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Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by

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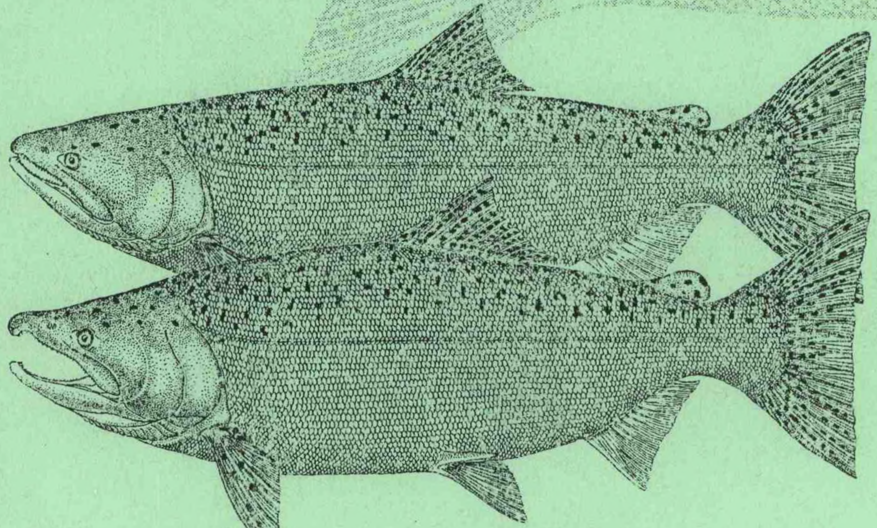
November 2003



EVALUATION OF A PROTOTYPE HIGH-VELOCITY FLUME SEPARATOR AT ICE HARBOR DAM, 1999

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Report of Research by

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EXECUTIVE SUMMARY

We evaluated operational criteria and the effects on fish of a prototype high-velocity flume (HVF) wet separator at Ice Harbor Dam. Prior to use, the test separator was evaluated for fish safety using hatchery salmonid smolts, and structural parameters were established to achieve the hydraulic conditions required for comparison among treatments. No test fish were injured during passage through the prototype HVF over four replicate releases. Several areas of concern were identified in the fish-handling portions of the flume, but these problems were corrected prior to the juvenile migration of spring 1999.

Three treatment factors were used in different combinations for a total of eight treatments. Treatment factors were separation-bar style (pedestal and non-pedestal), water velocity (1 and 2 m/s), and separation-bar depth (50 and 100 mm). Effects of the eight treatments on separation efficiency, separator exit efficiency, and fish condition were evaluated using river-run juvenile salmonids over their migration period. Fish were separated into small-fish (<180 mm fork length; FL) and large-fish (≥180 mm FL) groups by using a separation-bar spacing of 17 mm.

Twelve replicates were completed for each of the eight treatments, and results were analyzed using a block experimental design. For the total catch (all salmonids combined), there was no significant interaction among conditions for separation efficiency. Total catch separation efficiency was highest (78.3%) using pedestal separation bars, a water velocity of 2 m/s, and a depth of 50 mm. Separator exit efficiency was over 90% for all treatments and size groups. For the total catch, mean descaling values ranged from 2.7 to 4.1% for all combinations of separation-bar style and depth. Descaling was higher with water velocity at 2 m/s (3.9%) than at 1 m/s (3.0%).

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INTRODUCTION

Separation of smolts by size is an objective of juvenile bypass systems at hydroelectric dams on the Columbia and Snake Rivers. Juvenile chinook salmon *Oncorhynchus 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, Congleton et al. in press). In addition to stress reduction, separation provides management options based on different size classes.

Separation at U.S. Army Corps of Engineers (USACE) operated facilities evolved from the dry separation process, where fish were sorted using inclined pipes (McComas et al. 1998), to a wet separation approach. Wet separators presently used in bypass facilities at USACE-operated projects are similar to the wet separator developed and evaluated by Gessel et al. (1985). Since they keep fish submerged, wet separators are less stressful to migrants. These separators rely primarily on behavioral responses to induce smolts to attempt to sound (dive) between separation bars just under the water surface.

The wet separation process was described and operational separator units were diagramed in McComas et al. (1998). Essentially, conventional wet separators use a three-stage process designed to remove first small fish, then larger smolts, and finally adult salmonids, non-salmonid incidental species, and debris. Appropriate spacing of the separation bars in successive compartments determines the size of fish able to sound at each stage. Under ideal conditions, the first compartment, or "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, which are sorted in the center, or "B" section.

In practice, there have been several problems with existing wet separators. For example, in 1998, the McNary Dam separator exhibited poor performance in the A section, resulting in separator efficiency values of 41.4, 22.9, and 26.7% for yearling chinook, coho, and sockeye salmon respectively (Hurson et al. 1999). A possible explanation is that flow surges carried small fish through the first section with insufficient time or inadequate stimulus to generate a sounding response, which causes 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 existing separators (Schreck et al. in prep). This work suggests that fish may exit from fatigue generated by resistance to hydraulic conditions within the unit, resulting in increased overall stress, which could ultimately affect survival.

During the early spring of 1996, interagency meetings were held to present solutions and alternatives to the existing wet separator. One idea to emerge was the high-velocity flume (HVF) model, in which fish would be induced to separate in a flume while passing over an array of separation bars. Preliminary studies to evaluate juvenile salmonid separation in a high-velocity flume were conducted at McNary Dam during the latter part of the fall chinook salmon juvenile migration in 1996 (McComas et al. 1998).

Results demonstrated that a substantial proportion of fall chinook salmon will sound through separation bars at higher velocities than are normally present in existing wet separators, if sufficient separation-bar length is available. Evaluation of an expanded experimental HVF during 1997 and 1998 established initial criteria for separation-bar length, water velocity, separation-bar array orientation, depth of the bar array, and separation-bar spacing (McComas et al. 2000, 2003).

A fully functional prototype HVF separator was constructed at Ice Harbor Dam and available for testing in late November 1998 (Figure 1). Using criteria generated during the preliminary evaluation of HVF separators at McNary Dam, personnel of the National Marine Fisheries Service (NMFS) continued to develop HVF criteria at Ice Harbor Dam during the 1999 juvenile migration by considering the relationship among separation-bar array style (pedestal or non-pedestal), depth of the separation bars (50 or 10 mm), and water velocity (1 or 2 m/s).

The following were specific research objectives in 1999:

1. Establish operational criteria for evaluations of a high-velocity flume wet separator prior to the 1999 juvenile salmonid migration.

2. Evaluate the impacts on fish of a high-velocity wet-separator and its modular components.

3. Evaluate the effects of separation-bar style, water velocity, and separation-bar depth on volitional sounding response and separation in a high-velocity flume wet separator.

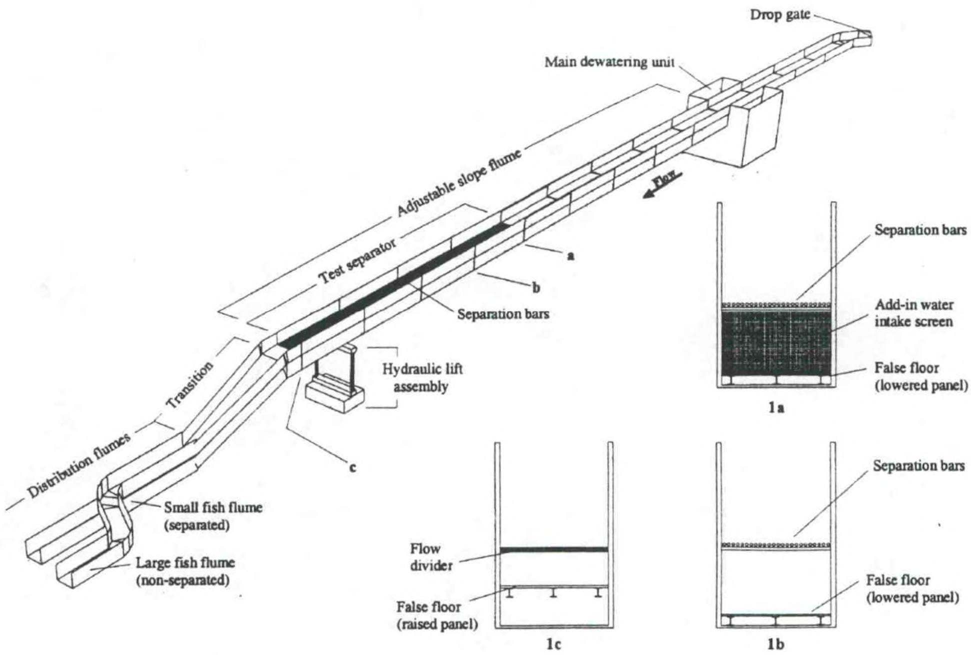


Figure 1. Relationship among major components of the test separator facility used during separation efficiency studies at Ice Harbor Dam, 1999. Cross sections (1a-1c) show the relationship of internal high-velocity flume components at the upstream (1a) and downstream (1c) ends of the test separator, and typical arrangement through the center (1b).

OBJECTIVE 1: Establish Operational Criteria for Biological Evaluations of a High-Velocity Flume Wet Separator Prior to the 1999 Juvenile Salmonid Migration

Test Separator Design

A prototype high-velocity flume wet separator was constructed parallel to and north of the existing Ice Harbor Dam juvenile fish bypass facility (Katz 1996, Katz et al. 1999). A new drop gate upstream from the existing facility allowed flow containing fish from the juvenile fish bypass channel to be diverted to the test separator during evaluation periods.

Following diversion to the test facility, flows passed through a primary dewaterer to reduce volume, then through a combined adjustable-slope channel and test-separator section (Figure 2b, 2c). Two distribution flumes, one for separated fish (fish which have sounded between the separation bars) and a second for non-separated fish, provided egress routes at the downstream end of the test separator (Figures 2e, 2f). Switch gates in each of the distribution flumes permitted fish to be directed to the juvenile bypass outfall pipe for direct return to the river, or to holding tanks for examination and enumeration.

The test separator occupied the downstream 12 m of the variable-slope flume (Figure 1). The separator was 1 m wide, 1.5 m high, and comprised of four 3-m sections. Separation-bar length could be varied in 3-m increments to a maximum of 12 m, and separation-bar array angle could be adjusted from 0° to approximately 2.3° relative to the stationary floor of the separator. A false floor under the separation bars was also constructed in four 3-m panels, and sections were independently adjustable from 0 to 360 mm depth under the bars (Figure 1b, 1c).

The adjustable-slope flume and test separator formed a single 30.5-m unit mounted to twin I-beams. The range of flume discharge entering the separator was adjustable from 0.064 to 0.576 m^3/s (2.26 to 20 ft^3/s). Slope was set using a hydraulic lift mechanism and was variable from 0 to 4° to provide water velocities from under 1 m/s to approximately 3 m/s. Velocity could be adjusted by raising or lowering the false floor, and each panel or the entire false floor could be angled or flat in relation to the floor of the flume.

Depth in the flume at the separator entrance was adjustable between about 50 and 230 mm. Depth over the bars could be varied either by using vertical adjusters for the separation-bar array, by adjusting the angle of the entire test separator, or by regulating the primary water supply and an independent makeup water supply under the separation bars at the upstream end of the separator unit.

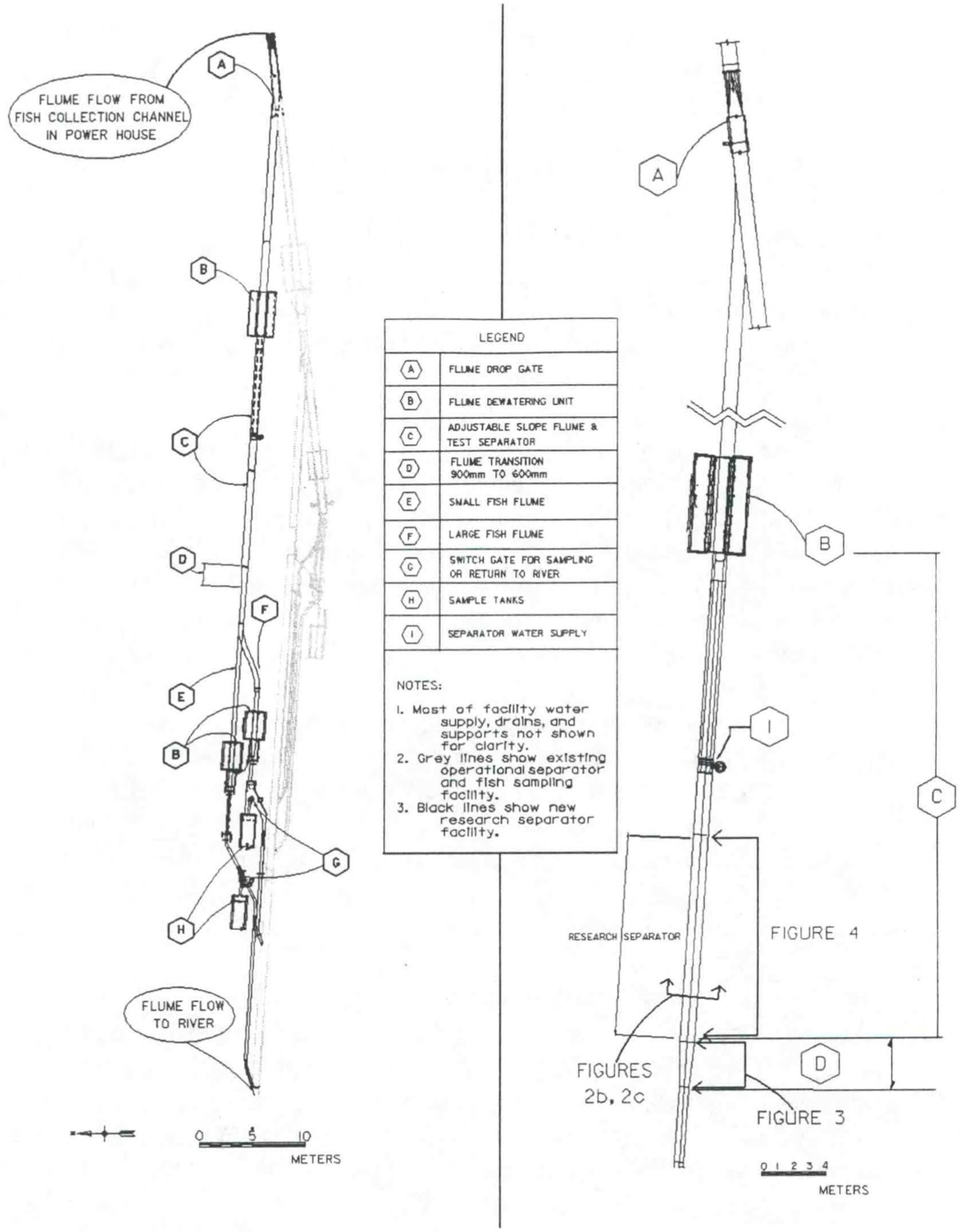


Figure 2. General plan view of the test separator system and existing fish separator/sampling facility (shown in grey on left) and enlarged plan view of new test separator system at Ice Harbor Dam. Flow is from top to bottom in each figure.

The test separator was designed to produce velocities and depths in the subcritical, critical, and supercritical ranges. Water surface, separation bars, and flume bottom were designed to be nearly parallel in the separator, and several adjustments were available to align them. A water supply pipe was designed to direct water downstream (underneath the separation bars) with velocity similar to that in the flume (Figure 2i). Water velocity in the flumes exiting the downstream end of the separator was similar to velocity in the separator. With the adjustable-slope flume, flume dewatering, and water supply, it was possible to control incoming water velocity and depth almost independently.

High-velocity separation, especially when near or above critical velocity, depends on a divider at the downstream end of the separation bars (Figure 3). The divider in the Ice Harbor test separator was rounded and did not protrude above or below the separation bars. This design was intended to prevent fish injury and delay by dividing the flow smoothly above and below the bars without forming a hydraulic jump.

Individual separation bars were spaced 17 mm (0.67 in) apart. Separation bars were 31.75-mm (1.25-in) aluminum tubing attached to perpendicular cross members to maintain lateral spacing between bars and to support the bars in the flume (Figures 4-5). Two separation bar designs were evaluated; each was composed of four interconnecting panels 0.90 m (3.00 ft) wide and 3.05 m (10.00 ft) long.

The two bar designs differed only in their method of support. In one design, bars were welded directly to the cross-support; in the other design, bars were welded to pedestals that effectively lowered the cross-supports 25.4 mm farther below the water surface (Figure 5). The lower support bars were considered potentially better hydraulically (less surface disturbance in high-velocity flow). The test separator had one stage and was designed to separate juvenile chinook salmon from larger size-classes. It was not a complete two-stage separator with the capability of simultaneously separating two size-classes of juveniles from adults and trash.

Flush lines were provided to the existing bypass facility and to the test facility to supply water when the drop gate was opened or closed. However, the flush lines furnished only about 0.15 m^3/s, compared to 0.9 m^3/s with normal flow through either system. Shut-down procedures for both the existing bypass and the test facility dewatering structures were documented to prevent stranding of fish remaining in the system when the drop gate was operated.

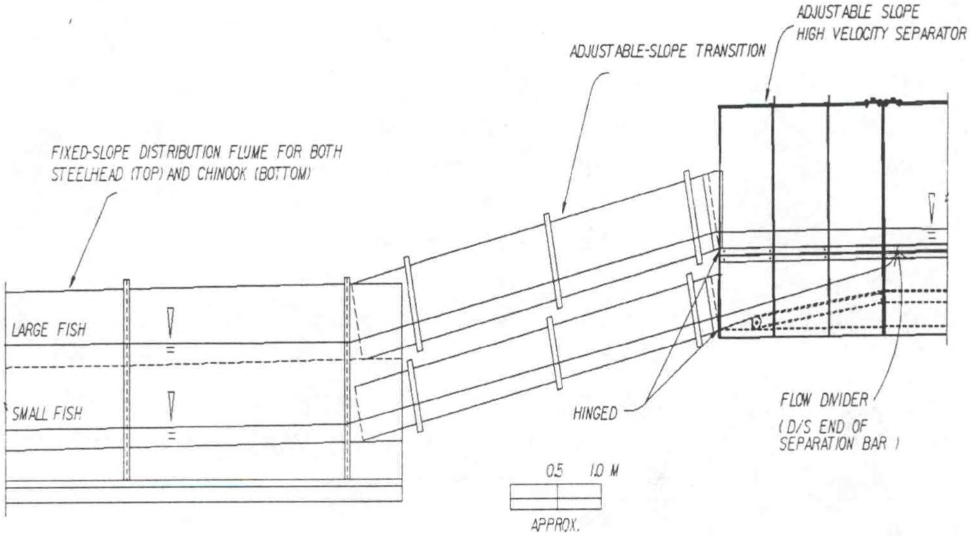


Figure 3. Elevation view of the adjustable-slope transition carrying fish from the downstream (D/S) end of the high-velocity flume wet separator to the fixed slope distribution flumes.

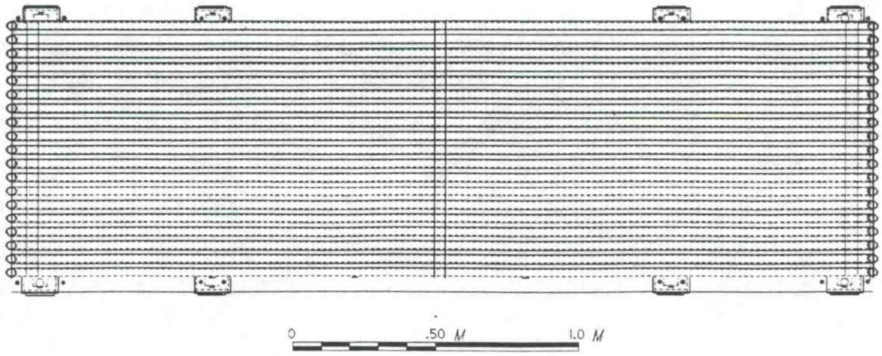
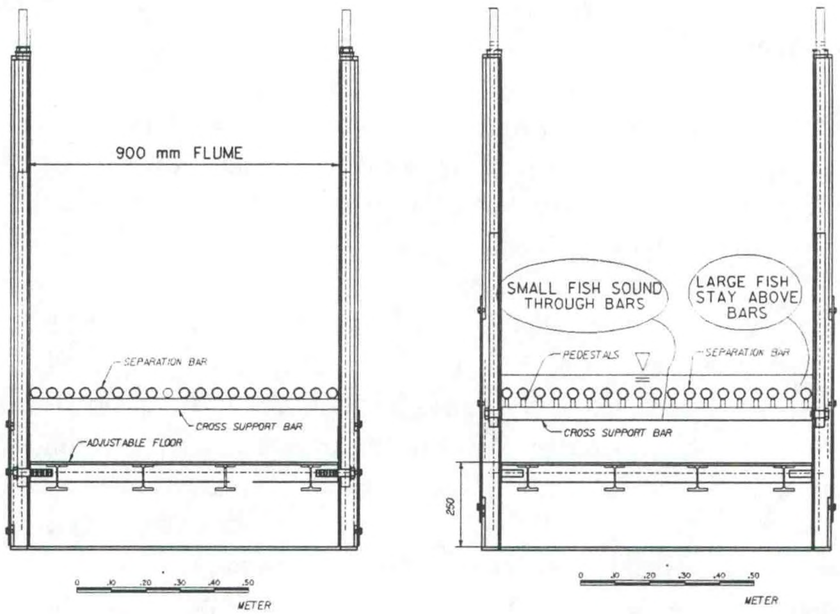


Figure 4. Plan view of a separation bar assembly representing one of four identical 3-m panels shown (for example, from point 6 to 7 in Appendix Figure A5).



(a) (b)

Figure 5. Separation bar and support detail. Separation bars welded directly to cross-supports (a) were compared to separation bars welded to pedestals on cross-supports (b).

Hydraulic Testing

Hydraulic testing was performed prior to the biological tests to reduce impacts to fish, which would otherwise have been subjected to trial and error calibration for each test treatment on successive replicates. Specific criteria for this objective involved identification and recording of primary dewaterer and variable-slope flume adjustments resulting in water depths over separation bars of 50 and 100 mm, with water velocities of 1 and 2 m/s at each depth. Aside from recording settings for the targeted hydraulic conditions, an additional purpose of hydrauic tests was to assure reproducibility of these conditions.

We had planned to test eight combinations of hydraulic conditions, all with water velocities higher than those found in existing operational separators (1 m/s and faster, Table 1). Treatments 1-4 were designed to use non-pedestal bar arrays, while Treatments 5-8 were designed to use the pedestal bars. However, the pedestal-style separation bars were not available prior to the juvenile migration; therefore, hydraulic conditions for Treatments 5, 6, 7, and 8 were not measured prior to evaluation with juvenile salmonids.

Water velocity and depth were replicated by recording the flume slope, water supply discharge, and dewatering settings for each hydraulic test. To assure that the conditions were reproducible, the hydraulic tests were performed twice for three of the four treatments (Treatments 1, 2, and 3).

For Treatments 1 through 4, velocity was measured above and below the separation bars at intervals of 3.05 m (10 ft) along the flume, at the end of each 3.05 m-long bar segment. A propeller meter (51-mm-diameter propeller) and an Acoustic Doppler Velocimeter (ADV) with sensors capable of detecting water movement in three dimensions (vertical, across the flume, and along the flume) were used. Velocities were measured for 20-40 s at each point with a Swoffer meter. This procedure assumed nearly one-dimensional, steady flow. The assumption was verified with three-dimensional, time-history measurements at selected points (obtained with the ADV).

Depth measurements for each separator test were made to determine the flow profile over the separator bars. Measurements were made with a tape measure and were accurate to within approximately 10 mm due to wave action.

Table 1. Target hydraulic conditions for separation evaluation conditions using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999. Treatments 5-8 (using pedestal bars) were not evaluated prior to biological testing. Depth below the separation bars was a constant at 410 mm for all treatments.

	Treatment number							
Condition	1	2	3	4	5	6	7	8
Water velocity (m/s)	1	1	2	2	1	1	2	2
Bar depth (mm)	50	100	50	100	50	100	50	100
Pedestal bar support	No	No	No	No	Yes	Yes	Yes	Yes

Results and Discussion

Test configurations generated both subcritical and critical flow velocities. Supercritical flow was generated, but not tested. Water depth in the test separator was governed by a downstream control (the change from mild to steep slope at the downstream end of the separator) when overall velocity was subcritical.

This was the case in the two conditions with an average flow velocity in the separator of 1 m/s and Froude number of about 0.45 (Treatments 1-2). The other two treatments reached nearly critical flow velocity (2 m/s) and a Froude number of 0.9. In these conditions, depth was controlled by channel slope and a combination of resistance caused by the separation bars and channel boundary.

For all four treatments, flow regime was clearly identifiable by observation. In subcritical flow, a hydraulic jump formed just upstream from the separator where rapid upstream flow met lower-velocity separator flow. In critical flow conditions (Treatments 3-4), no distinct jump was present, but a series of clearly defined standing waves appeared in the separator with crests at the separation bar cross-supports and troughs in between.

Surprisingly, the wave location and amplitude were predictable and stable. Care was taken to assure that wave troughs remained above the separation bars to avoid forcing juveniles across unsubmerged bars. While critical flow is typically associated with unpredictable wave action and potential structural damage in larger open channels, it did not pose any problems in the separator.

The minor, regular obstructions caused by cross-supports forced the critical flow into a regular wave pattern that was not harmful and may have improved separation efficiency by causing an alternating exchange of water through the separation bars. Wave amplitude was about 20 mm, resulting in a change in separation bar depth of about 40 mm over each 1.5-m interval between cross supports.

For each treatment, flow velocity above and below separator bars was kept approximately equal. In addition, there was little variability along or across the separation bars (Appendix Figures A1-A7), with the minor exception of small standing waves in critical flow. Most velocity measurements were within 10 percent of the intended average velocity for each treatment (Appendix Figures A1-A7 and Appendix Tables A1-A7).

Changes to distribution flume dewatering structure settings were documented for various flow conditions to prevent stranding or injury to fish while passing through those routes to holding tanks or the facility bypass pipe.

Two facility design restrictions were noted which were not correctable during the time available prior to the spring migration. To ensure fish safety, the test design for biological evaluations was modified to accommodate these system limitations by altering the orientation of components in the test separator facility. For example, with the false floor fully lowered and water velocities matched above and below the separation-bar array, flows were subverted at the downstream end of the flume for all conditions so that the downstream end of the bars and the entire upper (non-separated fish) transport flume were exposed.

To alleviate this problem, the downstream end of the downstream false floor panel was raised from the completely lowered position. This created a sloped floor over the last 3 m of the separator, and effectively formed a weir which forced water up through the downstream end of the separation bars and into the upper transport flume.

However, even with the false floor panel raised, using a water velocity of 1 m/s with a separation-bar depth of 50 mm resulted in all water being subverted to the lower (separated fish) distribution flume, so that the downstream end of the separation-bars and the upper (non-separated fish) distribution flume were dry.

Correcting this deficiency required lowering the downstream end of the downstream separation-bar panel approximately 76 mm to reestablish flows in the upper flume and submerge the end of the downstream panel. To maintain consistent conditions among treatments, all replicates in 1999 were conducted with this slope of about 1.5° along the downstream separation-bar panel.

OBJECTIVE 2: Evaluate the Impacts on Fish of a High-Velocity Flume Wet Separator and its Modular Components

Approach

The newly constructed test facility was evaluated to determine whether the system provided safe passage conditions for migrating juvenile fish. The entire system was encompassed in the evaluation, including the drop gate, main dewaterer, adjustable slope flume, distribution flumes, and handling facilities.

This evaluation was similar to previous evaluations of fish passage facilities, where groups of healthy, marked test fish were released above the test facility and recaptured and examined for injury during transit through the system. This portion of the study was completed in early December 1998 to allow time for hazardous conditions noted during evaluation to be corrected.

The goal of this approach was to gather the maximum of data for operational criteria (Objective 1) and to allow for hydraulic manipulation of the facility without concern for impacting large numbers of migrating juvenile salmonids. Unfortunately, hatchery yearling chinook salmon and steelhead were not available when this evaluation took place. Therefore, we used smolt-sized hatchery-reared rainbow trout *Salmo gairdneri* from Lyons Ferry Hatchery to evaluate gross problems with the system.

We recognized that rainbow trout were not adequate surrogates for migrant juvenile salmonids undergoing the physiological changes associated with parr-to-smolt transformation. However, during the 1999 juvenile salmonid migration, we compared descaling and injury rates (fish condition) of fish traversing our system to those passing the existing bypass system. Fish condition was evaluated biweekly during the juvenile migration by the Washington State Department of Fish and Wildlife for the Smolt Monitoring Program. Our comparisons indicated no material differences in descaling or injury between our system and the existing bypass system. This afforded a dependable check on the safety of the test facility, since the existing bypass system has been evaluated and judged safe for smolt passage (Gessel et al. 1997).

Following transport to the site, test fish were held and fed daily in the juvenile bypass facility holding tank for 5 d prior to the evaluation. Immediately preceding release, approximately 100 individuals of each release group were anesthetized and examined for visible signs of physical injury. Only non-descaled fish with no defects were used for the evaluation.

Test fish were marked by partially clipping one lobe of the caudal fin, alternating between upper and lower lobe clips for successive release groups. Following a period of at least 1 h for recovery from the effects of the anesthetic, test fish groups were released into the juvenile fish bypass transport pipe, approximately 2 m upstream from the new drop gate. The gate was left open to route flows through the new test facility.

After passing through the test facility, fish were routed into one of two holding tanks, depending on whether or not they had sounded between the separation bars. All fish captured in holding tanks were pre-anesthetized with tricaine methanesulfonate (MS-222) and transferred to a fish-handling building. Fish from each holding tank were examined for external injury, including mortality, abrasions, or contusions.

Percent descaling was recorded using Fish Transportation Oversight Team (FTOT) descaling criteria (Ceballos et al. 1992). Following recovery from anesthetic, test fish were returned to the facility holding tank and held separately from test fish that had not yet been used for evaluation. Incidental catch were allowed to recover separately and were released directly to the outfall pipe for return to the river.

Slope of the adjustable portion of the test facility was approximately 2°. Water velocity, measured using a Swoffer 2000[1] flow meter, was set to 2.1 m/s above the separation-bars and 1.8 m/s for makeup-water inflow below the bars. These velocities were held constant across all four replicates.

Water depth over the separation-bar array was approximately 100 mm for the first two replicates. All four separation-bar panels were in place during the first two replicates. However, few fish actually sounded between the bars during these replicates, possibly because of interactions among the size of test fish, water velocity, and water depth. This resulted in inadequate assessment of the separated-fish section of the test separator downstream from the separator. Therefore, the two upstream separation-bar panels were removed, and water depth from the primary dewaterer was lowered for the last two replicates. This effectively diverted flows under the two remaining (downstream) separation-bar panels, and forced most fish through the separated-fish portion of the test separator.

1 Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Results and Discussion

The biological evaluation was conducted on 1 December 1998, with the first release at 0930 and successive releases at approximately 1-h intervals, or as soon as all fish from the former release had been recaptured and evaluated. Actual time for a group to pass through the system from the release point to the holding tanks was approximately 10 min at test velocity. No fish were observed holding in the system during this evaluation. Timing for each replicate, total recaptures, and total incidental captures are listed in Table 2.

None of the recaptured test fish were injured by passage through the test facility. Only three test fish were found to have been partially descaled, and descaling on each of the three fish was less than 5%. Using FTOT descaling criteria, there was no descaling (0%) for any of the four releases.

Several fish were captured incidentally as a result of being entrained in bypass channel flows that were diverted into the test facility (Table 2). Incidentals included adult steelhead, juvenile chinook salmon, juvenile channel catfish *Ictalurus punctatus*, and juvenile shad *Alosa sapidissima*. None of the incidental salmonids or the catfish showed any signs of physical injury, and all were released unharmed. Nine juvenile shad mortalities were removed from the holding tanks or recovered in the fish handling building, and two juvenile shad were found impinged on the transport flume dewatering screens before the controls were properly adjusted prior to testing.

Though no injury was noted due to passage through the separator and attendant transport and dewatering structures, two test fish were killed as a result of being pinned by the anesthetic lift basket gate during removal from the holding tanks. In addition, several shad were killed as a result of operating difficulties with the lift basket and crowder in the holding tanks.

A previous evaluation (McComas et al. 1998) recommended alterations to the fish-handling portion of the HVF test separator facility before use during the 1999 juvenile migration. These alterations are detailed below; all were completed prior to the 1999 juvenile migration.

1. Stainless steel gates between the holding tanks and the anesthetic lift basket wells were replaced with similar gates fabricated from aluminum. This reduced weight and allowed more control when lowering the gate, to avoid crushing fish entering the lift basket well.

Table 2. Timing, incidental catch, and recapture results for test fish (rainbow trout *Salmo gairdneri*) released during biological evaluation of the prototype separator test facility at Ice Harbor Dam, 1 December 1998.

Replicate identifier			Incidental catch				Test fish recapture site			
No.	Start time	Stop time	Adult steel-head	Juvenile chinook salmon	Channel catfish	Shad	No. released	Separated tank	Non-separated tank	Total re-captured
1[a]	0930	1027	1	2	1	17	113	13	100	113
2	1035	1133		1		2	110	10	102	112
3[b]	1225	1310		1		6	115	113	2	115
4	1320	1415				4	111	111		111

a Replicates 1 and 2 conducted with all separation-bar panels in place.

b Replicates 3 and 4 conducted with two upstream separation-bar panels removed.

2. A soft rubber gasket was installed along the bottom of the gate between the anesthetic lift basket well and the holding tank to help seal the gate, preventing jets caused by head differential between the tank and the well when the well was drained to anesthetize fish. We noted that before sealing the bottom edge of the gate, jets were strong enough to push stragglers into the walls of the well and lift basket, creating the potential for injury.

3. Three juvenile shad were trapped in a gap between the anesthetic lift basket evacuation gate and the side of the lift basket wall. There was no way to remove these fish intact. The gap was sealed with a gasket.

4. Numerous leaks around the lift basket gate permitted water in the basket to escape before the basket could be lifted into position to release fish to the handling facility. To correct this deficiency, both lift baskets were removed and the faulty seals were re-fabricated.

5. Holding tank crowder mechanism seals allowed fish to escape to the area behind the crowders. Seals on both crowders were bolstered with stiffeners to prevent escape.

OBJECTIVE 3: Evaluate the Effects of Separation-Bar Style, Water Velocity, and Separation-Bar Depth on Volitional Sounding Response and Separation in a Prototype High-Velocity Flume Wet Separator

Approach

Volitional separation efficiency, separator exit efficiency, and fish condition were evaluated using 12-m separation-bar arrays oriented parallel to the water surface. Separation bars were made of 25.4-mm (1-in) untreated aluminum tubing with a 32-mm (1.25-in) outside diameter. Spacing, or gap, between individual bars was 17 mm, intended to segregate small juvenile salmonid migrants from larger smolts.

Spacing between separation bars was maintained by cross supports perpendicular to the separation bars at 1.5-m (5-ft) intervals along each of the four panels forming the 12-m array. Two styles of separation-bar array were evaluated: a pedstal style, with bars supported approximately 25 mm above cross members by a 13-mm vertical rod at each attachment point; and a non-pedestal style, with individual separation bars attached directly to the cross supports (Figures 6-7).

The test separator was operated at separation-bar array depths of 50 mm or 100 mm for each of the separation-bar styles. At each depth, separation efficiency, fish condition, and separator exit efficiency were evaluated at water velocities of 1 and 2 m/s. Together, the three conditions formed eight treatments (Table 1).

Water velocities and separation-bar array depths were determined during the operational criteria phase in Objective 1. Similar water velocities were maintained above and below the array for each treatment. To minimize the effect of timing bias, the eight treatments were performed as a block, and blocks were conducted successively throughout the juvenile migration of spring 1999. One entire block of all eight treatments was evaluated before beginning the next block.

Completely randomizing the three factors was not possible from an operational standpoint, since changing between separation-bar arrays was considerably more time-consuming than changing the other two conditions. All four treatment combinations of velocity and depth were therefore evaluated for each separation-bar style before changing to the alternative style. However, the order of velocity and depth treatments within blocks for a given separation-bar style was randomized.

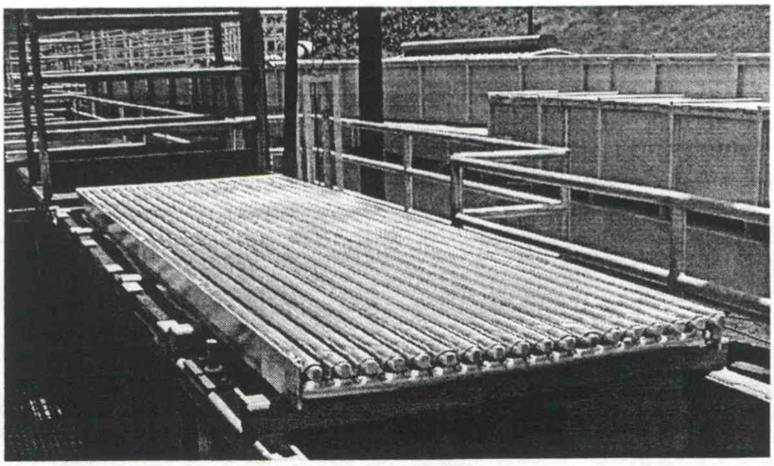


Figure 6. Typical 3-m long separation-bar panel used during evaluation of a high-velocity flume wet separator at Ice Harbor Dam, 1999.

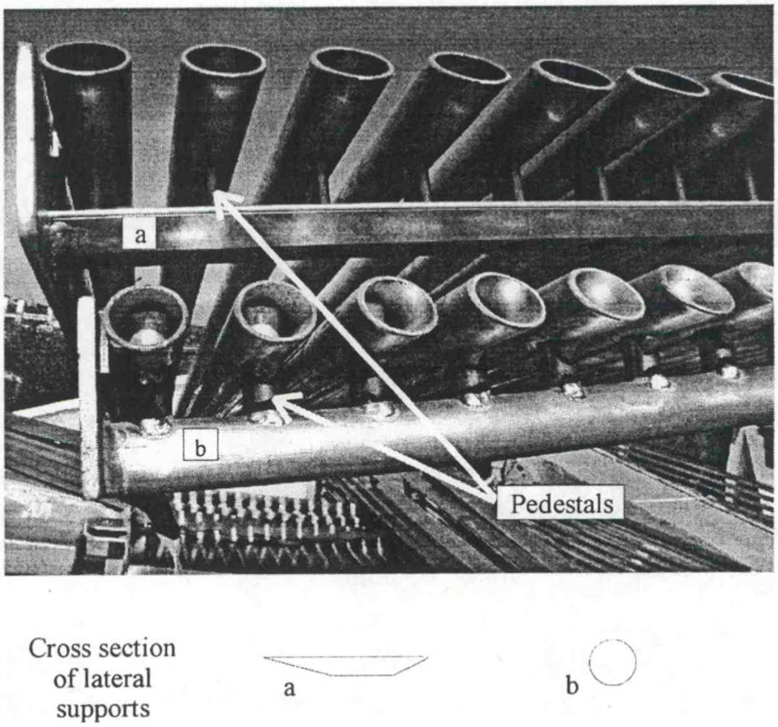


Figure 7. The two styles of lateral supports for pedestal-style separation-bar arrays: streamlined (a) and non-streamlined (b). Pedestal supports were compared during evaluations of a high-velocity wet separators at Ice Harbor Dam, 1999. Upstream-facing end is shown.

Prior to each replicate, treatment conditions were established in the flume. The test procedure was similar for each replicate. A replicate was initiated by opening the drop gate, allowing fish and flows exiting the Ice Harbor juvenile fish bypass channel to be routed to the test separator. River-run juvenile salmonid migrants were used for separation efficiency evaluations. Initial target sample size was 50-150 juvenile chinook salmon per replicate.

Replicate duration was dependent primarily on numbers of fish entering the flume rather than on time. A minimum sample size of 25 chinook salmon migrants was required for statistical validity, and the duration of replicates was contingent on obtaining at least this minimum sample. Fish exiting the separator section were routed into one of two holding tanks, dependent on whether they had separated (sounded between the separation bars) or not. When sufficient numbers of yearling chinook salmon had accumulated in the holding tanks, the drop gate was closed to shunt fish and flows back through the juvenile fish facility. Fish remaining in the separator were removed first from above and then from below the separation bars using flush water. Groups removed from above and below the bars formed the non-separated and separated groups, respectively.

Fish were anesthetized with tricaine methanesulfonate (MS-222) separately by recovery group (separator non-separated, separator separated, non-separated holding tank, separated holding tank), enumerated, and evaluated for descaling. Data were recorded by size group (<180 mm FL or ≥180 mm FL) for each species. Following a suitable period in fresh water for recovery from the effects of anesthetic, all fish were released into the juvenile bypass outfall pipe for return to the Snake River.

Separation efficiency (*SE*) was estimated by species, as the fraction of a given length group negotiating the separation bars divided by the total number of fish in that group having entered the separator during the test. *SE* was expressed as

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

where: A = *separated fraction*
T = *total number entering the test separator*

The separated fraction used in the calculation was relative to the size of the group under consideration. The separated fraction for small-fish groups represented the sum of fish from the separated-fish holding tank and those found in the separator below the separation bars at the end of the test. For large fish groups, the separated fraction represented fish that had not sounded between the bars, or the sum of those in the non-separated fish holding tanks and in the separator above the bars. Therefore, separation efficiency for small-fish groups increased with the number sounding between the separation bars, while separation efficiency for large fish increased with the number not sounding between the bars.

Separator exit efficiency (*EE*) was estimated as the proportion of fish having exited the test separator by the end of the test divided by the total number of fish entering the separator unit during the test, and was expressed as

$$EE_F = \frac{F}{T} \times 100\%$$

where: F = *fraction exiting the separator*
T = *total number entering the test separator*

Results and Discussion

A total of 26,396 smolts were included in evaluation of treatments using the Ice Harbor Dam prototype high-velocity flume separator facility in 1999. River-run yearling chinook salmon and steelhead comprised 51.5% (13,598) and 47.4% (12,512) of the catch, respectively. Steelhead made up 87% of the large-fish catch, while yearling chinook salmon made up 91% of the small-fish catch. Salmonid catch data are presented by replicate in Appendix Table B1. Total catch numbers for non-target incidental species are tabulated in Appendix Table B2.

Because of the practical limitations of exchanging separation-bar arrays, the randomization of treatments was restricted; the sequence of treatments within each block was not entirely random. Rather, treatments were evaluated for a given separation-bar style within a block before the alternative style was evaluated. Normally, this non-random effect is analyzed using a split-plot procedure (Petersen 1985), with time forming the two plots in this work (i.e., large time plots were blocks; small plots were separation-bar style groups within the blocks).

However, during similar studies in 1998 (McComas et al. 2003) we noted that because of weekend interruptions, a given replicate treatment in one block could actually be closer in time to replicates in the following or previous blocks than to other replicates within its own block. This was also true in 1999. For example, Treatments 1 and 2 in block 10 were completed on 21 May, closer in time to Treatments in block 9 than to Treatments 3 through 8 in block 10, which were completed on 24 and 25 May (Appendix Table B1). This type of disruption happened often enough during the study that we did not expect the "large time plots" and "small time plots" to differ much in their respective variances.

Confounding this point, sample sizes did not always meet the minimum criterion of 25. This often occurred for species other than chinook salmon, or for a size group of any species when the catch was divided into size classes. Where sample size for a given species/length group was less than 25, data were pooled with similar treatments from adjacent blocks. This resulted in further mixing of block data through time.

Data were therefore analyzed using a 3-factor analysis of variance rather than the split-plot procedure. Where pooling over successive blocks was not done, series (block) was included as a covariate. In general, sufficient numbers of smolts were available for analyses of separation efficiency, separator exit efficiency, and descaling for groups of small and large yearling chinook salmon and steelhead, as well as for total catch by species and group size. Evaluation of total catches was calculated by combining mean separation efficiency, descaling, or exit efficiency values for large and small size-groups.

Separation Efficiency

Results of statistical analyses among treatments for all separation efficiency comparisons are included in Appendix Table B3.

For small yearling chinook salmon there was a significant interaction between separation-bar depth and water velocity ($F = 2.37$, df = 1, $P = 0.017$), and between separation bar style and velocity ($F = 4.30$, df = 1, $P = 0.041$). Separation efficiency was significantly higher at 2 m/s water velocity with the bars submerged 50 mm (66%, s.e. = 2.1) than for all other depth/velocity relationships. Separation efficiency was also significantly higher using non-pedestal bars with the 2 m/s water velocity (61%, s.e. = 2.1) than for other style and velocity combinations.

Separation efficiency for large yearling chinook salmon exhibited no significant interaction among factors. Mean separation efficiency values were significantly higher ($F = 12.45$, df = 1, $P = 0.001$) at at a water velocity of 2 m/s (85%, s.e. = 2.49) than 1 m/s (73%, s.e. = 2.27) and higher ($F = 9.20$, df = 1, $P = 0.005$) with bars submerged 100 mm (84%, s.e. = 2.38) than 50 mm (74%, s.e. = 2.38).

Since 88% of the total chinook salmon catch were small fish, total chinook separation efficiency was similar to that for small chinook salmon. There was a significant interaction between separation-bar depth and water velocity ($F = 3.98$, df = 1, $P = 0.050$), and between separation-bar style and velocity ($F = 6.95$, df = 1, $P = 0.010$). Separation efficiency was significantly higher at 2 m/s water velocity with the bars submerged 50 mm (65%, s.e. = 1.93) than for other depth/velocity pairs, and higher using non-pedestal bars with the 2 m/s water velocity (62%, s.e. = 1.93) than for other bar style/velocity pairs.

There was no significant interaction among any combination of factors for small steelhead separation efficiency. Separation efficiency for this group was higher ($F = 6.43$, df = 1, $P = 0.020$) using pedestal separation bars (53%, s.e. = 3.52) than using non-pedestal bars (40%, s.e. = 3.40), and also higher ($F = 36.24$, df = 1, $P = 0.000$) at a velocity of 2 m/s (61%, s.e. = 3.40) than 1 m/s (32%, s.e. = 3.52).

Mean separation efficiency for the large steelhead group ranged from 93 to 98% among all comparisons, with little variability. With no interaction among factors, separation was significantly higher ($F = 11.53$, df = 1, $P = 0.001$) at a velocity of 1 m/s (97%, s.e. = 0.67) than 2 m/s (94%, s.e. = 0.68). Separation efficiency for all steelhead combined was similar to that of large steelhead, except that in addition to no interaction among treatment conditions, there were no significant differences among conditions. For the comparison of all eight treatments involving the three factors (style × velocity × depth), separation efficiency ranged from 89 to 93% (s.e. = 1.74).

With small chinook salmon comprising the bulk of the total number of small smolts sampled, separation efficiency of the total small salmonid catch was similar to that of the small chinook salmon catch. There was a significant interaction between separation-bar depth and water velocity ($F = 5.92$, df = 1, $P = 0.017$), and between separation-bar style and velocity ($F = 5.37$, df = 1, $P = 0.023$). Separation efficiency was significantly higher at 2 m/s water velocity with bars submerged 50 mm (65%, s.e. = 2.74) than for other paired depth/velocity combinations. Separation efficiency was also higher with non-pedestal bars and a velocity of 2 m/s (62%, s.e. = 2.74) than with other style and velocity combinations.

In a pattern similar to that seen with chinook salmon, analysis of separation efficiency for the large steelhead group paralled that of the total catch of steelhead. Significant differences in separation efficiency for the total large-smolt catch were observed with varying water velocity ($F = 18.83$, df = 1, $P = 0.00$) and separation-bar depth ($F = 5.66$, df = 1, $P = 0.020$). With no interaction among conditions, separation was higher at 1 m/s velocity (95%, s.e. = 0.83) than at 2 m/s (90%, s.e. = 0.83), and higher at the 100-mm (94%, s.e. = 0.83) than the 50-mm depth (91%, s.e. = 0.83).

In the absence of behavioral mechanisms, separation efficiency for the total salmonid catch probably offers the most realistic indication of overall performance of the test separator. In general, separation was high for large-fish groups and low for small cohorts, indicating that fish passed over the separation bars without encountering sufficient stimulus to produce a strong sounding response. For the total catch, separation efficiency displayed no interaction among any combination of conditions.

However, separation was significantly different for each individual factor (Appendix Table B3). Mean values were higher at 2 m/s water velocity (72%, s.e. = 1.15) than at 1 m/s (65%, s.e. = 1.15), and higher using pedestal separation bars (71%, s.e. = 1.15) than non-pedestal bars (66%, s.e. = 1.15). Separation was also higher at the 50-mm separation-bar depth (71%, s.e. = 1.15) than at the 100-mm depth (66%, s.e. = 1.15). The highest mean separation efficiency (78.3%, se = 2.31) was obtained with the pedestal separation bars submerged 50 mm with a 2-m/s water velocity.

During similar studies using an experimental high-velocity flume separator at McNary Dam, separation efficiency for the total salmonid catch was over 80% (McComas et. al 2003). Though separation was higher at a separation-bar depth of 50 mm than 100 mm during that study, it was also higher at a velocity of 1 m/s than 2 m/s.

Besides the variation in design between HVF separators at McNary and Ice Harbor Dam, there is also a difference in flow. In the HVF separator evaluted at McNary Dam, there was a consistent water exchange from above to below the separation bars over the length of the array (McComas et al. 2000). By contrast, there was little water exchange in HVF test separator evaluated here (Objective 1).

In addition, data from this evaluation suggest that fish using the prototype separator did not receive sufficient stimulus to sound (summed across all treatments), since total small-fish catch separation efficiency was low (46.3%, s.e. = 2.74) and total large-fish separation was high (93%, s.e. = 1.67). It is possible that increased flow interchange from above the bars may stimulate fish to sound to a greater depth. The relationship between separation and interchange of flows above and below the bars needs further clarification.

Separator Exit Efficiency

Mean separator exit efficiency, evaluated over the duration of each replicate, was over 98% for all replicates, regardless of species or size group under consideration (Table 3). Not surprisingly, mean exit efficiency was lower at the lower water velocity. Because exit efficiency was near 100% for all treatments, data for this variable were not formally analyzed.

Fish Condition

Results of statistical analyses among treatments for all descaling comparisons are presented in Appendix Table B4. There were no significant interactions among treatment factors for any yearling chinook salmon descaling comparison, and no statistical differences in descaling means for the large-chinook salmon group. Descaling was significantly higher at a water velocity of 2 m/s (6.6%, s.e. = 0.82) than 1 m/s (5.0%, s.e. = 0.82) for small fish ($F = 7.41$, df = 1, $P = 0.008$) and for the total chinook salmon catch ($F = 6.86$, df = 1, $P = 0.011$).

For large steelhead ($F = 8.63$, df =1, $P = 0.004$) and for the total steelhead catch ($F = 4.88$, df =1, $P = 0.030$), there was a significant interaction between separation-bar style and depth. Large steelhead descaling was significantly higher with the non-pedestal separation bars at the 100-mm depth than for all other separation-bar style and depth combinations (Table 3). For the total steelhead catch, descaling with the non-pedestal bars at the 100-mm depth was similar to descaling with the pedestal bars at the 50-mm depth, but was higher than descaling using the remaining two combinations.

Mean descaling for small steelhead ranged from 0.0 to 3.3% over the eight treatments. There were no significant interactions among conditions and no real differences among mean descaling values for the small-steelhead group.

Descaling for the total small-fish catch (all salmonids combined) exhibited a significant interaction among all three factors ($F = 4.11$, df = 1, $P = 0.046$). Small-smolt descaling was significantly higher at 2 m/s water velocity with the pedestal separation-bars at the 50-mm depth or with the non-pedestal bars at the 100-mm depth than for all other treatments except the non-pedestal bars at 50-mm depth with 2 m/s velocity (Table 4).

Table 3. Mean separator exit efficiency values by treatment for the total salmonid catch during separation efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999.

Treatment number	Separator exit efficiency (%)			
	Minimum	Maximum	Mean	s.e.
1	98.5	100.0	99.6	0.20
2	95.6	100.0	98.7	0.40
3	100.0	100.0	100.0	0.00
4	100.0	100.0	100.0	0.00
5	98.7	100.0	99.6	0.02
6	93.7	100.0	98.9	0.50
7	100.0	100.0	100.0	0.00
8	100.0	100.0	100.0	0.00

Table 4. Mean descaling values for large steelhead (≥180 mm FL) and the total steelhead catch by separation-bar style and depth during separation efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999.

Separation-bar style	Separation-bar depth (mm)	Percent descaling (s.e.)	
		Large steelhead (≥180 mm FL)	Total steelhead catch
non-pedestal	50	0.8 (0.32)	1.1 (0.31)
non-pedestal	100	2.4 (0.33)	2.1 (0.32)
pedestal	50	1.3 (0.33)	1.3 (0.31)
pedestal	100	1.0 (0.32)	1.0 (0.31)

As with steelhead, there was a significant interaction between separation-bar style and depth for the total smolt large-fish catch ($F = 5.55$, df = 1, $P = 0.021$) and for the total catch of all salmonids ($F = 6.60$, df = 1, $P = 0.021$). Descaling values using non-pedestal separation bars at 100-mm depth and pedestal separation bars at 50-mm depth were statistically similar for large fish, and significantly higher than the other two combinations (Table 5). For the total salmonid catch, descaling using pedestal bars 100 mm below the surface was significantly lower than all other paired factors. In addition descaling values for the total catch were significantly higher ($F = 6.10$, df = 1, $P = 0.016$) with 2 m/s water velocity (3.9%, s.e. = 0.27) compared to the 1 m/s treatments (3.0%, s.e. = 0.27).

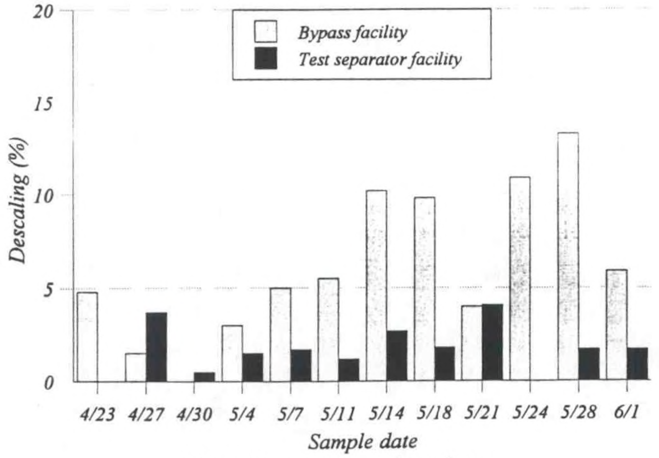
Over the course of the spring juvenile migration, personnel from the Washington Department of Fisheries and Wildlife (WDF&W) assessed fish condition, including descaling, for migrant juvenile salmonids passing through the Ice Harbor bypass facility. Total daily descaling values for each species obtained using the test separator were informally compared to similar values from the WDF&W sample on days for which both facilities were operated, in an effort to gauge whether operation of the test separator facility was causing injury to smolts. Descaling using the test facility was generally less than that for the smolt monitoring sample, and did not appear to be excessive at any time during the juvenile migration (Figure 8).

Table 5. Mean descaling values for the total small-fish catch of salmonids during separation efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999. Values resulted from interaction among separation-bar style, water velocity, and separation-bar array depth conditions.

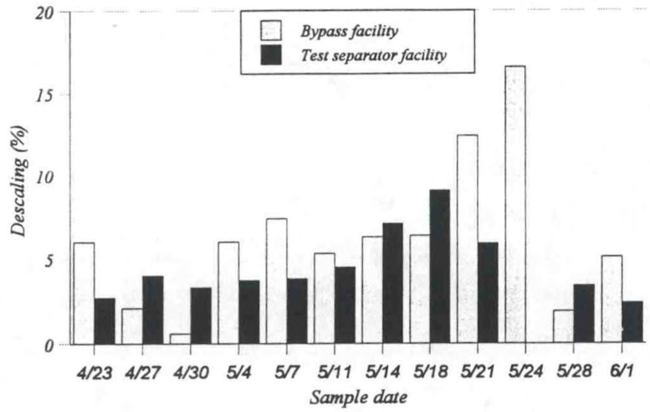
Separation-bar style	Water velocity (m/s)	Separation-bar depth (mm)	Percent descaling (s.e.) total small catch <180 mm FL
non-pedestal	1	50	4.96 (0.57)
non-pedestal	1	100	4.57 (0.57)
non-pedestal	2	50	6.03 (0.57)
non-pedestal	2	100	6.88 (0.57)
pedestal	1	50	4.43 (0.57)
pedestal	1	100	4.50 (0.57)
pedestal	2	50	7.39 (0.57)
pedestal	2	100	4.4 (0.57)

Table 6. Mean descaling values for the total large-fish catch (≥180 mm FL) and total catch of all salmonids combined by paired separation-bar style and depth conditions during separation efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999.

Paired conditions		Percent descaling (s.e.)	
Separation-bar style	Separation-bar depth (mm)	Total catch ≥180 mm FL	Total salmonid catch
non-pedestal	50	1.2 (0.33)	3.2 (0.38)
non-pedestal	100	2.2 (0.33)	4.1 (0.38)
pedestal	50	1.7 (0.33)	3.8 (0.38)
pedestal	100	1.2 (0.32)	2.7 (0.38)



Yearling chinook salmon



Steelhead

Figure 8. Mean yearling chinook salmon and steelhead descaling values from the Ice Harbor Dam juvenile bypass facility and test separator facility for dates on which both facilities were sampled in 1999. Bypass facility descaling rates include both wild and hatchery fish from smolt monitoring samples obtained by the Washington State Department of Fisheries and Wildlife. Test separator descaling rates were means of all replicates completed for a given date.

Conclusions

Comparison among the most advantageous separation efficiency conditions for all analyzed groups indicates that separation was generally highest for small fish using pedestal separation bars submerged 50 mm with a 2 m/s water velocity (Table 7). Unfortunately, descaling was also highest under these conditions. Conversely, separation for large-fish groups was higher with bars submerged at 100 mm and water velocity at1 m/s, and these conditions produced minimal descaling.

To apply the conditions that produced the highest separation efficiency for small fish to the large-fish groups would result in a small decrease in separation efficiency for the large-fish group. In contrast, to apply the optimal conditions for large fish separation would cause a larger decrease in small-fish separation. Except for yearling chinook salmon, this would also result in a decrease in large-fish descaling.

For example, using pedestal bars at 50 mm depth and 2 m/s velocity resulted in total large-fish separation efficiency of 88% (s.e. = 1.7), compared to 96% (s.e. = 1.2) using 100 mm depth and 1 m/s velocity. Descaling decreased from 2.2% (s.e. = 0.3) to 1.9% (s.e. = 0.5), respectively, for the same conditions. Applying optimal separation conditions for large fish to the small-fish groups resulted in a decrease in descaling for small fish, but also a dramatic 50% decrease in separation efficiency.

Based on these observations, we concluded that 1) pedestal separation bars at the 50-mm depth with a 2-m/s velocity could be used for large fish without a great decrease in separation efficiency, and 2) for small fish, the 1 m/s velocity combined with the 100-mm depth should not be used in the HVF test separator.

Table 7. High separation-efficiency and descaling values by fish size and species for separation-bar style, water velocity, and separation-bar array depth during evaluation of a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Comparison values indicate the means obtained for the opposite size-group using the high value group conditions. An asterisk (*) indicates all conditions for a given category.

				High mean percent (s.e.)	
Species	Bar style	Water velocity (m/s)	Depth (mm)	Small fish (<180 mm) high value	Large fish (≥180 mm) high value
Separation efficiency					
Yearling chinook	pedestal	2	50	69.6 (2.9)	69.7 (5.0)
Steelhead	pedestal	2	*	70.1 (4.8)	93.5 (1.0)
Total catch	pedestal	2	50	68.8 (2.7)	88.3 (1.7)
Yearling chinook	*	1	100	32.8 (2.1)	88.6 (2.4)
Steelhead	*	1	*	31.8 (3.5)	97.2 (0.7)
Total catch	*	1	100	32.6 (1.9)	96.0 (1.2)
Descaling					
Yearling chinook	pedestal	2	50	8.1 (0.8)	4.3 (1.4)
Steelhead	*	2	*	2.3 (0.6)	1.4 (0.2)
Total catch	pedestal	2	50	7.4 (0.6)	1.9 (0.5)
Yearling chinook	*	*	*	5.0 (0.6)	3.0 (0.5)
Steelhead	non-pedestal	*	100	0.5 (0.6)	2.4 (0.3)
Total catch	non-pedestal	*	100	4.5 (0.4)	2.2 (0.3)

CONCLUSIONS AND RECOMMENDATIONS

1. No fish injury or descaling was incurred by hatchery-reared test fish during passage through the prototype test facility drop gate, dewatering structures, flumes, high-velocity flume wet separator, transition flumes, or distribution flumes. Several conditions in the holding tanks and anesthetic lift baskets were found to be potentially dangerous to migrant smolts, but all were corrected prior to the beginning of the 1999 spring chinook salmon juvenile migration.

2. At 2 m/s, the test separator facility was capable of maintaining sustained separation-bar depths required for testing during 1999. However, slowing velocity to 1 m/s subverted flows at the downstream end of the separator unit, providing insufficient transport flow to the upper (non-separated or large fish) distribution flume.

   In order to reduce velocity to meet separation objectives, the 3-m separation-bar panel at the downstream end of the separator was lowered approximately 76 mm to intercept and divert flow into the upper flume. All separation evaluation replicates during 1999 were conducted with this slope (approximately 1.5°) over the furthest downstream bar panel.

3. Separation efficiency for the total salmonid catch displayed no significant interaction among treatment factors. Mean separation efficiency values were higher at the water velocity of 2 m/s (72%, s.e. = 1.15) than 1 m/s (65%, s.e. = 1.15) and higher using pedestal separation bars (71%, s.e. = 1.15) than non-pedestal bars (66%, s.e. = 1.15).

   Separation was also higher at a bar depth of 50 mm (71%, s.e. = 1.15) than 100 mm (66%, s.e. = 1.15). The highest mean separation efficiency (78.3%, se 2.31) was obtained using pedestal separation bars submerged to 50 mm at a water velocity of 2 m/s.

4. Separator exit efficiency values ranged from 93.7 to 100% for all treatments. All treatments involving 2 m/s water velocity had 100% separator exit efficiency.

5. Descaling for the total salmonid catch exhibited an interaction between separation-bar style and depth such that descaling with a non-pedestal separation bar array at the 100 mm depth (4.1%, s.e. = 0.38) was significantly higher than with a pedestal array at the same depth (2.7%, s.e. = 0.38).

   Ttotal salmonid descaling was also higher at the 2 m/s (3.9%, s.e. = 0.27) than at the 1 m/s velocity (3.0%, s.e. = 0.27). However, for both comparisons, the biological meaning of the differences in mean descaling values (1 and 1.4%) was doubtful.

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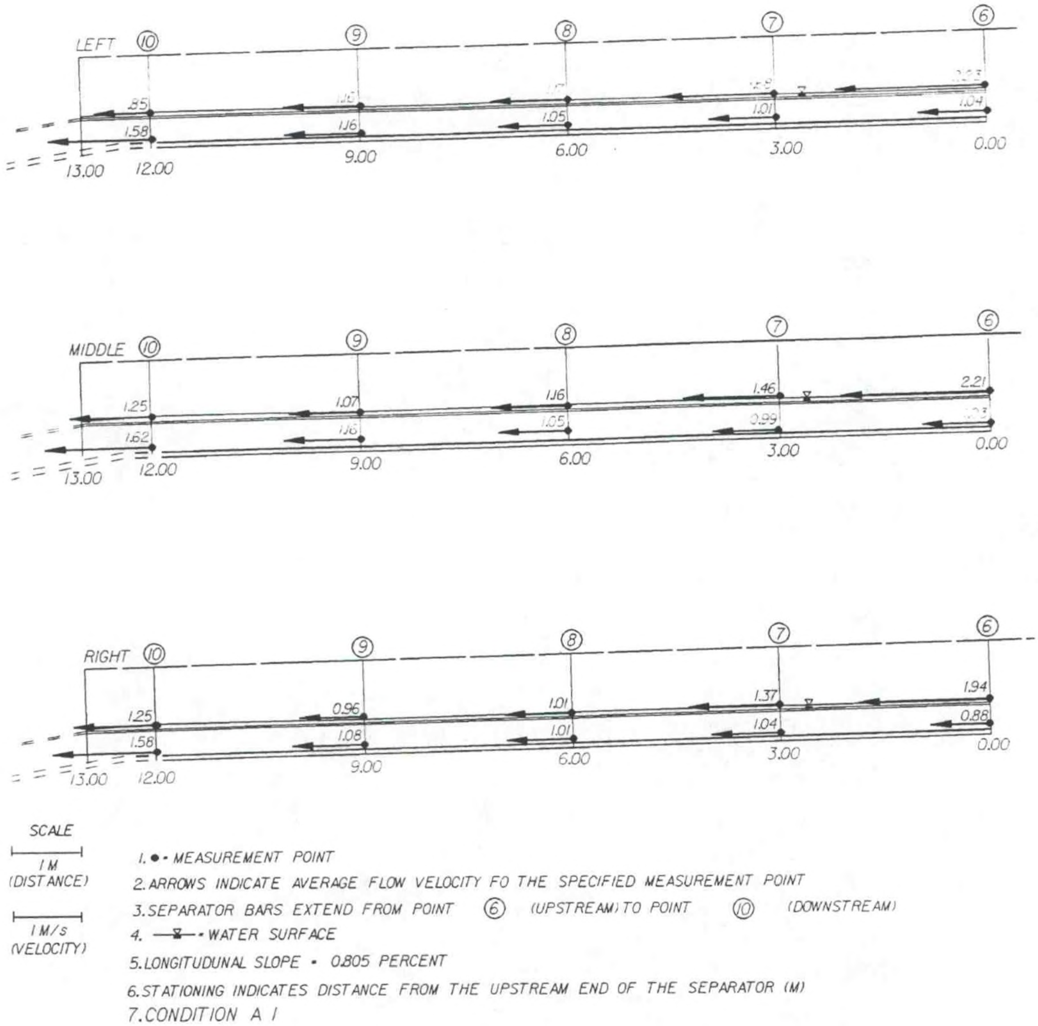
APPENDIX A

Flow Velocity Measurements

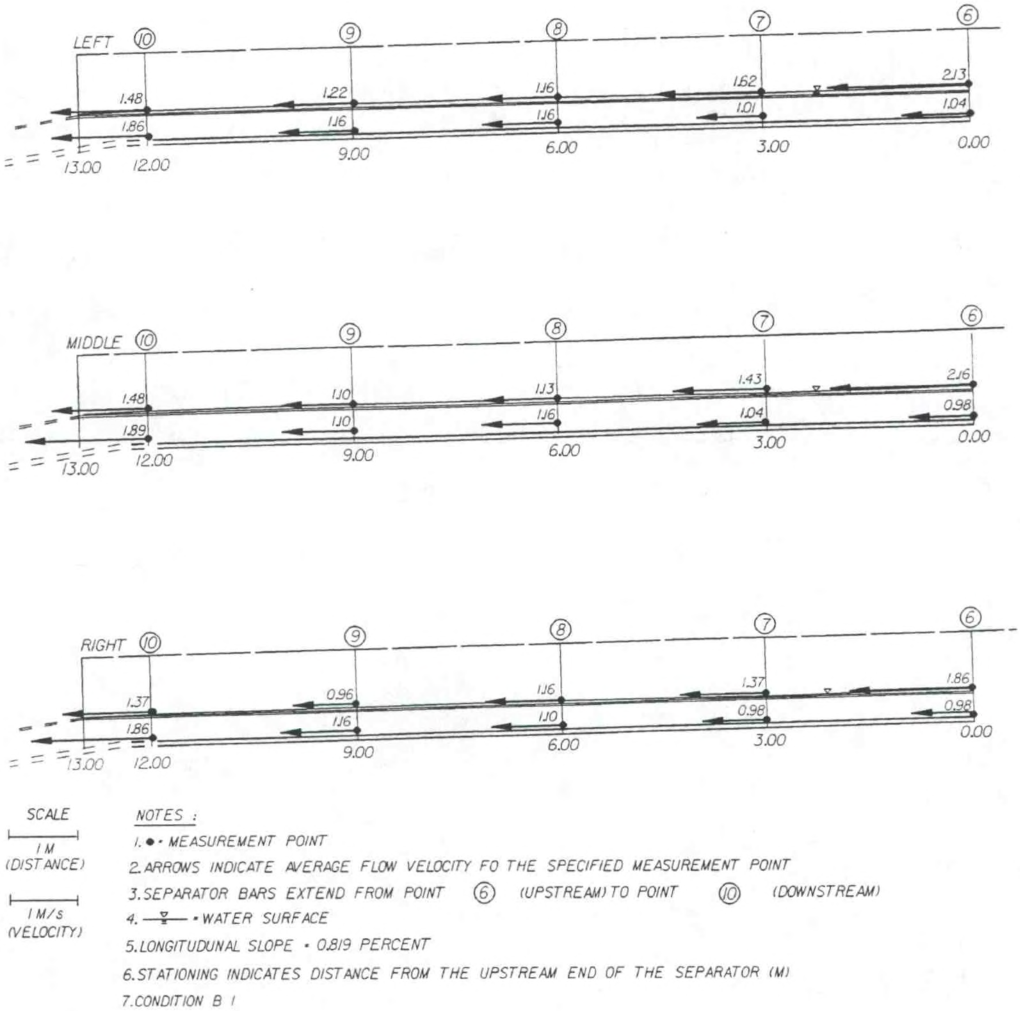


Appendix Figure A1. Profile of test separator at Ice Harbor Dam juvenile fish facility, 9 April 1999, showing average water velocity vectors (arrows) above and below the separation bars with the separator adjusted for conditions in Treatment 1: 50-mm bar depth, 1 m/s water velocity. Water supply below separation bars at Point 6 was 0.309 m^3/s (10.9 ft^3/s). Individual coordinate data are tabulated in Appendix Table A1.

Appendix Table A1. Individual velocity measurements at measured depth during evaluation of a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Data correspond to points mapped in Appendix Figure A1. Water supply indicates makeup water flow added under the separation bars at the above bars end of the separator to match flume flow above the bars.

9 April 1999, channel slope 0.008056 m/m, Treatment 1, 50 mm depth, 1-m/s water velocity, water supply 10.9 ft^3/s.

	Velocity					Combined
Station	Left (m/s)	Mid (m/s)	Right (m/s)	Depth (m)	Discharge (m^3/s)	discharge (m^3/s)
1-4						
5	2.9	3.2	2.9	0.0		0.1
6						0.4
Jump-unreliable reading						
Above bars	2.2	2.2	1.9	0.0	0.1	
Below bars	1.0	1.0	0.9	0.4	0.3	
7						0.4
Above bars	1.7	1.5	1.4	0.1	0.1	
Below bars	1.0	1.0	1.0	0.5	0.3	
8						0.4
Above bars	1.2	1.2	1.0	0.1	0.1	
Below bars	1.1	1.1	1.0	0.5	0.3	
9						0.4
Above bars	1.2	1.1	1.0	0.0	0.0	
Below bars	1.2	1.2	1.1	0.5	0.4	
10						0.3
Above bars	0.9	1.2	1.2	0.1	0.1	
Below bars	1.6	1.6	1.6	0.3	0.2	
11						0.5
Above bars	2.1	2.1	2.1	0.0	0.0	
Below bars	4.9	5.2	4.9	0.2	0.5	

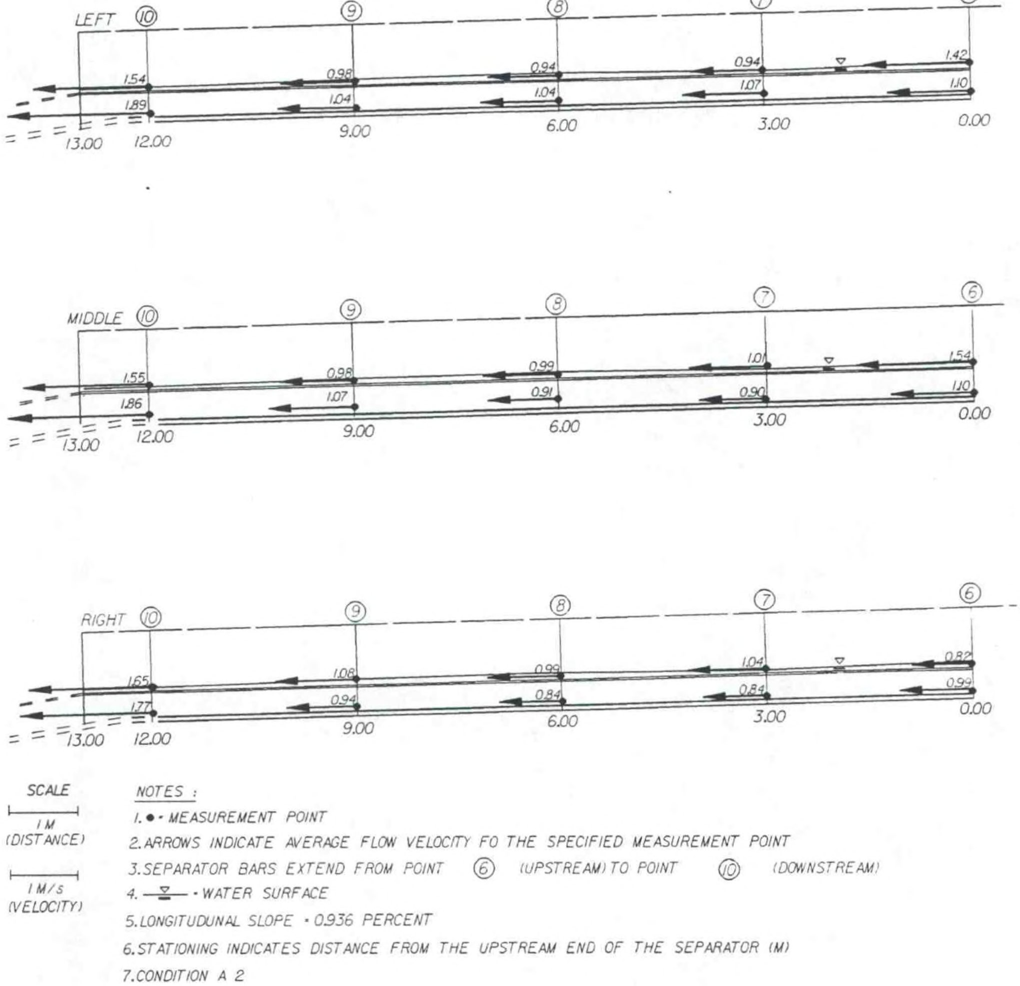


Appendix Figure A2. Research separator at Ice Harbor Dam, 12 April 1999, showing average water velocity vectors (arrows) above and below the separation bars with the separator adjusted for conditions in Treatment 1 (reproduced): 50-mm bar depth, 1 m/s water velocity. Water supply below separation bars at Point 6 was 0.336 m^3/s (11.85 ft^3/s). Coordinate data are tabulated in Appendix Table A2.

Appendix Table A2. Individual velocity measurements at measured depth during calibration for biological evaluations using a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Data correspond to points mapped in Appendix Figure A2. Water supply indicates makeup water flow added under the separation bars at the above bars end of the separator to match flume flow above the bars.

12 April 1999; channel slope 0.008186 ft/ft; Treatment 1 (reproduced), 50 mm depth, 1 m/s water velocity; water supply 11.65-11.85 range; 11.85 avg.

Station	Velocity Left (m/s)	Velocity Mid (m/s)	Velocity Right (m/s)	Depth (m)	Discharge (m^3/s)	Combined discharge (m^3/s)
1-5						
6						0.4
Jump-unreliable reading						
Above bars	2.1	2.2	1.9	0.1	0.1	
Below bars	1.0	1.0	1.0	0.4	0.3	
7						0.4
Above bars	1.6	1.4	1.4	0.1	0.1	
Below bars	1.0	1.0	1.0	0.5	0.3	
8						0.4
Above bars	1.2	1.1	1.2	0.1	0.1	
Below bars	1.2	1.2	1.1	0.5	0.4	
Wave Crest						
9						0.4
Above bars	1.2	1.1	1.0	0.1	0.0	
Below bars	1.2	1.1	1.2	0.4	0.3	
Wave length = 2.5 ft.						
10						0.3
Above bars	1.5	1.5	1.4	0.0	0.0	
Below bars	1.9	1.9	1.9	0.3	0.3	
11						
Above bars						
Below bars						

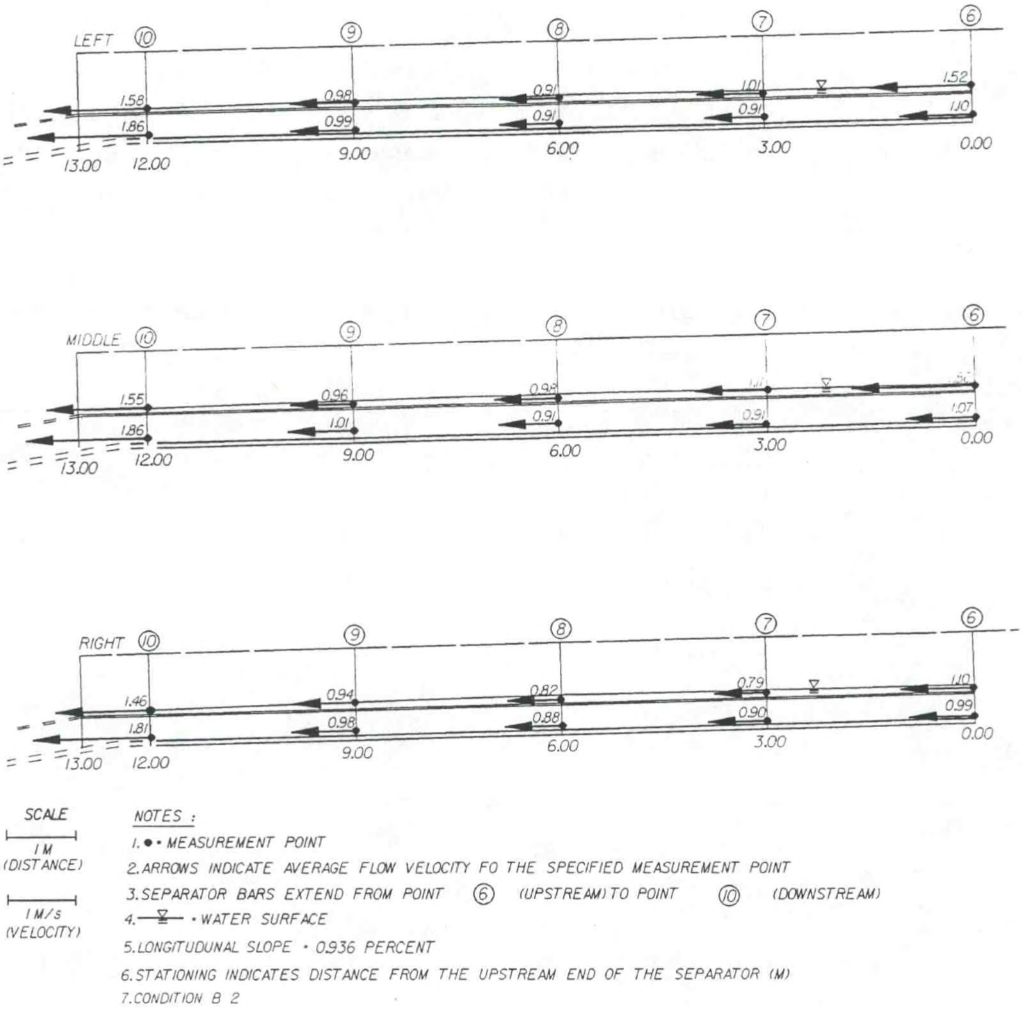


Appendix Figure A3. Profile of research separator at Ice Harbor Dam, 8 April 1999, showing average water velocity vectors (arrows) above and below the separation bars with the separator adjusted for conditions in Treatment 2: 100-mm separation-bar depth and 1 m/s water velocity. Water supply below separation bars at Point 6 was 0.361 m^3/s (12.75 ft^3/s). Individual coordinate data are tabulated in Appendix Table A3.

Appendix Table A3. Individual velocity measurements at measured depth during calibration of a biological evaluation treatment (Description) using a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Data correspond to points mapped in Appendix Figure A3. Water supply indicates makeup water flow added under the separation bars at the above bars end of the separator to match flume flow above the bars.

4 April 1999; channel slope, 0.00936 m/m; Treatment 2, 100-mm depth, 1 m/s-water velocity; water supply, 12.75 ft^3/s

	Velocity					Combined
Station	Left (m/s)	Mid (m/s)	Right (m/s)	Depth (m)	Discharge (m^3/s)	discharge (m^3/s)
1-4						
5	3.0	3.4	3.0	0.0		0.1
6						0.5
jump; unreliable reading						
Above bars	1.4	1.5	0.8	0.1	0.1	
Below bars	1.1	1.1	1.0	0.5	0.3	
7						0.4
Above bars	0.9	1.0	1.0	0.1	0.1	
Below bars	1.1	0.9	0.8	0.5	0.3	
8						0.4
Above bars	0.9	1.0	1.0	0.1	0.1	
Below bars	1.0	0.9	0.8	0.5	0.3	
9						0.4
Above bars	1.0	1.0	1.1	0.1	0.1	
Below bars	1.0	1.1	0.9	0.5	0.3	
10						0.4
Above bars	1.5	1.6	1.6	0.1	0.1	
Below bars	1.9	1.9	1.8	0.3	0.3	
11						0.4
Above bars	2.6	2.6	2.6	0.0	0.0	
Below bars	5.2	5.2	5.2	0.1	0.4	

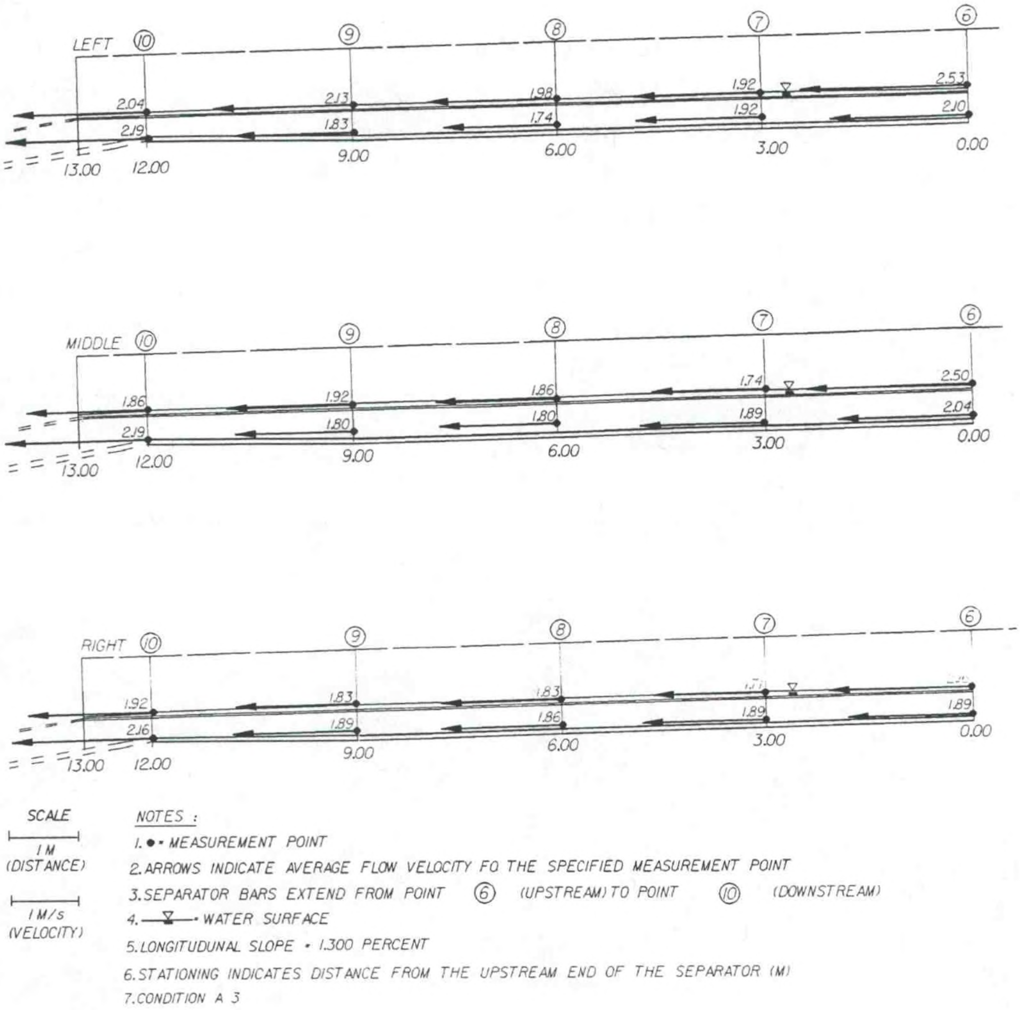


Appendix Figure A4. Profile of research separator at Ice Harbor Dam juvenile fish facility, 12 April 1999, showing average water velocity vectors (arrows) above and below the separation bars with the separator adjusted for conditions in Treatment 2 (reproduced): 100-mm separation-bar depth, 1 m/s water velocity. Water supply below separation bars at Point 6 was 0.374 m^3/s (13.2 ft^3/s). Individual coordinate data are tabulated in Appendix Table A4.

Appendix Table A4. Individual velocity measurements at measured depth during calibration of a biological evaluation Treatment 2 (reproduced) using a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Data correspond to points mapped in Appendix Figure A4. Water supply indicates makeup water flow added under the separation bars at the above bars end of the separator to match flume flow above the bars.

12 April 1999; channel slope, 0.009358 m/m; Treatment 2 (reproduced), 100-mm depth, 1 m/s-water velocity; water supply, 13.2 ft^3/s

	Velocity					Combined
Station	Left (m/s)	Mid (m/s)	Right (m/s)	Depth (m)	Discharge (m^3/s)	discharge (m^3/s)
1	4.1	3.9	3.6	0.3		0.9
2						
3	3.7	3.7	3.2	0.3		0.8
4	3.7	4.1	3.9	0.1		0.4
5	3.0	3.0	2.8	0.0		0.1
6						0.4
Above bars	1.5	1.9	1.1	0.1	0.1	
Below bars	1.1	1.1	1.0	0.5	0.3	
7						0.4
Above bars	1.0	1.1	0.8	0.1	0.1	
Below bars	0.9	0.9	0.9	0.5	0.3	
8						0.4
Above bars	0.9	1.0	0.8	0.1	0.1	
Below bars	0.9	0.9	0.9	0.5	0.3	
9						0.4
Above bars	1.0	1.0	0.9	0.1	0.1	
Below bars	1.0	1.0	1.0	0.5	0.3	
10						0.3
Above bars	1.6	1.6	1.5	0.1	0.1	
Below bars	1.9	1.9	1.8	0.3	0.3	
11						0.5
Above bars	2.3	2.6	2.5	0.0	0.1	
Below bars	5.3	5.2	5.1	0.1	0.4	

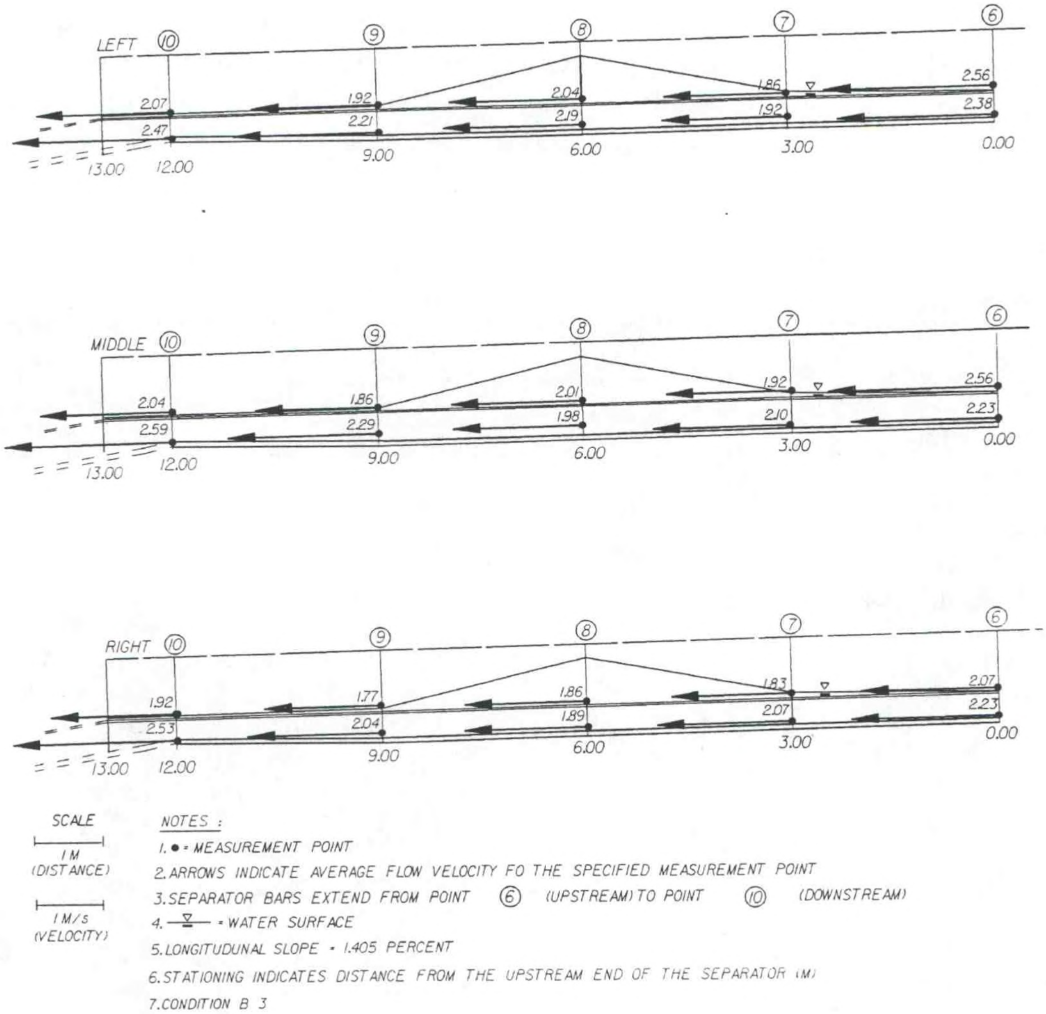


Appendix Figure A5. Profile of research separator at Ice Harbor Dam juvenile fish facility, 13 April 1999, showing average water velocity vectors (arrows) above and below separation bars with the separator adjusted for conditions in Treatment 3: 50-mm separation-bar depth and 2 m/s water velocity. Water supply below separation bars at Point 6 was 0.666 m^3/s (23.5 ft^3/s). Individual coordinate data are tabulated in Appendix Table A5.

Appendix Table A5. Individual velocity measurements at measured depth during calibration for biological evaluation Treatment 3 using a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Data corresponds to points mapped in Appendix Figure A5. Water supply indicates makeup water flow added under the separation bars to match flume flow above the bars.

13 April 1999; channel slope, 0.013 m/m; Treatment 3; 50-mm depth; 2 m/s-water velocity; water supply, 23.5 ft^3/s

	Velocity					Combined
Station	Left (m/s)	Mid (m/s)	Right (m/s)	Depth (m)	Discharge (m^3/s)	discharge (m^3/s)
1-4						
5	3.4	3.4	3.0	0.0		0.1
6 (0+0.0) (undular jump, 4-7 ft. upstream into separator)						0.7
Above bars	2.5	2.5	2.2	0.1	0.1	
Below bars	2.1	2.0	1.9	0.4	0.6	
0+7.5 above bars	2.2	2.1	2.0	0.1	0.1	0.7
0+7.5 below bars	2.2	2.1	2.0	0.5	0.6	
7						0.7
Above bars	1.9	1.7	1.7	0.1	0.2	
Below bars	1.9	1.9	1.9	0.5	0.5	
0+17.5 above bars	2.2	2.0	1.9	0.1	0.1	0.7
0+17.5 below bars	2.2	2.0	1.9	0.5	0.6	
8						0.7
Above bars	2.0	1.9	1.8	0.1	0.2	
Below bars	1.7	1.8	1.9	0.5	0.5	
0+27.5 above bars	2.0	2.0	1.8	0.1	0.1	0.7
0+27.5 below bars	2.0	2.0	1.8	0.5	0.6	
9						0.7
Above bars	2.1	1.9	1.8	0.1	0.2	
Below bars	1.8	1.8	1.9	0.5	0.6	
0+37.5 above bars	2.0	2.0	1.8	0.1	0.2	0.6
0+37.5 below bars	2.0	2.0	1.8	0.4	0.5	
10						0.7
Above bars	2.0	1.9	1.9	0.1	0.1	
Below bars	2.2	2.2	2.2	0.4	0.5	
11						0.9
Above bars	2.8	3.3	3.0	0.1	0.1	
Below bars	5.2	5.9	5.6	0.3	9.6	

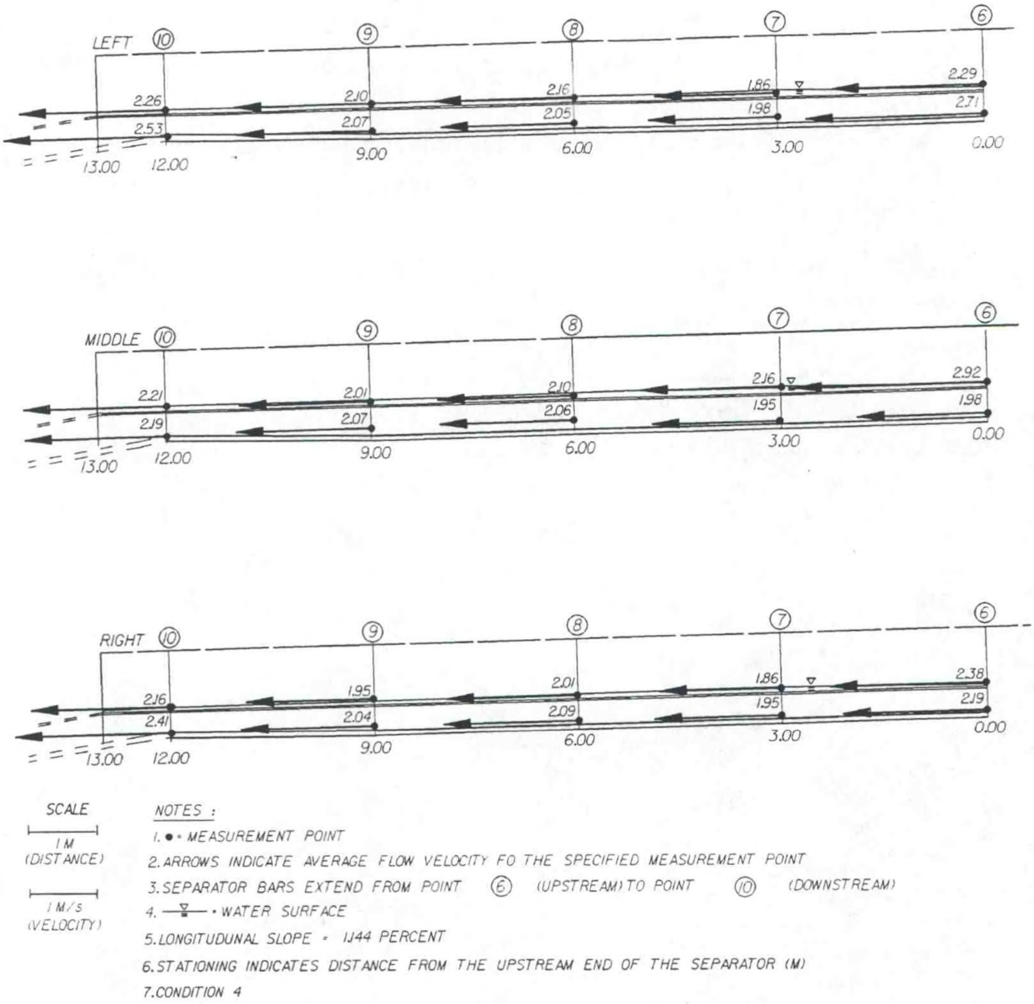


Appendix Figure A6. Profile of research separator at Ice Harbor Dam juvenile fish facility, 14 April 1999, showing average water velocity vectors (arrows) above and below the separation bars with the separator adjusted for conditions in Treatment 3 (reproduced): 50-mm bar depth and 2 m/s water velocity. Water supply below separation bars at Point 6 was 0.674 m^3/s (23.8 ft^3/s). Individual coordinate data are tabulated in Appendix Table A6.

Appendix Table A6. Individual velocity measurements at measured depth during calibration of a biological evaluation Treatment 3 (reproduced) using a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Data correspond to points mapped in Appendix Figure A6. Water supply indicates makeup water flow added under the separation bars to match flume flow above the bars.

14 April 1999; channel slope, -0.01404 m/m; Treatment 3 (reproduced); 50-mm depth; 2 m/s-water velocity; water supply, 23.8 ft^3/s

	Velocity					Combined
Station	Left (m/s)	Mid (m/s)	Right (m/s)	Depth (m)	Discharge (m^3/s)	discharge (m^3/s)
1-4						
5	3.1	3.4	3.0	0.0	0.1	0.8
6 (0+0.0)						0.8
Above bars	2.6	2.6	2.1	0.1	0.1	
Below bars	2.4	2.1	2.2	0.4	0.6	
0+7.5 Above bars	2.1	2.1	1.9	0.1	0.2	0.8
0+7.5 Below bars	2.1	2.1	1.9	0.5	0.6	
7						0.8
Above bars	1.9	1.9	1.8	0.1	0.2	
Below bars	1.9	2.1	2.1	0.5	0.6	
0+17.5 Above bars	2.1	2.1	1.9	0.1	0.1	0.7
0+17.5 Below bars	2.1	2.1	1.9	0.5	0.6	
8						0.7
Above bars	2.0	2.0	1.9	1.1	2.0	
Below bars	2.2	2.0	1.9	0.5	-1.3	
0+27.5 Above bars	2.0	2.0	1.9	0.1	0.1	0.7
0+27.5 Below bars	2.0	2.0	1.9	0.5	0.6	
9						0.8
Above bars	1.9	1.9	1.8	0.1	0.1	
Below bars	2.2	2.3	2.0	0.5	0.7	
0+37.5 Above bars	2.0	2.0	1.7	0.1	0.1	0.6
0+37.5 Below bars	2.0	2.0	1.7	0.4	0.5	
10						0.8
Above bars	2.1	2.0	1.9	0.1	0.1	
Below bars	2.5	2.6	2.5	0.4	0.6	
11						0.9
Above bars	3.1	3.5	3.1	0.1	0.1	
Below bars	5.3	5.6	5.2	0.2	0.7	



Appendix Figure A7. Profile of research separator at Ice Harbor Dam juvenile fish facility, 14 April 1999, showing average water velocity vectors (arrows) above and below the separation bars with the separator adjusted for conditions in Treatment 4: 100-mm separation-bar depth and 2 m/s water velocity. Water supply below separation bars at Point 6 was 0.674 m^3/s (23.8 ft^3/s). Stationing indicates distance (m) from the upstream end of the separator. Individual coordinate data are tabulated in Appendix Table A7.

Appendix Table A7. Individual velocity measurements at measured depth during calibration for biological evaluation Treatment 4 using a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Data correspond to points mapped in Appendix Figure A7. Water supply indicates makeup water flow added under the separation bars at the above bars end of the separator to match flume flow above the bars.

14 April 1999; channel slope, -0.01144 m/m; Treatment 4; 100-mm depth; 2 m/s-water velocity; water supply, 23.8 ft^3/s

	Velocity					Combined
Station	Left (m/s)	Mid (m/s)	Right (m/s)	Depth (m)	Discharge (m^3/s)	discharge (m^3/s)
1-4						
5	3.6	3.6	3.5	0.1	0.2	0.8
6 (0+0.0)						0.8
Above bars	2.3	2.9	2.4	0.1	0.2	
Below bars	2.7	2.0	2.2	0.5	0.7	
0+7.5 Above bars	2.3	2.3	2.0	0.1	0.2	0.9
0+7.5 Below bars	2.3	2.3	2.0	0.5	0.7	
7						0.8
Above bars	1.9	2.2	1.9	0.2	0.3	
Below bars	2.0	2.0	2.0	0.5	0.6	
0+17.5 Above bars	2.2	2.2	1.9	0.1	0.2	0.8
0+17.5 Below bars	2.2	2.2	1.9	0.5	0.6	
8						0.8
Above bars	2.2	2.1	2.0	0.1	0.2	
Below bars	2.1	2.1	2.1	0.5	0.6	
0+27.5 Above bars	2.2	2.2	2.0	0.1	0.2	0.8
0+27.5 Below bars	2.2	2.2	2.0	0.5	0.6	
9						0.8
Above bars	2.1	2.0	2.0	0.1	0.2	
Below bars	2.1	2.1	2.0	0.5	0.7	
0+37.5 Above bars	2.1	2.0	2.0	0.1	0.2	0.7
0+37.5 Below bars	2.1	2.0	2.0	0.5	0.5	
10						0.7
Above bars	2.3	2.2	2.2	0.1	0.2	
Below bars	2.5	2.2	2.4	0.4	0.6	
11						0.9
Above bars	3.3	3.5	3.8	0.1	0.1	
Below bars	5.2	5.8	5.3	0.2	0.7	

APPENDIX B

Data Tables

Appendix Table B1. Total catch by species, for individual replicates using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999.

	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 1, April 22										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			43	5	2	1				
non-separated			122	57	1	41				
Separator: separated										
non-separated										
Replicate 2, Treatment 1, April 28										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			32	3	1	6				
non-separated			90	64	3	135				
Separator: separated			1	4						
non-separated										
Replicate 3, Treatment 1, April 29										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			58	23	1	1			2	
non-separated			92	37	7	189			1	
Separator: separated										
non-separated										
Replicate 4, Treatment 1, May 4										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			27	5	4	3				
non-separated			85	6	7	82				
Separator: separated										
non-separated										
Replicate 5, Treatment 1, May 6										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			47	2	1	1				
non-separated			71	11	8	94				
Separator: separated										
non-separated										
Replicate 6, Treatment 1, May 10										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			53	1	3	4				
non-separated			47	8	14	74				
Separator: separated										
non-separated										
Replicate 7, Treatment 1, May 13										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			17		1				1	
non-separated			53	7		12				
Separator: separated						1				
non-separated										

Appendix Table B1. Continued.

Source		Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 8, Treatment 1, May 14											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			61	2	1				2	
	non-separated			62	6	2	46				
Separator:	separated						1				
	non-separated										
Replicate 9, Treatment 1, May 19											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			44	2	2	2				
	non-separated			40	6	11	109				
Separator:	separated			1							
	non-separated										
Replicate 10, Treatment 1, May 21											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			30		1		1			
	non-separated			47	2	9	62				
Separator:	separated										
	non-separated										
Replicate 11, Treatment 1, May 25											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			23	1	1	2				
	non-separated			31	2	4	120	3		2	
Separator:	separated						2				
	non-separated										
Replicate 12, Treatment 1, May 26											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			30		68					
	non-separated			43	2	4	296	6			
Separator:	separated										
	non-separated										
Replicate 1, Treatment 2, April 21											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			25	6	1					
	non-separated			53	86		30				
Separator:	separated										
	non-separated										
Replicate 2, Treatment 2, April 26											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			38	4		1				
	non-separated			87	31	2	50				
Separator:	separated										
	non-separated										

Appendix Table B1. Continued.

Source	Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 3, Treatment 2, April 30										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			53	2	1					
non-separated			74	28	15	108				
Separator: separated			2		1	1				
non-separated										
Replicate 4, Treatment 2, May 4										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			63	4	4	2			1	
non-separated			98	26	5	73				
Separator: separated										
non-separated										
Replicate 5, Treatment 2, May 6										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			36	2	7	1				
non-separated			125	11	13	79				
Separator: separated				1	2	2				
non-separated										
Replicate 6, Treatment 2, May 10										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			53	1		1				
non-separated			67	5	9	60				
Separator: separated			5		4					
non-separated										
Replicate 7, Treatment 2, May 12										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			83	2	2	1				
non-separated			133	11	5	65			1	
Separator: separated			3		2	2				
non-separated										
Replicate 8, Treatment 2, May 14										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			43	3	2	1				
non-separated			59	7	7	44				
Separator: separated						1				
non-separated										
Replicate 9, Treatment 2, May 19										
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			25			1				
non-separated			49		10	72				
Separator: separated		1								
non-separated										

Appendix Table B1. Continued.

Source		Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 10, Treatment 2, May 21											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			33	1	3		1			
	non-separated			53	2	3	75	3		3	
Separator:	separated										
	non-separated										
Replicate 11, Treatment 2, May 25											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			28	1	3	2				
	non-separated			56	5	4	158	1			
Separator:	separated			3			1				
	non-separated										
Replicate 12, Treatment 2, May 27											
Separation-bar style: non-pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			33	2	6	4	2			
	non-separated			118	2	10	178	2			
Separator:	separated			1		1	10				
	non-separated										
Replicate 1, Treatment 3, April 22											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm											
Tanks:	separated			77	5	1					
	non-separated			62	31	2	36				
Separator:	separated										
	non-separated										
Replicate 2, Treatment 3, April 27											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm											
Tanks:	separated			161	19	1	5			2	
	non-separated			88	36	1	105				
Separator:	separated										
	non-separated										
Replicate 3, Treatment 3, April 30											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm											
Tanks:	separated			90	11	11	9				
	non-separated			61	10	3	104				
Separator:	separated										
	non-separated										
Replicate 4, Treatment 3, May 4											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm											
Tanks:	separated			81	11	3	9				
	non-separated			52	12	1	122				
Separator:	separated										
	non-separated										

Appendix Table B1. Continued.

Source	Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 5, Treatment 3, May 5										
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			43	13	2	8				
non-separated			13	15		55			1	
Separator: separated										
non-separated										
Replicate 6, Treatment 3, May 10										
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			94	6	6	3				
non-separated			41	13	4	51				
Separator: separated										
non-separated										
Replicate 7, Treatment 3, May 12										
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			123	5	6	9				
non-separated			62	5	5	73				
Separator: separated										
non-separated										
Replicate 8, Treatment 3, May 14										
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			49	5	7	12				
non-separated			13		8	52				
Separator: separated										
non-separated										
Replicate 9, Treatment 3, May 19										
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			71	1	7	6	1			
non-separated			40	3	8	75	2		1	
Separator: separated										
non-separated										
Replicate 10, Treatment 3, May 24										
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			99	2	15	4			2	2
non-separated			71	8	10	161				
Separator: separated										
non-separated										
Replicate 11, Treatment 3, May 25										
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			35		1	2	1			
non-separated			44		4	88				
Separator: separated										
non-separated										

Appendix Table B1. Continued.

Source		Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 12, Treatment 3, May 27											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm											
Tanks:	separated			54		9	26	2			
	non-separated			69	1	12	437	2			
Separator:	separated										
	non-separated										
Replicate 1, Treatment 4, April 22											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			31	1	1	1				
	non-separated			104	37	1	84				
Separator:	separated										
	non-separated										
Replicate 2, Treatment 4, April 27											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			140	16		6				
	non-separated			118	48	9	115				
Separator:	separated										
	non-separated										
Replicate 3, Treatment 4, April 30											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			141	5	12	4				
	non-separated			128	25	1	101			2	
Separator:	separated										
	non-separated										
Replicate 4, Treatment 4, May 3											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			39	5	2	4			1	
	non-separated			39	12	1	50				
Separator:	separated										
	non-separated										
Replicate 5, Treatment 4, May 6											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			76	5	4	7				
	non-separated			90	14	4	129			2	
Separator:	separated										
	non-separated										
Replicate 6, Treatment 4, May 10											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			78	4	8	1				
	non-separated			64	11	1	84			1	
Separator:	separated										
	non-separated										

Appendix Table B1. Continued.

Source		Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
		<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 7, Treatment 4, May 12											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			76	6	12	4			1	
	non-separated			63	11	11	134			3	
Separator:	separated										
	non-separated										
Replicate 8, Treatment 4, May 17											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			31	1	4	4				
	non-separated			69	4	2	60				
Separator:	separated										
	non-separated										
Replicate 9, Treatment 4, May 19											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			14		2	1				
	non-separated			45			21				
Separator:	separated										
	non-separated										
Replicate 10, Treatment 4, May 21											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			39		2	3				
	non-separated			29		8	49				
Separator:	separated										
	non-separated										
Replicate 11, Treatment 4, May 25											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			32	1		2				
	non-separated			54	4	5	119	1			
Separator:	separated										
	non-separated										
Replicate 12, Treatment 4, May 27											
Separation-bar style: non-pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			38	2	11	22	1		1	
	non-separated			70	2	17	320	2		1	
Separator:	separated										
	non-separated										
Replicate 1, Treatment 5, April 26											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			43	1	1					
	non-separated			120	42	2	57			1	
Separator:	separated				3						
	non-separated										

Appendix Table B1. Continued.

Source	Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 2, Treatment 5, April 28										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			39	8	2					
non-separated			56	54	5	124				
Separator: separated										
non-separated										
Replicate 3, Treatment 5, May 3										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			79	2	5	2				
non-separated			126	18	2	70				
Separator: separated			1		2	1				
non-separated										
Replicate 4, Treatment 5, May 5										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			48	6	2	5				
non-separated			40	16	1	67				
Separator: separated										
non-separated										
Replicate 5, Treatment 5, May 6										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			21	1	4	1				
non-separated			15	7	4	77				
Separator: separated										
non-separated										
Replicate 6, Treatment 5, May 11										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			73	4						
non-separated			65	8	16	73				
Separator: separated										
non-separated										
Replicate 7, Treatment 5, May 13										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			55	1	1	2				
non-separated			74	6	4	134				
Separator: separated										
non-separated										
Replicate 8, Treatment 5, May 17										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm										
Tanks: separated			48	1	5	3			2	2
non-separated			147	3	18	219				
Separator: separated										
non-separated										

Appendix Table B1. Continued.

	Source	Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 9, Treatment 5, May 20											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			13	1	1					
	non-separated			27		2	50			1	
Separator:	separated			1							
	non-separated										
Replicate 10, Treatment 5, May 24											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			42	5	2	5				
	non-separated			36	3	8	123	4		3	
Separator:	separated			2							
	non-separated										
Replicate 11, Treatment 5, May 26											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			36	1	3	2			1	
	non-separated			39	1	2	189	2			
Separator:	separated						1				
	non-separated										
Replicate 12, Treatment 5, May 28											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 50 mm											
Tanks:	separated			24		6	6	1			
	non-separated			39		3	81	1			
Separator:	separated										
	non-separated										
Replicate 1, Treatment 6, April 23											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			10		2					
	non-separated			95	20	5	43			1	
Separator:	separated										
	non-separated										
Replicate 2, Treatment 6, April 29											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			33	3	1	1				
	non-separated			93	27	1	101				
Separator:	separated			1	1						
	non-separated										
Replicate 3, Treatment 6, May 3											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			23			1				
	non-separated			101	16	1	80				
Separator:	separated			1	1		1				
	non-separated										

Appendix Table B1. Continued.

	Source	Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 4, Treatment 6, May 5											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			19	4						
	non-separated			59	12	4	53				
Separator:	separated										
	non-separated										
Replicate 5, Treatment 6, May 6											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			24	1	2	1				
	non-separated			49	7	8	111				
Separator:	separated										
	non-separated										
Replicate 6, Treatment 6, May 11											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			69	3	7	2				
	non-separated			79	10	8	69				
Separator:	separated										
	non-separated										
Replicate 7, Treatment 6, May 13											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			31		2					
	non-separated			47	4	5	87			1	
Separator:	separated			9							
	non-separated			1			2				
Replicate 8, Treatment 6, May 18											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			71		3	1				
	non-separated			133	6	16	135				1
Separator:	separated					1	2				
	non-separated						1				
Replicate 9, Treatment 6, May 20											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			12		1	1				
	non-separated			56	8	2	84			1	
Separator:	separated						5				
	non-separated										
Replicate 10, Treatment 6, May 24											
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm											
Tanks:	separated			16		1					
	non-separated			43	5	2	72		1		
Separator:	separated										
	non-separated										

Appendix Table B1. Continued.

Source	Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 11, Treatment 6, May 26										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			29		1	8	2		1	
non-separated			33	1	2	193	1			
Separator: separated										
non-separated										
Replicate 12, Treatment 6, May 28										
Separation-bar style: pedestal, water velocity: 1 m/s, separation-bar depth: 100 mm										
Tanks: separated			25		9	10	1			
non-separated			58		7	175	3		1	
Separator: separated						1				
non-separated										
Replicate 1, Treatment 7, April 26										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			114	7	1					
non-separated			60	26	3	73				
Separator: separated										
non-separated										
Replicate 2, Treatment 7, April 29										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			104	13	8	11				
non-separated			52	25	3	24				
Separator: separated										
non-separated										
Replicate 3, Treatment 7, May 3										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			68	7	3	9				
non-separated			25	12	3	58				
Separator: separated										
non-separated										
Replicate 4, Treatment 7, May 5										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			65	5	2	3				
non-separated			23	14	1	60			2	
Separator: separated										
non-separated										
Replicate 5, Treatment 7, May 7										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks separated			138	1	3	14				
non-separated			72	14		106				
Separator separated										
non-separated										

Appendix Table B1. Continued.

Source	Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 6, Treatment 7, May 12										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			36	4	4				1	
non-separated			21	5		22				
Separator: separated										
non-separated										
Replicate 7, Treatment 7, May 13										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			107	3	7	13				
non-separated			56	4	2	53				
Separator: separated										
non-separated										
Replicate 8, Treatment 7, May 18										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			67	1	6	3				
non-separated			12			64				
Separator: separated										
non-separated										
Replicate 9, Treatment 7, May 20										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			30		2	3				
non-separated			24		2	45			1	
Separator: separated										
non-separated										
Replicate 10, Treatment 7, May 24										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			94	1	9	2	2			
non-separated			28	2	4	88	2	1		
Separator: separated										
non-separated										
Replicate 11, Treatment 7, May 26										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			67	3	7	11	3			
non-separated			28		3	284	2		2	
Separator: separated										
non-separated										
Replicate 12, Treatment 7, May 27										
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 50 mm										
Tanks: separated			26		12	20	3			
non-separated			10		8	262	2			
Separator: separated										
non-separated										

Appendix Table B1. Continued.

Source		Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 1, Treatment 8, April 23											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			96	2	1					
	non-separated			82	31	2	65			1	
Separator:	separated										
	non-separated										
Replicate 2, Treatment 8, April 28											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			105	14	2	5				
	non-separated			70	51	2	127				
Separator:	separated										
	non-separated										
Replicate 3, Treatment 8, May 3											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			111	8	11	5				
	non-separated			140	36	5	132				
Separator:	separated										
	non-separated										
Replicate 4, Treatment 8, May 4											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			48	10	3	5			1	
	non-separated			91	30	4	71				
Separator:	separated										
	non-separated										
Replicate 5, Treatment 8, May 7											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			243	12	19	17				
	non-separated			115	29	5	214				
Separator:	separated										
	non-separated										
Replicate 6, Treatment 8, May 11											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			122	4	9					
	non-separated			60	11	3	138				
Separator:	separated										
	non-separated										
Replicate 7, Treatment 8, May 13											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			87	2	4	4				
	non-separated			44	4	2	69				
Separator:	separated										
	non-separated										

Appendix Table B1. Continued.

Source		Subyearling chinook <180	Subyearling chinook ≥180	Yearling chinook <180	Yearling chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 8, Treatment 8, May 18											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			14		5	16				
	non-separated			12	1		20				
Separator:	separated										
	non-separated										
Replicate 9, Treatment 8, May 20											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			11		2	1				
	non-separated			53	7	3	27				
Separator:	separated										
	non-separated										
Replicate 10, Treatment 8, May 24											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			61	1	6		1			
	non-separated			35	2	2	112	1			
Separator:	separated										
	non-separated										
Replicate 11, Treatment 8, May 26											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			39	2	8	15			1	
	non-separated			48	2	5	290	3		2	
Separator:	separated										
	non-separated										
Replicate 12, Treatment 8, May 27											
Separation-bar style: pedestal, water velocity: 2 m/s, separation-bar depth: 100 mm											
Tanks:	separated			22		17	3				
	non-separated			18			200	1			
Separator:	separated										
	non-separated										

Appendix Table B2. Incidental species captured during separator efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 27 April to 4 June 1999. Species are listed in order of total capture frequency.

Common name	Scientific name	Total catch
crappie	*Proxomus* spp.	168
channel catfish	*Ictalurus punctatus*	45
sucker	*Catostomus* spp.	26
whitefish	*Prosopium williamsoni*	13
yellow perch	*Perca flavescens*	11
lamprey	*Lampetra tridentata*	10
sand roller	*Columbia transmontanus*	10
chiselmouth	*Acrocheilus alutaceus*	6
bass	*Micropterus* spp.	5
northern pikeminnow	*Ptychocheilus oregonensis*	4
carp	*Cyprinus carpio*	2
peamouth	*Mylocheilus caurinus*	1
pumpkinseed	*Lepomis gibbosus*	1

Appendix Table B3. Statistical analysis results of comparisons among mean separation efficiency values by group for treatments evaluated using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999. Asterisks indicate significant differences ($\alpha = 0.05$) among treatment factors.

		Calculated statistic			
Group	Treatment conditions	*F*	df	*P*	
yearling chinook salmon <180 mm	replicate series (block)	2.73	11	0.005	*
	separation-bar style	3.74	1	0.057	
	water velocity	94.17	1	0.000	*
	separation-bar depth	38.20	1	0.000	*
	style vs. velocity	4.30	1	0.041	*
	style vs. depth	1.05	1	0.308	
	velocity vs. depth	5.93	1	0.017	*
	style vs. velocity vs. depth	1.91	1	0.171	
yearling chinook salmon ≥180 mm	separation-bar style	0.42	1	0.522	
	water velocity	12.45	1	0.001	*
	separation-bar depth	9.20	1	0.005	*
	style vs. velocity	0.06	1	0.801	
	style vs. depth	0.22	1	0.646	
	velocity vs. depth	0.61	1	0.441	
	style vs. velocity vs. depth	0.29	1	0.592	
yearling chinook salmon, total catch	replicate series (block)	2.63	11	0.014	
	separation-bar style	3.21	1	0.077	
	water velocity	67.21	1	0.000	*
	separation-bar depth	29.05	1	0.000	*
	style vs. velocity	6.95	1	0.010	*
	style vs. depth	1.00	1	0.321	
	velocity vs. depth	3.98	1	0.050	*
	style vs. velocity vs. depth	1.50	1	0.225	

Appendix Table B3. Continued.

Group	Treatment conditions	Calculated statistic *F*	df	*P*	
steelhead <180 mm	separation-bar style	6.43	1	0.020	*
	water velocity	36.24	1	0.000	*
	separation-bar depth	0.32	1	0.581	
	style vs. velocity	1.17	1	0.294	
	style vs. depth	0.24	1	0.629	
	velocity vs. depth	0.34	1	0.568	
	style vs. velocity vs. depth	1.83	1	0.192	
steelhead ≥180 mm	separation-bar style	0.03	1	0.853	
	water velocity	11.53	1	0.001	*
	separation-bar depth	2.67	1	0.106	
	style vs. velocity	1.06	1	0.305	
	style vs. depth	0.25	1	0.617	
	velocity vs. depth	0.86	1	0.355	
	style vs. velocity vs. depth	0.00	1	0.959	
steelhead, total catch	replicate series (block)	1.66	11	0.100	
	separation-bar style	0.96	1	0.329	
	water velocity	0.66	1	0.419	
	separation-bar depth	0.72	1	0.398	
	style vs. velocity	1.41	1	0.238	
	style vs. depth	0.08	1	0.784	
	velocity vs. depth	0.86	1	0.356	
	style vs. velocity vs. depth	0.09	1	0.761	

Appendix Table B3. Continued.

Group	Treatment conditions	Calculated statistic F	df	P	
					*
total salmonid catch <180 mm	replicate series (block)	2.91	11	0.003	*
	separation-bar style	6.49	1	0.013	*
	water velocity	117.72	1	0.000	*
	separation-bar depth	34.22	1	0.000	*
	style vs. velocity	5.37	1	0.023	*
	style vs. depth	0.78	1	0.379	
	velocity vs. depth	5.92	1	0.017	*
	style vs. velocity vs. depth	3.16	1	0.079	
total salmonid catch ≥180 mm	replicate series (block)	2.31	11	0.017	*
	separation-bar style	0.07	1	0.794	
	water velocity	18.83	1	0.000	*
	separation-bar depth	5.66	1	0.020	*
	style vs. velocity	1.20	1	0.276	
	style vs. depth	0.32	1	0.573	
	velocity vs. depth	1.37	1	0.245	
	style vs. velocity vs. depth	0.31	1	0.578	
total salmonid catch	replicate series (block)	3.66	11	0.000	*
	separation-bar style	7.21	1	0.009	*
	water velocity	23.09	1	0.000	*
	separation-bar depth	12.54	1	0.001	*
	style vs. velocity	0.18	1	0.673	
	style vs. depth	0.05	1	0.828	
	velocity vs. depth	0.89	1	0.349	
	style vs. velocity vs. depth	0.53	1	0.471	

Appendix Table B4. Statistical analysis results of comparisons among mean descaling values by group for treatments evaluated using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999. Asterisks indicate significant differences ($\alpha = 0.05$) among treatment factors.

Group	Treatment conditions	Calculated statistic *F*	df	*P*
yearling chinook salmon <180 mm	replicate series (block)	5.28	11	0.000 *
	separation-bar style	0.44	1	0.510
	water velocity	7.41	1	0.008 *
	separation-bar depth	1.65	1	0.203
	style vs. velocity	0.06	1	0.800
	style vs. depth	2.98	1	0.088
	velocity vs. depth	1.04	1	0.311
	style vs. velocity vs. depth	3.63	1	0.060
yearling chinook salmon ≥ 180 mm	separation-bar style	0.33	1	0.569
	water velocity	0.02	1	0.876
	separation-bar depth	1.41	1	0.245
	style vs. velocity	0.93	1	0.343
	style vs. depth	1.05	1	0.313
	velocity vs. depth	0.000	1	0.961
	style vs. velocity vs. depth	0.73	1	0.399
yearling chinook salmon, total catch	replicate series (block)	5.26	11	0.000 *
	separation-bar style	0.48	1	0.486
	water velocity	6.86	1	0.011 *
	separation-bar depth	1.46	1	0.231
	style vs. velocity	0.05	1	0.816
	style vs. depth	3.28	1	0.074
	velocity vs. depth	0.92	1	0.339
	style vs. velocity vs.	3.66	1	0.060

Appendix Table B4. Continued.

Group	Treatment conditions	Calculated statistic F	df	P	
steelhead <180 mm	separation-bar style	0.95	1	0.342	
	water velocity	4.01	1	0.060	
	separation-bar depth	0.10	1	0.759	
	style vs. velocity	1.32	1	0.265	
	style vs. depth	0.18	1	0.677	
	velocity vs. depth	0.24	1	0.632	
	style vs. velocity vs. depth	0.71	1	0.410	
steelhead ≥180 mm	separation-bar style	1.94	1	0.167	
	water velocity	0.00	1	0.948	
	separation-bar depth	3.23	1	0.076	
	style vs. velocity	0.04	1	0.850	
	style vs. depth	8.63	1	0.004	*
	velocity vs. depth	0.67	1	0.416	
	style vs. velocity vs. depth	0.13	1	0.717	
steelhead, total catch	replicate series (block)	1.42	11	0.184	
	separation-bar style	1.85	1	0.178	
	water velocity	0.59	1	0.444	
	separation-bar depth	0.97	1	0.329	
	style vs. velocity	0.00	1	0.999	
	style vs. depth	4.88	1	0.030	*
	velocity vs. depth	0.99	1	0.322	
	style vs. velocity vs. depth	0.03	1	0.862	

Appendix Table B4. Continued.

Group	Treatment conditions	Calculated statistic *F*	df	*P*
total salmonid catch <180 mm	replicate series (block)	4.81	11	0.000 *
	separation-bar style	0.67	1	0.417
	water velocity	8.42	1	0.005 *
	separation-bar depth	1.36	1	0.247
	style vs. velocity	0.06	1	0.800
	style vs. depth	2.58	1	0.113
	velocity vs. depth	0.76	1	0.387
	style vs. velocity vs. depth	4.11	1	0.046
total salmonid catch ≥180 mm	replicate series (block)	1.03	11	0.431
	separation-bar style	0.42	1	0.517
	water velocity	0.00	1	0.995
	separation-bar depth	0.75	1	0.390
	style vs. velocity	0.20	1	0.655
	style vs. depth	5.55	1	0.021 *
	velocity vs. depth	0.24	1	0.628
	style vs. velocity vs. depth	0.00	1	0.955
total salmonid catch	replicate series (block)	2.36	11	0.014 *
	separation-bar style	1.10	1	0.289
	water velocity	6.10	1	0.016 *
	separation-bar depth	0.08	1	0.775
	style vs. velocity	0.01	1	0.939
	style vs. depth	6.60	1	0.012 *
	velocity vs. depth	0.82	1	0.369
	style vs. velocity vs. depth	1.61	1	0.209