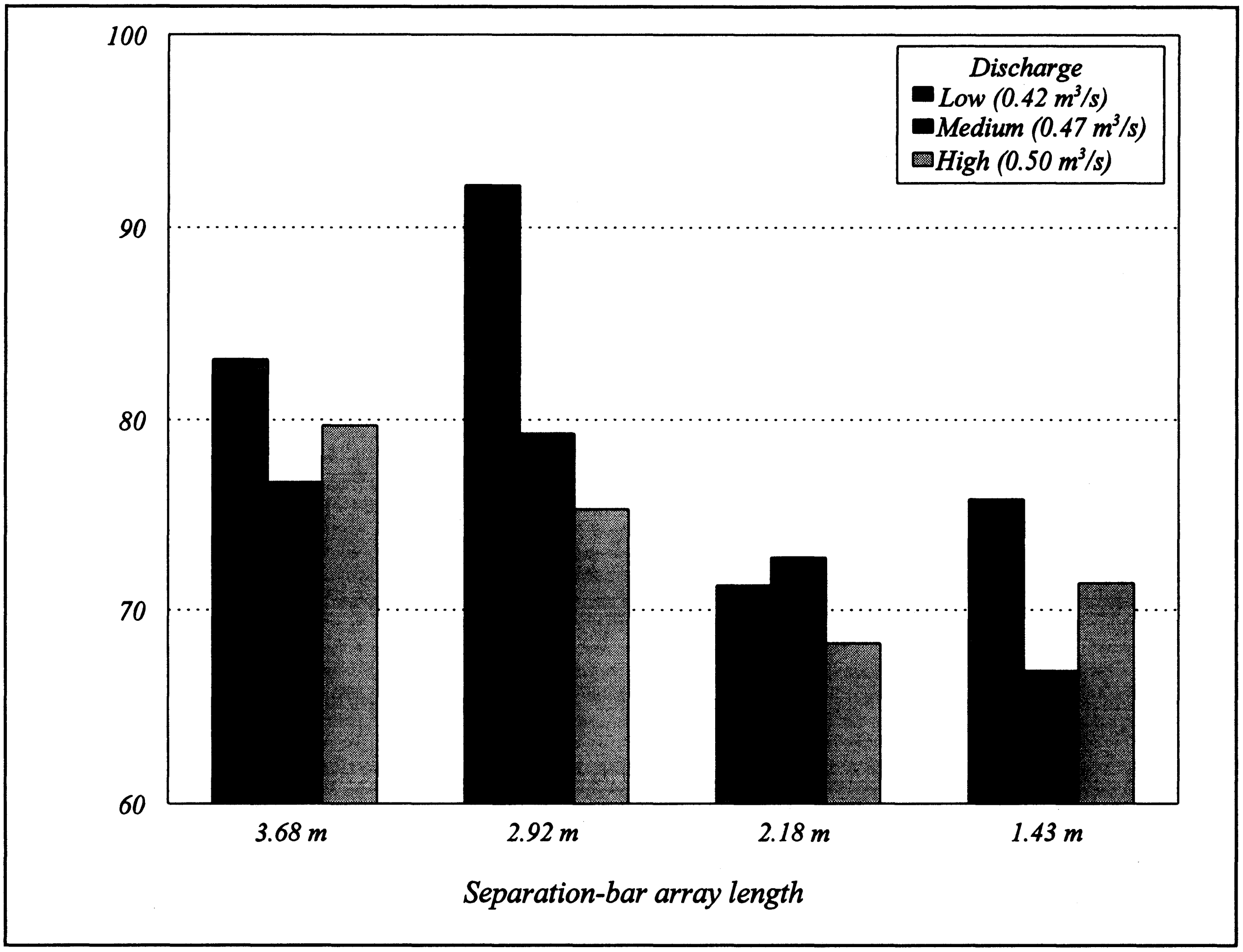

Figure 5. Mean subyearling chinook salmon separation efficiency values obtained for low, medium, and high discharges at four separation-bar array lengths using an evaluation high-velocity flume separator at McNary Dam, 1996.

Combined over all three discharges, mean subyearling chinook salmon separation efficiency values were 79, 84, 73, and 72% for separation-bar array lengths of 3.7 m, 2.9 m, 2.2 m, and 1.4 m, respectively.

Separation bar lengths of 2.2 m or less had a slightly lower efficiency. Although a regression of the data was significant (P = 0.004), the relationship of separation-bar lengths to separation was low ($R^2 = 0.15$). It is not known how much of an increase in separator bar length would be needed to substantially improve separation.

Velocities in the evaluation flume were restricted to gravity-fed flows from gatewell dewatering. Since head differential between the dewatering reservoir and evaluation flume was small, the velocities used in this study should probably be considered minimal. Also, the time frame available (just prior to the end of the subyearling chinook salmon outmigration) restricted the scope of fabrication for accomplishing this objective. One result was that upstream and downstream heights of the ends of the separation-bar array were fixed in relation to each other, so that the array angle increased as length decreased (Table 2). The effect of these angle variations on separation efficiency values is unknown.

Despite these limitations, mean separation efficiency over all replicates using the evaluation high-velocity flume was 76% (SE = 1.4) for subyearling chinook salmon. This is comparable to the better efficiencies obtained using operating wet separators and indicates that this method warrants further study as an alternative for fish separation.

SUMMARY

1) There was no significant difference in orifice exit efficiency between shallow (15 cm depth) and deep (66 cm depth) circular orifice treatments for yearling chinook salmon or steelhead regardless of height of the submerged orifice above the floor of the evaluation separator.
2) Subyearling chinook salmon orifice exit efficiency using an evaluation separator was significantly higher for the shallow (23 cm depth) orifice treatment than for a similar orifice deeper (61 cm depth) in the water column.
3) Using an evaluation separator, there was no significant difference between mean orifice exit efficiency values obtained using 15-cm circular orifices with and without orifice attraction-flow jets for yearling or subyearling chinook salmon.
4) Mean subyearling chinook salmon orifice exit efficiency was significantly higher with a 7.6-cm by 25.4-cm rectangular orifice in line with inflow than with a 15-cm circular orifice oriented 90° to inflow in an evaluation separator.
5) Using an evaluation high-velocity flume separator, there was a significant (although small) difference in mean separation efficiency values among four separation-bar array lengths evaluated (range: 1.4-3.7 m), with the two shorter lengths having decreased separation. There was no significant interaction between separation-bar array length and discharge, or among mean separation efficiency values based on discharge among any of the four bar lengths.

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Appendix Table 1. Catch and orifice exit efficiency (OEE) results from wet-separator biological design criteria testing at McNary Dam, 1996.

Test Series 1 (deep orifice vs shallow orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE (%)
2 May	1a, deep	2	100	18	72					1	100	21	76
	1b, shallow	7	0	9	44	2	50			2	0	20	25
3 May	2a, deep	3	100	47	30	33	18			5	60	88	30
	2b, shallow			57	68	57	35			6	100	120	54
6 May	3a, deep	2	100	18	11	3	0			6	100	29	34
	3b, shallow	2	50	12	42	8	75	1	0	4	75	27	56
7 May	4a, deep	1	100	39	33	12	67			8	88	60	48
	4b, shallow			10	60	9	44			6	100	25	64
8 May	5a, deep	2	100	62	44	7	57			23	83	94	57
	5b, shallow	3	100	91	27	42	60			8	50	144	40
9 May	6a, deep			134	27	23	43	1		17	76	175	34
	6b, shallow			95	61	61	67			10	100	166	66
10 May	7a, deep	3	100	44	59	14	43			5	100	66	61
	7b, shallow	3	100	52	21	18	33	1	100	3	67	77	30

Test Series 2 (deep orifice vs shallow orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE (%)
13 May	1a, deep	2	100	31	32	16	25					49	33
	1b, shallow			48	56	30	77			3	67	81	64
14 May	2a, deep			60	30	9	44	10	10	7	57	86	31
	2b, shallow	2	100	72	54	45	87	9	56	8	100	136	68

Appendix Table 1. Continued.

Test Series 2 (deep orifice vs shallow orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE (%)
15 May	3a, deep			63	78	93	83	16	63	9	100	181	80
	3b, shallow			63	75	6	83	23	26	6	50	98	62
16 May	4a, deep			47	21	5	80	14	50	2	0	68	31
	4b, shallow	3	100	66	80	60	85	25	68	8	100	162	81
17 May	5a, deep			110	48	32	53	26	46	8	88	176	51
	5b, shallow	5	100	119	67	34	59	42	62	4	50	204	65

Test Series 3 (orifice attraction flow jets vs no orifice attraction flow jets exit efficiency)

Date	Replicate, treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE (%)
30 May	1a, jets	39	79	29	41	20	45	1	100	1	100	90	60
	1b, no jets	16	88	30	30	17	53			4	25	67	49
31 May	2a, jets	67	90	79	49	26	65			2	100	174	68
	2b, no jets	18	83	41	10	23	48			2	0	84	36
4 June	3a, jets	16	94	39	31	19	63			1	100	75	53
	3b, no jets	25	72	64	36	19	68			5	100	113	52
5 June	4a, jets	30	70	21	43	4	50			2	100	57	60
	4b, no jets	18	94	9	22	2	50			4	75	33	70
6 June	5a, jets	58	48	18	11	3	33					79	39
	5b, no jets	46	83	10	30	7	71			1	100	64	73
7 June	6a, jets	66	80	22	36	4	50					92	68
	6b, no jets	82	91	11	45	9	89					102	86

Appendix Table 1. Continued.

Test Series 4 (in-line rectangular orifice vs 90° circular orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE (%)
12 June	1a, circular	2	50	2	100							4	75
	1b, rectangular	66	97	23	100					1	100	90	98
12 June	2a, circular	10	50	6	50	1	100					17	53
	2b, rectangular	61	92	16	88	1	100					78	91
12 June	3a, circular	19	68	4	0							23	57
	3b, rectangular	12	92	4	100							16	94
13 June	4a, circular	27	96	10	70	2	100			1	100	40	90
	4b, rectangular	29	79	10	100			1	100			40	85
13 June	5a, circular	36	83	9	67							45	80
	5b, rectangular	50	90	11	100							61	92
13 June	6a, circular	35	86	5	80	2	100					42	86
	6b, rectangular	39	95	11	100	3	100					53	96
14 June	7a, circular	33	91	1	100	2	100					36	92
	7b, rectangular	26	100	2	50	4	50					32	91
16 June	8a, circular	91	96	13	38	18	33	1	100	2	50	125	80
	8b, rectangular	113	100	13	100	9	100			1	100	136	100
17 June	9a, circular	123	89	8	25	3	0					134	83
	9b, rectangular	41	100	5	80	7	57					54	93
17 June	10a, circular	51	65	9	56	5	100					62	65
	10b, rectangular	41	95	7	100	7	100			1	100	56	96
18 June	11a, circular	53	68	2	50	1	100					56	68
	11b, rectangular	49	96									49	96

Appendix Table 1. Continued.

Test Series 4 (in-line rectangular orifice vs 90° circular orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye		Total catch	
		Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)
18 June	12a, circular	113	100									113	100
	12b, rectangular	149	97	3	100	1	0					153	96
18 June	13a, circular	243	58	2	50	2	50					247	58
	13b, rectangular	149	97	3	100	1	0					153	96
19 June	14a, circular	99	67	2	50	1	100					102	67
	14b, rectangular	65	97	2	100							67	97
20 June	15a, circular	155	81	1	100							156	81
	15b, rectangular	174	75									174	75
20 June	16a, circular	34	88									34	88
	16b, rectangular	80	100									80	100
20 June	17a, circular	89	97	2	0	1	0					92	93
	17b, rectangular	7	86									7	86
20 June	18a, circular	157	93			1	0					158	92
	18b, rectangular	126	95	2	100	3	100					131	95
21 June	19a, circular	37	92	2	50							39	90
	19b, rectangular	95	100	5	100					1	100	101	100
21 June	20a, circular	83	82	3	100	1	100					87	83
	20b, rectangular	199	99	4	100							203	100
22 June	21a, circular	54	100			1	0					55	98
	21b, rectangular	115	100	2	100							117	100
22 June	22a, circular	68	91	3	33	1	0					72	88
	22b, rectangular	209	100	6	100					1	100	216	100

Appendix Table 1. Continued.

Test Series 4 (in-line rectangular orifice vs 90° circular orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye		Total catch	
		Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)
24 June	23a, circular	70	100	4	100							74	100
	23b, rectangular	140	100							2	100	142	100
24 June	24a, circular	52	98									52	98
	24b, rectangular	112	99	7	100							119	99
24 June	25a, circular	62	92	1	100	1	0					64	91
	25b, rectangular	127	99	1	100							128	99
25 June	26a, circular	67	60	2	50	1	100					70	60
	26b, rectangular	124	100	1	100							128	100
25 June	27a, circular	113	90	2	100							115	90
	27b, rectangular	215	100									215	100
25 June	28a, circular	97	77									97	77
	28b, rectangular	110	96									110	96
26 June	29a, circular	140	81	2	100							142	81
	29b, rectangular	52	100									52	100
26 June	30a, circular	189	84									189	84
	30b, rectangular	46	100	3	100	1	100					50	100
26 June	31a, circular	136	93	1	100	1	0					138	92
	31b, rectangular	70	100	1	100							71	100
27 June	32a, circular	130	89									130	89
	32b, rectangular	80	100									80	100
27 June	33a, circular	73	97									73	97
	33b, rectangular	26	100									26	100

Appendix Table 1. Continued.

Test Series 4 (in-line rectangular orifice vs 90° circular orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE (%)
27 June	34a, circular	72	78	1	0	1	0					74	76
	34b, rectangular	74	99	2	100							76	99
28 June	35a, circular	158	87	2	50	4	50					164	86
	35b, rectangular	42	100			2	100					44	100

Test Series 5 (in-line rectangular orifice vs lowered 90° circular orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE(%)
28 June	1a, circular	226	84	3	67	5	80					234	83
	1b, rectangular	82	91	4	100	4	100					90	92
29 June	2a, circular	109	83			1	0					110	83
	2b, rectangular	31	81			1	100					32	81
29 June	3a, circular	241	95	1	100	1	0					243	95
	3b, rectangular	79	99									79	99
29 June	4a, circular	250	91	1	0							251	91
	4b, rectangular	76	100									76	100
29 June	5a, circular	92	72	1	0	1	0					94	70
	5b, rectangular	100	91									100	91
1 July	6a, circular	300	83	2	100							302	83
	6b, rectangular	195	97	1	100							196	97

Appendix Table 1. Continued.

Test Series 5 (in-line rectangular orifice vs lowered 90° circular orifice exit efficiency)

Date	Replicate, Treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE (%)
1 July	7a, circular	302	77									302	77
	7b, rectangular	111	99									111	99
1 July	8a, circular	40	83									40	83
	8b, rectangular	174	100									174	100
1 July	9a, circular	178	89									178	98
	9b, rectangular	114	97									114	97
1 July	10a, circular	63	70									63	70
	10b, rectangular	332	96	1	100							333	96
2 July	11a, circular	54	81									54	81
	11b, rectangular	323	97									323	97
3 July	12a, circular	124	98									124	98
	12b, rectangular	168	99									168	99
3 July	13a, circular	52	73									52	73
	13b, rectangular	152	100									152	100

Test Series 6 (deep in-line rectangular orifice vs shallow in-line rectangular orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook Catch	Subyearling chinook OEE (%)	Yearling chinook Catch	Yearling chinook OEE (%)	Steelhead Catch	Steelhead OEE (%)	Coho Catch	Coho OEE (%)	Sockeye Catch	Sockeye OEE (%)	Total catch Catch	Total catch OEE (%)
16 July	1a, deep	72	94									72	94
	1b, shallow	111	99									111	99
16 July	2a, deep	44	93									44	93
	2b, shallow	95	97									95	97

Appendix Table 1. Continued.

Test Series 6 (deep in-line rectangular orifice vs shallow in-line rectangular orifice exit efficiency)

Date	Replicate, treatment	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye		Total catch	
		Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)	Catch	OEE (%)
16 July	3a, deep	26	88									26	88
	3b, shallow	28	96									28	96
17 July	4a, deep	105	89	3	100							108	89
	4b, shallow	62	95	3	100							65	95
17 July	5a, deep	50	98	2	100							52	98
	5b, shallow	72	100	2	100							74	100
17 July	6a, deep	340	97	3	100							343	97
	6b, shallow	28	100									28	100

Appendix Table 2. Statistical analyses of mean orifice exit efficiency (OEE) and separation efficiency values obtained during biological design criteria testing at McNary Dam, 1996. Asterisks indicate statistically significant differences between means.

Test series	Test dates	Species	Analysis source	Analysis type	Calculated test statistic	df	P
1	2-10 May	Yearling chinook salmon	Orifice depth (deep vs. shallow)	2 t-test[a]	0.3962	7	0.7038
		Steelhead	OEE[b]	2 t-test	0.9591	4	0.3918
		Total salmonids		2 t-test	0.6949	10	0.5029
2	13-17 May	Yearling chinook salmon	Orifice depth (deep vs. shallow)	2 t-test	2.2011	8	0.0589
		Steelhead	OEE	2 t-test	1.3595	5	0.2321
		Total salmonids		2 t-test	2.2965	8	0.0507
3	30-31 May	Subyearling chinook salmon	Orifice attraction jets (jetted	2 t-test	1.1425	7	0.2908
	4-6 June	Yearling chinook salmon	vs. non-jetted orifice) OEE	2 t-test	1.3243	6	0.2336
		Total salmonids		2 t-test	0.3432	10	0.7385
4	12-28 June	Subyearling chinook salmon	Perpendicular circular vs. in-line rectangular orifice OEE	paired t-test[c]	5.1782*	28	<0.0001
5	28-29 June	Subyearling chinook salmon	Lowered perpendicular circular orifice vs. in-line rectangular orifice OEE	paired t-test	5.0082*	12	0.0003
6	16-17 July	Subyearling chinook salmon	Orifice depth (deep vs. shallow) OEE	paired t-test	5.0096*	5	0.0041
7-10	6-15 Aug	Subyearling chinook salmon	HVF[d], separation bar length	ANOVA[e]	5.12*	3,43	0.0041
			HVF, flume discharge	ANOVA	2.73	2,43	0.0768
			HVF, interaction between separation bar length flume discharge	ANOVA	0.80	6.43	0.5781
		Subyearling chinook salmon	HVF, separation efficiency vs. separation bar length	regression coefficient	0.15*		0.0039

[a] Two sample t-test.
[b] Orifice exit efficiency.
[c] Paired t-test.
[d] High velocity flume separator.
[e] Two factor analysis of variance.

Appendix Table 3. Numbers of subyearling chinook salmon caught for individual replicates of separation efficiency tests using a prototype high-velocity flume at McNary Dam, 1996.

Test series	Sample date	Separation-bar length (m), angle	Discharge (m^3/s)	Total catch	Number separated	Separation efficiency (%)
7	6 Aug	3.7 (4.5°)	0.42	101	93	92
		3.7 (4.5°)	0.42	80	67	84
		3.7 (4.5°)	0.42	60	51	85
		3.7 (4.5°)	0.42	125	85	68
	7 Aug	3.7 (4.5°)	0.42	104	90	87
	5 Aug	3.7 (4.5°)	0.47	52	30	58
	6 Aug	3.7 (4.5°)	0.47	114	68	60
	6 Aug	3.7 (4.5°)	0.47	120	98	82
	6 Aug	3.7 (4.5°)	0.47	56	48	86
	6 Aug	3.7 (4.5°)	0.47	25	24	96
	7 Aug	3.7 (4.5°)	0.50	55	46	84
	7 Aug	3.7 (4.5°)	0.50	185	164	89
	7 Aug	3.7 (4.5°)	0.50	120	75	90
	7 Aug	3.7 (4.5°)	0.50	109	84	75
	7 Aug	3.7 (4.5°)	0.50	119	90	77
	7 Aug	3.7 (4.5°)	0.50	25	24	96
8	8 Aug	2.9 (5.4°)	0.42	189	182	96
	8 Aug	2.9 (5.4°)	0.42	115	104	90
	8 Aug	2.9 (5.4°)	0.42	50	45	90
	8 Aug	2.9 (5.4°)	0.47	80	76	61
	8 Aug	2.9 (5.4°)	0.47	61	49	80
	8 Aug	2.9 (5.4°)	0.47	64	52	81
	8 Aug	2.9 (5.4°)	0.50	112	81	72
	8 Aug	2.9 (5.4°)	0.50	163	126	77
	8 Aug	2.9 (5.4°)	0.50	30	19	63
	8 Aug	2.9 (5.4°)	0.50	86	76	88
9	9 Aug	2.2 (7.3°)	0.42	32	23	72
	9 Aug	2.2 (7.3°)	0.42	112	98	88
	10 Aug	2.2 (7.3°)	0.42	35	20	57
	10 Aug	2.2 (7.3°)	0.42	77	53	69
	10 Aug	2.2 (7.3°)	0.47	61	43	70
	10 Aug	2.2 (7.3°)	0.47	30	20	67
	10 Aug	2.2 (7.3°)	0.47	37	30	81
	9 Aug	2.2 (7.3°)	0.50	50	30	60
	9 Aug	2.2 (7.3°)	0.50	85	56	66
	9 Aug	2.2 (7.3°)	0.50	71	56	79

Appendix Table 3. Continued.

Test series	Sample date	Separation-bar length (m), angle	Discharge (m^3/s)	Total catch	Number separated	Separation efficiency (%)
10	12 Aug	1.4 (11.1°)	0.42	48	34	71
	12 Aug	1.4 (11.1°)	0.42	104	79	76
	12 Aug	1.4 (11.1°)	0.42	70	52	74
	12 Aug	1.4 (11.1°)	0.42	83	63	76
	12 Aug	1.4 (11.1°)	0.42	124	96	77
	12 Aug	1.4 (11.1°)	0.42	81	70	86
	12 Aug	1.4 (11.1°)	0.42	75	48	64
	12 Aug	1.4 (11.1°)	0.42	69	50	72
	12 Aug	1.4 (11.1°)	0.42	110	90	82
	12 Aug	1.4 (11.1°)	0.42	93	73	78
	12 Aug	1.4 (11.1°)	0.47	46	32	70
	12 Aug	1.4 (11.1°)	0.47	135	69	51
	12 Aug	1.4 (11.1°)	0.47	159	116	73
	13 Aug	1.4 (11.1°)	0.47	48	34	71
	13 Aug	1.4 (11.1°)	0.47	67	47	70
	12 Aug	1.4 (11.1°)	0.50	66	49	74
	12 Aug	1.4 (11.1°)	0.50	40	27	68
	13 Aug	1.4 (11.1°)	0.50	59	43	73
	13 Aug	1.4 (11.1°)	0.50	100	71	71

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