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Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

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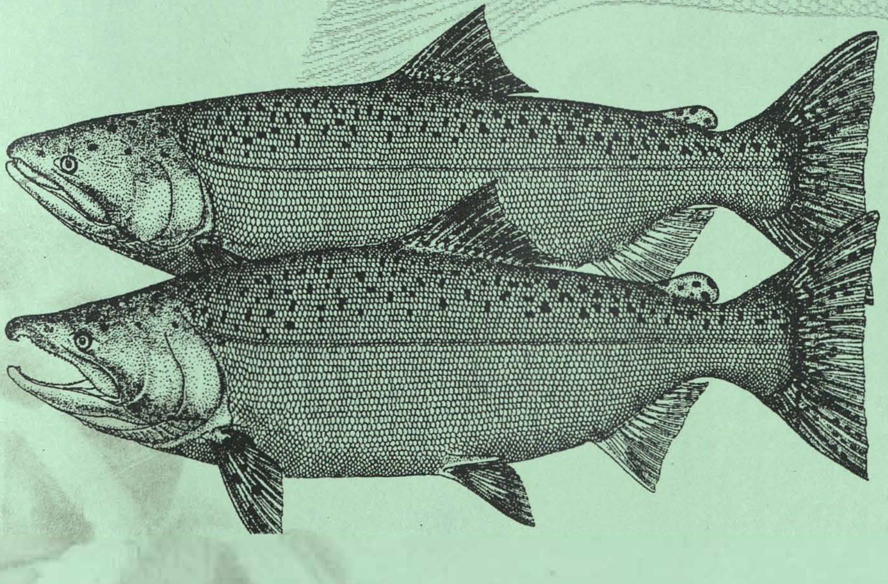
April 2010



Biological Design Criteria for Fish Passage Facilities: High-Velocity Flume Development and Improved Wet-Separator Efficiency, 2000

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Report of research by

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Walla Walla, Washington 99326-1876
Delivery Order E86910060

April 2010

EXECUTIVE SUMMARY

Size separation of juvenile Pacific salmonids *Oncorhynchus* spp. is important for the effective management of Columbia and Snake River systems and the fish transportation program. Studies continued in 2000 at Ice Harbor Dam on the Snake River and at McNary Dam on the Columbia River to improve wet-separation techniques for implementation in juvenile bypass facilities at hydroelectric facilities.

The effects of eight treatments on separation efficiency, separator exit efficiency (a measure of residence time in the separator unit), and fish condition (descaling) were evaluated using river-run juvenile salmonid migrants over the spring migration period at the Ice Harbor Dam high-velocity flume (HVF) test separator facility. Treatment factors included combinations of water velocity (1 m/s and 2 m/s), wave height (high and low), and separation bar array orientation (angled or parallel). Fish were separated by species into small and large fish groups (fork length (FL) <180 mm or ≥180 mm), using bars spaced 17 mm apart.

Seven replicates were completed for each treatment using a randomized block experimental design. Wave height had no effect on separation efficiency for any size group. Total catch separation efficiency was highest and equivalent at 2 m/s with parallel bars (80%, se = 1.8), and at 1 m/s velocity with angled bars (79%, se = 1.8). However, separator exit efficiency was significantly lower using the 1 m/s velocity and angled bars. Descaling for the total catch was higher at 2 m/s (8.1%, se = 0.6) than at 1 m/s (5.7%, se = 0.6).

A concept separator for removing large adult and incidental fish upstream from a juvenile separator was evaluated during the fall of 2000 using the Ice Harbor test separator facility. A total of 26 replicates compared separation efficiency at transport velocities of 2 m/s and 3 m/s. Except for shad *Alosa sapidissima*, adult separation was 100% for all species. Juvenile fish separation was 92% at the 2 m/s and 97% at the 3 m/s velocity. Due to limitations in adapting the test facility for this work, the juvenile fish separation efficiency values should be considered low.

At McNary Dam, separation research was conducted over the spring and summer migrations of juvenile Chinook salmon *O. tshawytscha* using evaluation HVF and conventional wet separators. In both units, four treatments compared the effects of salmonid density (low and high) and separator lighting level (low, medium, and high) on salmonid size separation, separator exit efficiency, and descaling.

Separation efficiency was generally significantly higher with increasing light level for small and total salmonid catch groups using both units. Mean total catch separation efficiency values using the high light level during the spring migration period was 75% (se = 1.5) using the conventional separator and 82% (se = 1.8) using the HVF unit. Subyearling Chinook salmon separation efficiency values during the summer migration were 90 and 99%, respectively. Separator exit efficiency was over 93% for all comparison groups using the conventional separator, and over 85% using the HVF. Mean descaling for the total catch was not significantly different among light level conditions for either evaluation separator during either migration period.

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INTRODUCTION

Bypass facilities at hydroelectric dams on the Snake and Columbia Rivers are used to collect juvenile Pacific salmonids *Oncorhynchus* spp. for subsequent transport and/or release downriver. Because it is believed that juvenile Chinook salmon *O. tshawytscha* transported with juvenile steelhead *O. mykiss* (which are generally larger than Chinook salmon smolts) experience higher levels of stress than those transported with other Chinook salmon (McCabe et al. 1979), separation of smolts by size has been an objective of juvenile bypass systems since shortly after their inception. A study in 1981 (Gessel et al. 1985) led to the implementation of wet separators at collection/bypass sites. These wet separators have been in use since 1983, but with mixed results.

Most wet separators utilize the three-stage separation process described by McComas et al. (1998). Following partial dewatering, all fish are deposited in the first section (A section) of the separator. Bars just under the water surface in this section are spaced to allow smaller fish to pass through to a fish collection area under the bars and eventual egress to a "small fish" holding area in the fish passage facility. Larger fish continue on to the second section (B section), where the next size class is removed in a similar manner. Fish too large to negotiate separation-bar spaces in the B section pass into a flume at the end of the system for return to the river.

For salmonids, under ideal conditions, the A section is intended to segregate smaller smolts such as Chinook, coho *O. kisutch*, and sockeye *O. nerka* salmon from the larger, predominantly hatchery steelhead smolts, which are filtered through the B section. Large fish eliminated from the process are generally adult salmonid fallbacks and non-salmonid incidental species.

In practice, there are several problems with existing wet separators. For example, the McNary separator exhibits poor performance in the A section, which resulted in 1998 separator efficiency values of 41.4, 22.9, and 26.7% for yearling Chinook, coho, and sockeye salmon, respectively (Hurson et al 1999). Possible reasons include flow surges which carry smaller fish through the first section with insufficient time to sound through the separator bars, and an inadequate stimulus to generate a sounding response.

Behavior and physiology studies have indicated that fish also hold under the bars for extended periods rather than exit expeditiously from the separator unit (Schreck et al. in prep). This suggests that many fish exit only after they are fatigued as a result of swimming to avoid hydraulic conditions within the unit.

A series of studies was initiated to explore methods for improving wet separator performance using two approaches, and two evaluation separator units were constructed to evaluate juvenile salmonid behavior relative to various design changes (McComas et al. 2000). One approach was to improve the function and design of existing operational separators; the second was to explore alternatives to the existing separator design.

The most promising alternative to emerge has been the high-velocity flume (HVF) approach. Under this strategy, smolts enter a section of open flume directly after transport from the bypass channel. While traveling at velocities higher than those in current operational separators, (1-2 m/s), smaller smolts could sound between appropriately spaced separation bars within the flume, effecting separation from larger smolts unable to fit between the bars. Both groups would continue to different holding areas without the interruption caused by significant velocity reduction, and without migration timing delays, stress, and fatigue induced by resisting flows within the separator.

Results using an evaluation HVF separator during the 1998 juvenile salmonid migration period indicated that over 80% separation could be achieved for the total catch of all salmonid species combined at a velocity of 1 m/s, using separation bars submerged 50 mm below and parallel to the water surface, and spaced 19 mm apart (McComas et al. 2001). Based on these conclusions, a full-scale prototype HVF separator was constructed at Ice Harbor Dam for evaluation during the 1999 juvenile migration.

However, testing at Ice Harbor has resulted in a preliminary estimate of less than 70% for the same conditions, and indicated that fish resisted sounding at the lower velocity. Although fish did separate more efficiently with the separation-bar array submerged at 50 mm rather than 100 mm, separation efficiency increased at 2 m/s velocity compared to 1 m/s.

Existing three-stage juvenile separators currently in operation at Columbia and Snake River bypass facilities do not remove salmonid adults and large incidental catch prior to the juvenile fish separator. Thus large fish (generally >400 mm) are obliged to pass through the shallow water above the separation bars of both the upstream and downstream sections, to a discrete compartment at the end of the separator for eventual bypass. The process is disruptive to juvenile separation in existing separators, and raises the potential for reduced separation efficiency, injury, and stress to juveniles.

In an HVF separator, juveniles are separated during transport to holding areas, and there is no provision made for removing adults. Though large fish could conceivably be isolated from the large smolt contingent after the smaller smolts are separated, it would be more efficient to segregate adult fish prior to arrival at the HVF. This would not only keep large animals from disrupting juvenile separation, but would remove larger debris before it could become lodged in the juvenile separator unit.

One difference between conditions in the prototype high-velocity flume and the evaluation separators concerns incident light. The prototype flume has been tested only during daylight hours, and the majority of replicates were conducted in full sunlight. By contrast, incident lighting on the evaluation separators was subdued for the majority of the tests, since incident bright sunlight falls on either unit for only a few hours during the middle of the day. The difference may directly relate to separation differences between the two sites using the high-velocity flume units, and light may be relevant to separation in general.

During the 2000 spring and summer Chinook salmon migration, personnel of the National Marine Fisheries Service continued to evaluate conditions intended to improve salmonid smolt separation efficiency using the prototype HVF wet separator at Ice Harbor Dam. Concurrently, similar evaluations were conducted to investigate effects of artificial light and smolt density on the separation process using conventional and HVF test separators at McNary Dam.

Subsequent to the smolt migration, we began development of an adult separator intended to segregate large fish from migrant smolts during transport from the bypass channel and prior to their arrival at the separator. Specific objectives in 2000 were:

1) Evaluate the effects of water velocity, flow exchange through separation-bars, and standing waves on volitional sounding response (resulting in salmonid size class separation), exit efficiency, and fish condition in a high-velocity flume environment.

2) Evaluate the function, reliability, and safety of an in-flume adult separator design for isolating and removing adult salmonids and other large incidental species from juvenile fish upstream from the juvenile salmonid wet separator.

3) Evaluate separation efficiency, exit efficiency, and fish condition at two loading densities and under three lighting conditions using evaluation high-velocity flume and conventional wet separators.

OBJECTIVE 1: Evaluate the effects of water-velocity, flow exchange, and standing waves on volitional sounding response, exit efficiency, and fish condition in a high-velocity flume

Methods

A prototype HVF wet-separator test facility was constructed parallel to and north of the existing Ice Harbor Dam juvenile fish bypass facility (Katz 1996, Katz et al. 1999, McComas et al. 2003b). A new drop gate upstream from the existing facility allows the entire water flow and fish collection from the juvenile fish bypass channel to be diverted through test separator during evaluations.

Following diversion to the test facility, flows pass through a primary dewaterer to reduce volume, then through a combined adjustable-slope channel and test-separator section. Two distribution flumes, for separated fish (fish which have sounded between the separation bars) and non-separated fish, provide egress routes at the downstream end of the adjustable-slope channel/test-separator unit. Switch gates in each of the distribution flumes permit fish to be directed into the bypass facility outfall pipe for direct return to the river, or diverted to holding tanks for examination and enumeration.

The adjustable-slope channel and test separator form a single 30.5-m unit mounted to twin I-beams. Slope of the adjustable-slope unit is set using a hydraulic lift mechanism under local control, and is variable from 0 to 4° to provide water velocities up to approximately 3 m/s. The high-velocity flume test separator occupies the downstream 12 m of the variable slope flume. The separator is 1 m wide, 1.5 m high, and comprised of four 3-m sections. Separation-bar length can be varied in 3-m increments to a maximum of 12 m, and separation-bar array angle is independently variable (relative to the floor of the separator) from 0° to approximately 2.3° with 12-m separation bars, or about 9.1° over one 3-m section.

Water depth over the separation-bar array can be varied using vertical adjusters to raise and lower the array, by adjusting the angle of the variable-slope flume/test separator unit, 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. A false floor under the separation bars is also constructed in four 3-m sections, and sections are independently adjustable from 0 to 360 mm depth under the bars. Each false floor panel or the entire false floor can be angled or flat in relation to the floor of the separator flume.

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 salmonid migrants (fish <180 mm fork length, FL) from larger smolts (≥180 mm FL).

Spacing between separation bars was maintained by three 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 separation-bar array styles were evaluated (streamlined and non-streamlined), with the style determined primarily by cross section of the these supports. The cross section in turn influenced the height of standing waves produced by each type of lateral support (Figure 1). Cross supports for the streamlined supports had a cross section resembling an inverted airplane wing airfoil; non-streamlined supports were round. Both styles had individual separation bars supported above cross members on 25-mm pedestals at each of three attachment points. Streamlined pedestals were 9.5-mm (.375-in) thick aluminum bar stock with the upstream edge rounded. Non-streamlined pedestals were 13-mm (0.5-in) solid round aluminum rods.

For each style, separation efficiency, fish condition and separator exit efficiency were evaluated at water velocities of 1 and 2 m/s. We also oriented the separation-bar arrays either parallel or angled relative to water surface for each style and water velocity. The parallel arrays were maintained at a constant submergence of 50 mm, while the angled arrays sloped from approximately 410 mm (16 in) submergence at the upstream end of the separator to 30 mm at the downstream end.

Prototype separator adjustments (adjustable flume angles, makeup-water requirements, dewatering adjustments, and adjustable false floor angles) resulting flow conditions to be evaluated were established and documented prior to the beginning of the migration season (Appendix A).

Together, the three conditions formed eight treatments (Table 1). To minimize the effect of timing bias, the eight treatments were performed as a block, and blocks were conducted successively throughout the spring migration. One entire block of all eight treatments was evaluated before beginning the next block, with all eight treatments randomized within the block.

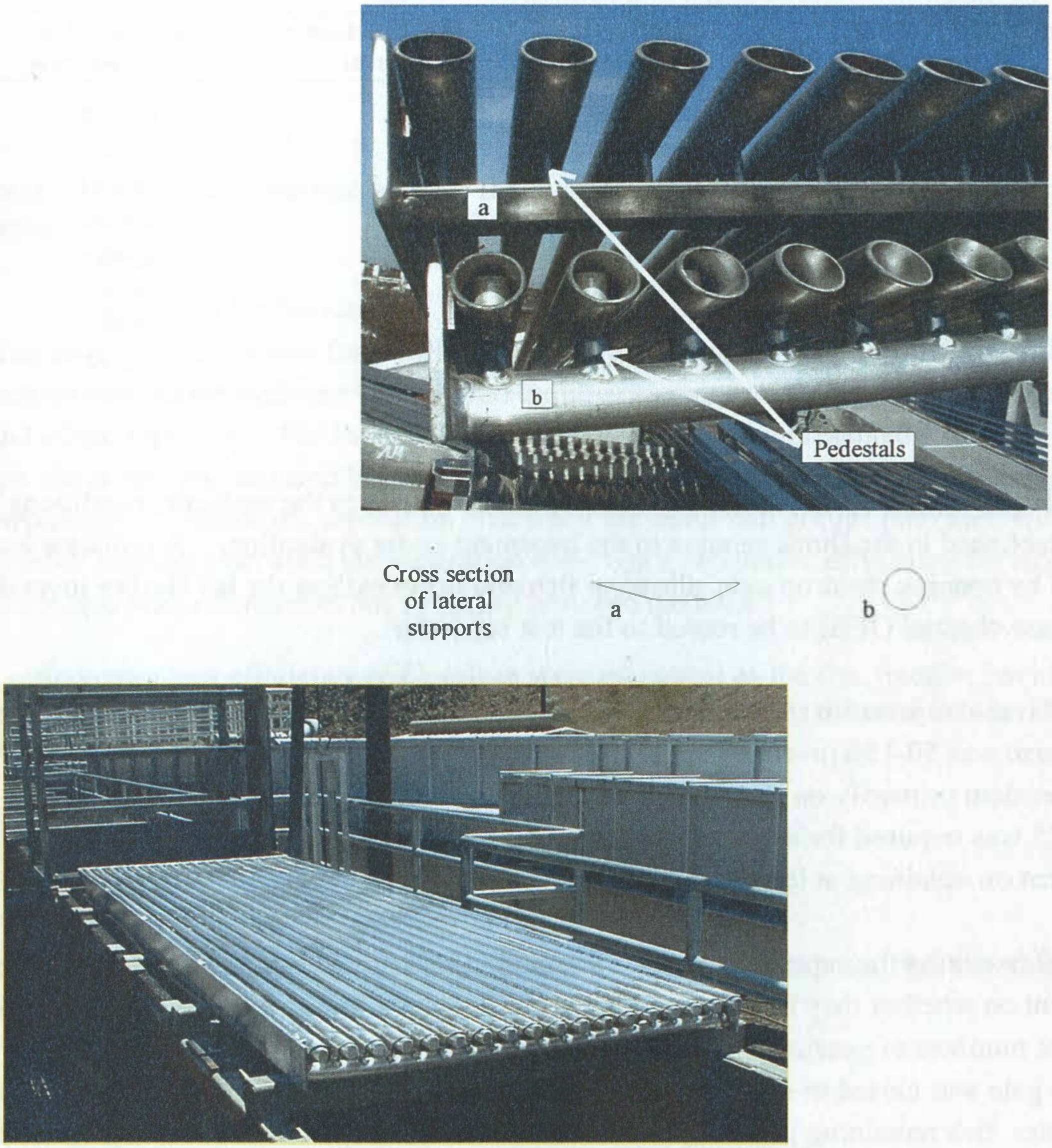

Figure 1. Top: Different lateral supports of the two separation-bar styles. Upper bars have streamlined supports; lower bar supports are non-streamlined. Below: typical separation bar panel used during evaluation of a high-velocity flume wet separator at Ice Harbor Dam, 2000.

Table 1. Conditions and treatments evaluated during separation efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 1999.

Treatment number	Wave condition	Separation-bar support style	Water velocity (m/s)	Separation-bar array orientation
1	low	streamlined	1	parallel
2	low	streamlined	1	angled
3	low	streamlined	2	parallel
4	low	streamlined	2	angled
5	high	non-streamlined	1	parallel
6	high	non-streamlined	1	angled
7	high	non-streamlined	2	parallel
8	high	non-streamlined	2	angled

Test procedure was similar for each replicate. Prior to the replicate, conditions were established in the flume relative to the treatment under evaluation. A replicate was initiated by opening the drop gate, allowing fish and flows exiting the Ice Harbor juvenile fish bypass channel (JFB) to be routed to the test separator.

River-run juvenile salmonid migrants were used as test fish. Initial target sample size was 50-150 juvenile Chinook salmon per replicate, and replicate duration was dependent primarily on numbers of fish entering the flume. A minimum sample size of 25 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 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 JFB. Operating on flush water, fish remaining in the separator were removed first from above and then from below the separation bars. These respectively formed the non-separated and separated groups used in separator exit efficiency calculations.

Fish from each group were anesthetized separately using tricaine methane sulfonate (MS-222) and enumerated by species; each specimen was categorized by length group as small fish (<180 mm fork length; FL) or large fish (≥180 mm FL). Fish condition was also noted using Fish Transportation Oversight Team descaling criteria (Ceballos et al. 1992). Following a suitable period in fresh water for recovery from the effects of anesthetic, all fish were released into the existing JFB outfall pipe for return to the Snake River.

Separation efficiency values (*SE*) were 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 replicate:

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

where A = the separated fraction and T = the total number of fish entering the test separator.

The separated fraction used in the calculation was relative to the size group under consideration. The 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 replicate. For large fish, the separated fraction represented fish from groups which had not sounded between the bars (non-separated holding tanks, separator non-separated). 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*) values were estimated as the fish fraction having exited the test separator by the end of the test replicate, divided by the total number of fish entering the separator unit during the replicate:

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

where A = the fraction entering the separator and T = the total number of fish entering the test separator.

Results and Discussion

A total of 6,965 salmonid smolts were encountered during evaluation of Objective 1 using the Ice Harbor Dam prototype high-velocity flume separator facility in 2000. Yearling Chinook salmon and steelhead comprised 44.7% (3,115) and 54.7% (3,813) of the total catch, respectively. Steelhead made up 91% of the large fish catch, while 96% of the small fish catch was yearling Chinook salmon. 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.

Seven replicates were completed for each treatment between 25 April and 2 June and data were analyzed using a 3-factor analysis of variance (ANOVA). Where sample size for a given species/length group was <25 fish, data were pooled with similar treatments from adjacent blocks. Where pooling over successive blocks was not done, series (date) was included as a covariate.

In general, sufficient numbers of smolts were available for separation efficiency, separator exit efficiency, and descaling analyses for the following seven groups: small yearling Chinook salmon, total yearling Chinook salmon, large steelhead, total steelhead, total small salmonids, total large salmonids, and total salmonids. Data for totals were 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. Wave height was not a significant factor for any comparison.

For small yearling Chinook salmon there was a significant interaction between separation-bar orientation and water velocity (F = 16.77, df = 1, $P = 0.000$). Separation efficiency was statistically similar using 2 m/s velocity with bars parallel to the flow (63%, se = 4.6) or 1 m/s with bars angled relative to the flow (60%, se = 3.9). Both of these configurations produced significantly higher *SE*s than their respective alternate bar-orientation/velocity configurations.

Since 96% of the total Chinook salmon catch were small fish, total Chinook separation efficiency was similar to that for small Chinook salmon with a significant interaction between separation-bar orientation and water velocity (F = 16.29, df = 1, $P = 0.000$). Separation efficiency was similar under configurations using parallel separation bars at 2 m/s (63%, se = 4.4) and angled bars at 1 m/s (62%, se = 3.8). Both of these configurations produced significantly higher *SE* than their alternates.

For the large steelhead group, mean separation efficiency ranged from 79 to 100% across all treatments. As with the Chinook salmon results, there was a significant interaction between bar orientation and water velocity (F = 8.85, df = 1, *P* = 0.005). However, separation efficiency was significantly lower for large steelhead only with angled bars at 1 m/s (91%, se = 1.1). Separation efficiency was similar for configurations using parallel bars at 1 m/s (96%, se = 1.1), angled bars at 2 m/s (96%, se = 1.1), and parallel bars at 2 m/s (95%, se = 1.0).

For separation efficiency of the total steelhead catch, there were no interactions among factors and no significant differences between configurations. Overall mean separation efficiency for the total steelhead group was 91% (se = 08.).

Because small Chinook salmon comprised the bulk of the total small smolts sampled, separation efficiency for the total small salmonid catch was similar to that of the small Chinook salmon catch. For small fish, there was a significant interaction between bar orientation and water velocity (F = 17.31, df = 1, *P* = 0.000). Separation efficiency was similar with parallel bars at 2 m/s (60%, se = 3.7) and with angled bars at 1 m/s (64%, se = 4.2). Both of these combinations were significantly higher than the alternate configurations of angled bars at 2 m/s (45%, se = 3.7) or parallel bars at 1 m/s (47%, se = 3.9).

Similar to the trend seen with Chinook salmon and small fish, separation efficiencies for large steelhead were similar to those of the total catch of large fish. For large fish groups, there was an interaction between water velocity and bar orientation (F = 11.36, df = 1, *P* = 0.002) with significantly lower *SE*s using angled bars at 1 m/s (90%, se = 1.1) than for the remaining bar-orientation/velocity configurations. Separation efficiency did not differ among configurations using parallel bars at 1 m/s (96%, se = 1.1), angled bars at 2 m/s (96%, se = 1.1), or parallel bars at 2 m/s (94%, se = 1.0).

Separation efficiency for the total salmonid catch probably offers the most practicable indication of the overall performance of a separator. In general, separation was high for large fish and low for small fish groups, indicating that small fish are passing over the separation bars without encountering sufficient stimulus to produce a strong sounding response. For total catch *SE*, there was a strong interaction between bar orientation and water velocity (F = 16.76, df = 1, *P* = 0.000). Separation efficiency was significantly higher with parallel bars at 2 m/s (80%, se = 1.8) and with angled bars at 1 m/s (79%, Se = 1.8).

Separator Exit Efficiency

Mean separator exit efficiencies were not significantly different between wave heights for any of the seven groups analyzed (Table 2). As for separation efficiency, there was significant interaction between bar orientation and water velocity for separator exit efficiencies. Exit efficiency was significantly lower for all groups analyzed using angled bars at 1 m/s than for all other combinations (Table 3). Mean exit efficiency values were similar among the remaining combinations for each length group. Complete results of statistical comparisons among treatment groups for separator exit efficiency are presented in Appendix Table B4.

Table 2. Mean separator exit efficiency values by wave condition for salmonid smolt length groups analyzed during separation efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 2000. Small fish were <180 mm and large fish were ≥180 mm FL.

	Exit efficiency (%)						
Wave condition (separation-bar support type)	Small Chinook salmon	Total Chinook salmon	Large steelhead	Total steelhead	Total small salmonid catch	Total large salmonid catch	Total salmonid catch
low wave (streamlined)	83	83	84	83	82	83	83
high wave (non-streamlined)	87	87	83	83	87	83	85

Table 3. Mean separator exit efficiency values for each orientation/velocity configuration by salmonid group during separation efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 2000. Small fish were <180 mm and large fish were ≥180 mm fork length. Shaded cells indicate significantly lower exit efficiency.

	Exit efficiency (%)						
Bar orientation, water velocity	Small Chinook salmon	Total Chinook salmon	Large steelhead	Total steelhead	Total small salmonid catch	Total large salmonid catch	Total salmonid catch
angled, 1 m/s	64	64	49	50	63	49	58
parallel, 1 m/s	93	93	94	94	92	94	93
angled, 2 m/s	88	88	95	94	88	95	92
parallel, 2 m/s	95	95	96	95	94	96	95

Fish Condition

There were no interactions among treatment factors for any descaling comparison, and wave height had no effect on descaling results. Results of statistical analyses among treatments for all descaling comparisons are presented in Appendix Table B5.

The small Chinook salmon group descaling was high, ranging from 2% to nearly 28% over all treatments for replicates with >25 animals. Descaling was significantly higher for small yearling Chinook salmon (F = 6.36, df = 1, *P* = 0.016), and for the total Chinook salmon catch (F = 6.29, df = 1, *P* = 0.017) using 2 m/s water velocity than using 1 m/s velocity. Respective mean descaling values for the small and total Chinook salmon groups were 13.8% (se = 1.2) and 13.4% (se = 1.2) at 2 m/s velocity, compared to 9.4% (se = 1.3) and 9.1% (se = 1.3) at 1 m/s.

Descaling for large steelhead ranged from 0.0 to 13.2% over all replicates having at least 25 fish, with one exception: in one replicate of 25 large steelhead sampled on 17 May, 13 fish (52%) were found to be descaled. This sample was considered an anomaly and was not included in analyses. Without this outlier, mean large steelhead descaling for all replicates was 3.5% (se = 0.5). There were no significant interactions among conditions, and no real differences between mean descaling values for any of the conditions evaluated. Descaling for the total steelhead catch was similar to that of the large steelhead, with no interactions among factors and no significant differences between orientation/velocity configurations.

Although there were no interactions among factors for descaling, there was significantly higher descaling (F = 7.09, df = 1, *P* = 0.012) at 2 m/s (12.5%, se = 1.0) than at 1 m/s (8.4%, se = 1.1) for the total small fish catch. For the total large fish catch, there were no interactions among factors and no differences in descaling between individual factors. However, when the two groups were combined (total salmonid catch), descaling was again significantly higher (F = 6.86, df = 1, *P* = 0.012) at the 2 m/s (8.1%, se = 0.6) than the 1 m/s (5.7%, se = 0.6) velocity.

Over the course of the spring migration, personnel from the Washington Department of Fisheries and Wildlife (WDFW) monitored migrant smolts to assess condition, including descaling, for fish passing through the Ice Harbor bypass facility. Total daily descaling values for each species obtained using the HVF test separator were informally compared to values from the WDFW sample for days both facilities were operated. This comparison was intended as a preliminary indicator of whether the HVF separator was causing injury to smolts. Descaling of fish in the HVF separator was generally similar to that of fish in the WDFW smolt monitoring sample (Figure 2).

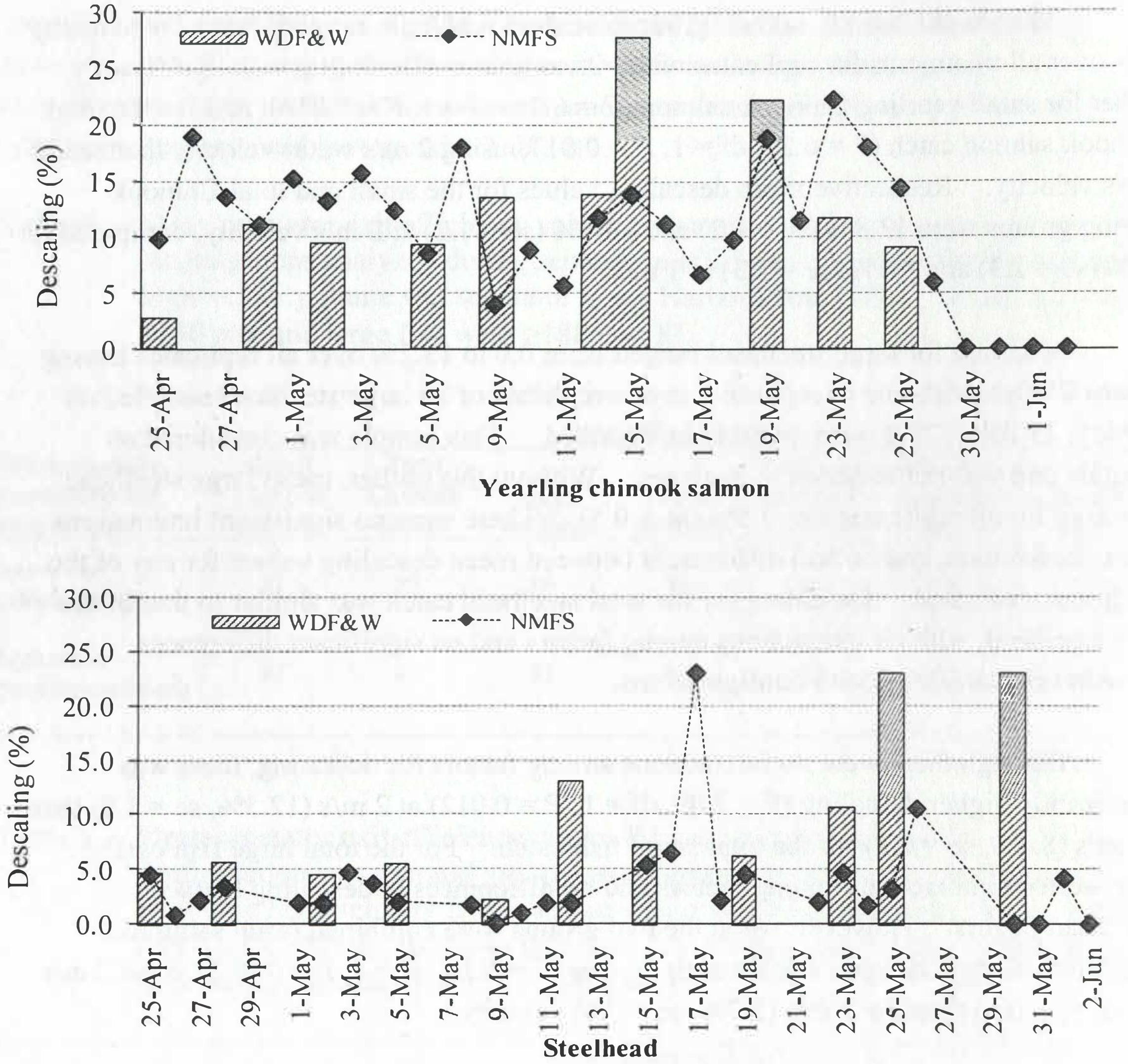

Figure 2. Yearling Chinook salmon and steelhead descaling values obtained from the Ice Harbor Dam juvenile bypass and test separator facilities by sample date, 2000. WDFW values are means from the bypass facility smolt-monitoring samples of wild and hatchery fish combined obtained by Washington State Department of Fisheries and Wildlife personnel. NMFS values are means of all replicates completed during separation efficiency evaluations of the high-velocity flume wet separator.

OBJECTIVE 2: Evaluate an in-flume adult separator for removing adult salmonids and other large incidental species upstream from the primary wet separator

Approach

The test separator facility at Ice Harbor Dam described under Objective 1 was used to evaluate an adult separator for removing adult salmonids, large incidental species and large debris from smaller juvenile salmonids. Sequentially, the adult unit under consideration would immediately precede a juvenile separator so that large fish would be removed for return to the river prior to entry into the juvenile separator unit. This would allow the adult unit to be used with any juvenile separator.

For this evaluation, the separator portion of the adjustable-slope flume was modified by covering the three upstream separation-bar panels with 4.8 mm (0.1875 in) aluminum plate. Edges of the plate panels were fitted with 3.2 mm (0.125 in) thick rubber gaskets along their entire length. These modifications effectively converted the upstream portion of the separator into an extension of the transport flume.

The downstream separation-bar panel was replaced by a panel with bar spacing of 32 mm (1.25 in) for adult separation. The downstream end of the false-floor panel was raised to help maintain water depth in the separator (Figure 3). This evaluation focused on safety for both juvenile and large fish, including minimizing exposure and reducing stress.

To this end, transport flow velocities bringing fish into the adult separator were not abated on approach the unit. During operation, this resulted in flows being carried across approximately 25-30% of the upstream separation-bar length with depth gradually subsiding. The velocity served to eject large adult fish along the bars toward the non-separated distribution flume, while the majority of smolt-sized animals moved between the separation bars with the water as the surface dropped. For the remaining (exposed) separation-bar length, depth in the separator was maintained at approximately half of the separation-bar height. In addition, a spray bar was suspended approximately 610 mm (24 in) above the longitudinal centerline of the bars. Jets in the spray bar were directed downward to keep exposed fish moist during the brief transit along the bars.

Figure 3. Large fish separator in high-velocity flume test facility at Ice Harbor Dam, 2000. The camera view is from inside the flume looking downstream, showing water surface elevation change at the separation bar/adjustable slope flume interface. Note the water surface elevation along the sides of the exposed portion of the separation bars, and auxiliary water supply to the large fish flume at the end of the separator. The overhead spray bar (top center) is turned off for clarity.

We evaluated the adult separator at transport velocities of 2 and 3 m/s. Before beginning a replicate, makeup water and flush water were added to the separator, and the flume was raised to a predetermined slope for the velocity under consideration. In addition, auxiliary water was supplied at the upstream end of the transition into the distribution flumes, and at the upstream end of the large fish distribution flume. When sufficient water depth had accumulated in the separator and distribution flumes, the new drop gate was lowered to divert fish and flows from the bypass transport flume into the test facility. Dewatering was adjusted to maintain a minimum 152 mm (6 in) water depth through the upper portion of the separator.

Lowering the drop gate initiated a replicate. During the replicate, at least three observers with radios were stationed at points along the separator facility. Each observer noted the passing of a large fish past his observation point, and relayed the information to observers downstream. Large fish which did not pass between the separation bars were identified by species during passage, and diverted directly to the bypass pipe downstream from the test facility. All other fish were diverted into one of the two holding tanks dependent on passage either between or over the separation bars.

Replicates were ended by raising the drop gate. At the end of a replicate, fish from each holding tank were anesthetized, enumerated and data was recorded by species as described under Objective 1.

Results and Discussion

A total of 12 replicates using 2 m/s velocity and 14 replicates using 3 m/s were completed from 2 to 20 October. This period was chosen to impact as few migrant salmonids as possible during evaluation. Total catch and separation efficiency are tabulated by species in Table 4.

Table 4. Total catch and separation efficiency by species for fish encountered during evaluation of a concept adult separator using the high-velocity flume test separator facility at Ice Harbor Dam, 2000.

Length group	Water velocity (m/s)	Source	Chinook salmon	Steelhead	Shad	Other species
Adult	2	Catch	14	13	1	6
		Separation efficiency (%)	100	100	0	100
	3	Catch	28	16	4	6
		Separation efficiency (%)	100	100	25	67
Juvenile	2	Catch	12	2	2,668	19
		Separation efficiency (%)	95	100	92	89
	3	Catch	22	2	3,184	20
		Separation efficiency (%)	95	100	97	95

Since the total adult catch for any given replicate was considerably smaller than the 25 fish required for statistical validity, adult data were not formally analyzed. The majority of adult-sized fish encountering the separator traversed the exposed portion of the separation bars and entered the transition to the large fish flume with little difficulty. In a few cases individual fish needed assistance completing the traverse; this was accomplished by a gentle push toward the downstream end of the bars. This problem could be minimized or averted by sloping the bars about 3° downward toward the downstream end of the panel, and by directing the overhead spray jets downstream to act in a pushing capacity.

Separation efficiency was 100% for all adults except shad *Alosa sapidissima*. Of the five adult shad encountered during this work, four were recovered from the small fish sample tank. All four were emaciated and moribund. These types of small or laterally compressed species can be expected to slip between the separation bars and enter the juvenile separator.

Shad made up the majority (98.7%) of juvenile fish encountered, and constituted the only specific group with sufficient numbers for statistical analysis. Mean juvenile shad separation efficiency using the 3 m/s condition (98%, se = 0.7) was significantly higher ($t = -4.94$, $df = 16$, $P = 0.000$) than using the 2 m/s velocity (90%, se = 1.5).

With the possible exception of the adult shad, the large fish separation efficiency values obtained are probably an accurate indication of performance potential for an operational adult separator of this concept. However, the values for juvenile fish should be considered low, because they were obtained under the hydraulic constraints of the test separator facility, rather with a specific design. For example, at the downstream end of the separation bars in the prototype HVF, a splitter plate divides flows from above and below the separation bars, directing separated and non-separated groups into their appropriate distribution flumes.

The splitter plate is 38 mm (1.5") high and intercepts flow between the separation bars, forcing a portion of flow upward into the large fish transition above the bars. Small fish which had already negotiated the separation bars were often seen being shunted back up between the bars and into the upper flume along with this water. In addition, the combination of the adjustable flume elevation and dewatering settings required to maintain the 2 m/s velocity in the test separator exacerbated this condition, and may have accounted for the decreased separation efficiency values obtained for juvenile fish using that condition. In an adult separator designed for the purpose, the floor of the unit at the downstream end of the separation bars could be designed to eliminate this problem.

OBJECTIVE 3: Compare separation efficiency, exit efficiency, and fish condition at two loading densities and under three lighting conditions using high-velocity flume and conventional wet separators

Approach

Two evaluation separators were used to evaluate the effects of fish density and light conditions on separation and exit efficiency and descaling. Both units were installed on platforms suspended over the collection channel and received fish exiting volitionally from the north and south orifices of Gatewell 6B (test gatewell) as test animals.

The separator on the north platform was a full-sized evaluation separator unit fabricated to simulate the function of the small fish section of an operational wet separator similar to those in use at McNary and Lower Monumental Dams (McComas et al. 1998). Several modifications were incorporated into this conventional separator during construction to reduce or eliminate recognized functional weaknesses in operational units. A full-sized separator section was used so that favorable changes to the evaluation separator could be adapted to existing operational wet separators without requiring major revision to the existing unit.

The evaluation conventional separator measured 1.52 m (5 ft) wide, 3.96 m (13 ft) long and 1.2 m (4 ft) high. Maximum water depth was 0.8 m, with add-in water supplied through a 254-mm (10-in) siphon drawing water from the forebay. Major modifications to this basic unit involved removal of the downwell sump located in the downstream end of operational separators, and reduction and redirection of add-in water (McComas et al. 2001). Separation bars were contained in an array oriented parallel to flow along the long axis of the evaluation unit, and sloped from 76 mm (3 in) below the water surface at the upstream end to 30 mm (1.25 in) below the surface at the downstream end. The array consisted of two panels 0.76 m (2.5 ft) wide and 3.35 m (11 ft) long, with individual bars of 254-mm (1-in) ID aluminum tubing. Spacing was 17 mm (0.6875 in) between individual bars. Total separation-bar area of the evaluation separator unit (with reduced length due to the downwell modification) was 5.11 m^2 (55 ft^2), or approximately 85% of the total area available in the upstream section of an operational conventional separator (5.85 m^2, 65 ft^2).

In operational separators, a downwell sump serves as the entrance to an exit orifice for fish which have sounded between the separation bars (separated fish). The orifice is located at the bottom of the downwell, approximately 1.5 m (5 ft) below the water surface. Video recordings of behavior near the sump entrance have shown that accelerating water velocities through the downwell cause smolts to resist entering the sump by swimming vigorously against the flow. (J. L. Congleton, University of Idaho, personal communication), suggesting delayed migration and increased stress as a result of hydraulic conditions within the unit.

To simulate modification of a conventional separator, the area containing the downwell sump was eliminated from the test separator by installing a vertical partition 610 mm (2 ft) from the downstream end and horizontally across the width of the unit. The partition supported the downstream end of the separation-bar array at a height which allowed approximately 30 mm (1.25 in) water depth over the separation bars, forming the overflow orifice for fish not passing between the bars (non-separated fish).

The other major difference between the test separator unit and a conventional separator involved the make-up water delivery system, and this is linked to placement of the submerged exit orifice. In addition to a drain supply furnishing water directly to the orifice, the volume of water needed to support a downwell orifice at the 1.5 m depth in an operational unit is augmented by forced inflow up through a perforated plate false bottom at three points along the longitudinal centerline of each separator section. Fish have been observed swimming into this flow, in a head-down orientation toward the perforated plate. Minimally, this hydraulic situation contributes to increased holding time in the separator, and probably to increased fatigue and stress.

Previous evaluations of conventional separators have demonstrated that a shallower orifice configuration can be more efficient at passing fish than an orifice deeper in the water column (McComas et al. 1998). The bottom of the submerged orifice in the evaluation unit for this study was placed 230 mm (9 in) below the water surface to reduce velocity and volume through the opening. The submerged orifice measured 76 mm (3 in) by 610 mm (24 in), and was centered in the partition at the downstream end of the unit. A perforated plate false bottom sloped from the bottom edge of the submerged orifice to 152 mm (6 in) below the water surface at the upstream end of the separator.

Make-up water was also redirected to eliminate the upward flow component which appeared to attract fish. A 245-mm (10-in) PVC tube through the longitudinal centerline and along the floor of the separator under the false bottom received water from the siphon. Flow was regulated by 245-mm (10-in) valves on both ends of this tube. Four lateral 101-mm (4-in) pipes were attached to each side of the 245-mm tube, and each pipe was equipped with double rows of 9-mm (3/8-in) holes directed toward the floor at approximately 30 degrees to the vertical. This arrangement dispersed make-up water inflow throughout the separator with no apparent upwelling.

The south orifice platform was built to accommodate an aluminum HVF test separator with a 0.9-m square cross section. The downstream end of the HVF was equipped with an adjustable leaf gate to control flow through the flume. Secondary upper and lower collection flumes and holding tanks were provided for non-separated and separated fish groups, respectively. Add-in water was supplied through siphons from the forebay, entering the collection channel over forebay sluice gates. Separation bars used in the HVF separator were similar to those described for the conventional unit, with a 17-mm spacing between bars. The separation bar array was composed of eight 0.9-m wide interlocking panels 1.5 m (5 ft) long. For all tests separation bars were oriented flat (parallel) in relation to the water surface, and water velocity was uniform at 1 m/sec.

We compared separation efficiency, separator exit efficiency, and fish condition at high and low smolt loading densities, and at low, medium, and high light levels, using both evaluation separators. The number of smolts normally exiting the test gatewell is less than 200 per hour when spill mandates are in effect, which is less than required for adequate load testing. To augment numbers across the test separator, the test gatewell was seeded with fish obtained by netting fish from adjacent (A and C) gatewells using a crane-operated dip basket. The dip basket was a modification of the design implemented by Swan et al. (1979) which allowed fish to be removed from the adjacent gatewell and released into the test gatewell without interim transfer to, and release from, another container. For the high-density evaluation, all smolts were removed from adjacent gatewells and placed in the test gatewell prior to beginning the replicate. A low-density test was defined as the number of fish exiting the unseeded test gatewell over the duration of the replicate.

The effects of high, medium and low incident light levels on the dependent variables was evaluated concurrently with loading density. To control light on the separator units, both separators were covered with a light exclusive enclosure. The enclosures consisted of a structural framework covered with plywood paneling and light blocking tarps, which blanketed the fish-travel path from the gatewell orifice through the separator and holding tanks. Extraneous light was excluded for all tests. Controlled artificial light was delivered through a light system manufactured by the 3M Corporation[1], called a Light Pipe®. This system consisted of a 1000-W metal halide lamp directed

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

through a 254-mm (10-in) horizontal polymer tube with a reflective upper surface. Light striking the upper surface is conducted through the translucent polymer, resulting in a consistent illumination over the length and width of the separation-bar array surface. In addition, the length of the light tube was variable in 2 m increments, so that the conventional unit was equipped with a 4-m light system, while a 12-m system was used with the HVF (Figure 4).

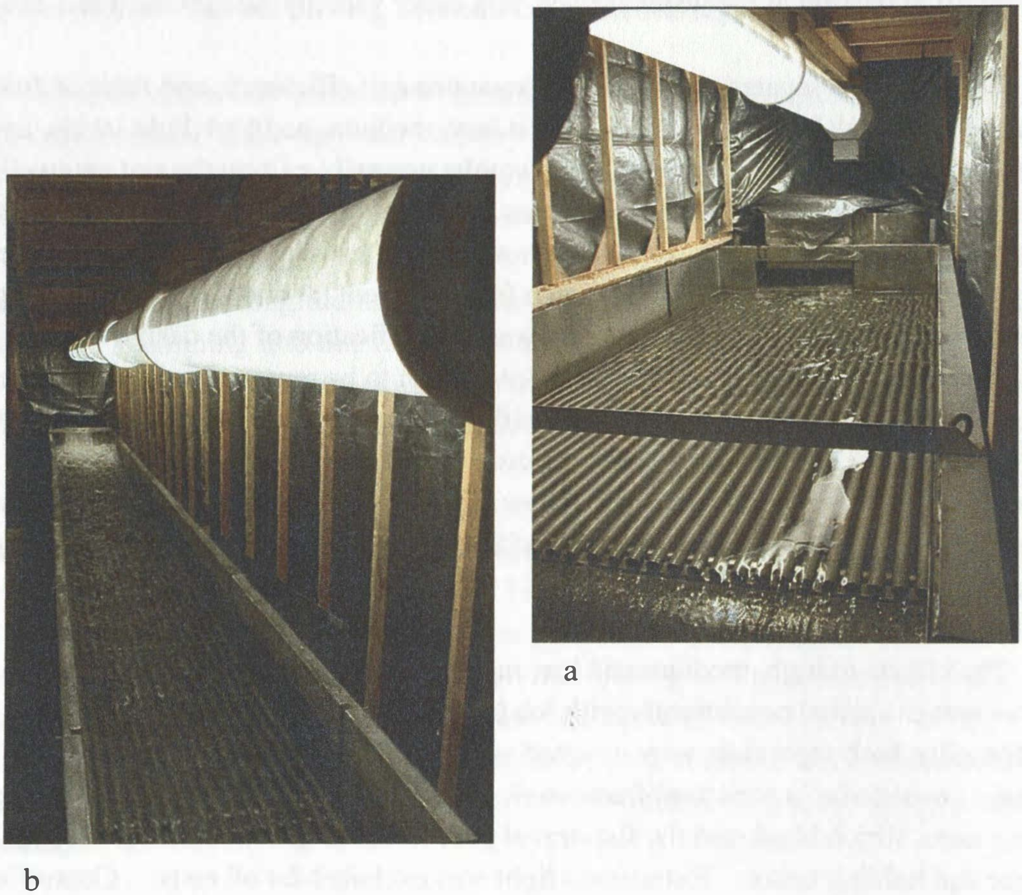

Figure 4. Artificial illumination of (a) conventional and (b) high-velocity flume wet separators studied at McNary Dam, 2000. Both light sources are 1000-W metal halide light, and both photographs show the high light condition.

Both light systems were suspended from the ceiling structures of the light exclusion enclosures for their respective separator units. However, because of non-test period operational differences between separators, the distance from the light tube to the separation bars (measured along the longitudinal centerline if the separation-bar array) was 1500 mm (59 in) in the HVF and 1170 mm (46 in) in the conventional test separator.

Since irradiance is dependent on distance from the light source (Ryer 1997), high and medium artificial light levels were somewhat higher for the conventional unit than for the HVF separator. The high light level in both separators was defined as the full intensity light emitted from the light tube. Because the light systems used were not equipped with dimmers, medium light was effected by shrouding the entire length of the light tube with a single layer of black muslin cloth. The low light condition was effectively dark, with the light source turned off.

Irradiance levels for the various light levels on each separator were measured using an IL 1700 Radiometer from International Light coupled to a Digikröm CM110 monochromator/spectrograph manufactured by CVI Laser Corporation. For these measurements the spectrograph was calibrated for a 0.30-mm slit width, and used an International Light SIW #382 detector head. Beginning 1 m from the upstream end of both separators, irradiance for each light condition was measured at 2-m intervals along the centerline of the separation-bar array at a point 203 mm (8 in) above the water surface. Since measurements for a given separator unit were similar over the length of the light system, only the resulting irradiance curves from the upstream sample point on each evaluation separator are presented (Figure 5).

During studies in 1999, we found no difference in separation efficiency or separator exit efficiency between short (0.5-6 h) and diel (24-h) tests (McComas et al. 2003a), indicating that these variables were not dependent on a time interval. In 2000, we therefore compared values obtained using time periods of approximately 4 h for all replicates. Before starting a replicate, density conditions were established in the test gatewell, and flow and light conditions were stabilized subject to conditions to be evaluated in the separator being used.

A replicate was initiated by opening the gatewell orifice, which allowed test fish to enter the upstream end of unit. After the replicate was ended, test fish were collected first from above, then from below the separation bars within the separator. Animals from the two holding tanks were examined last, and data was collected and recorded as described for Objective 1.

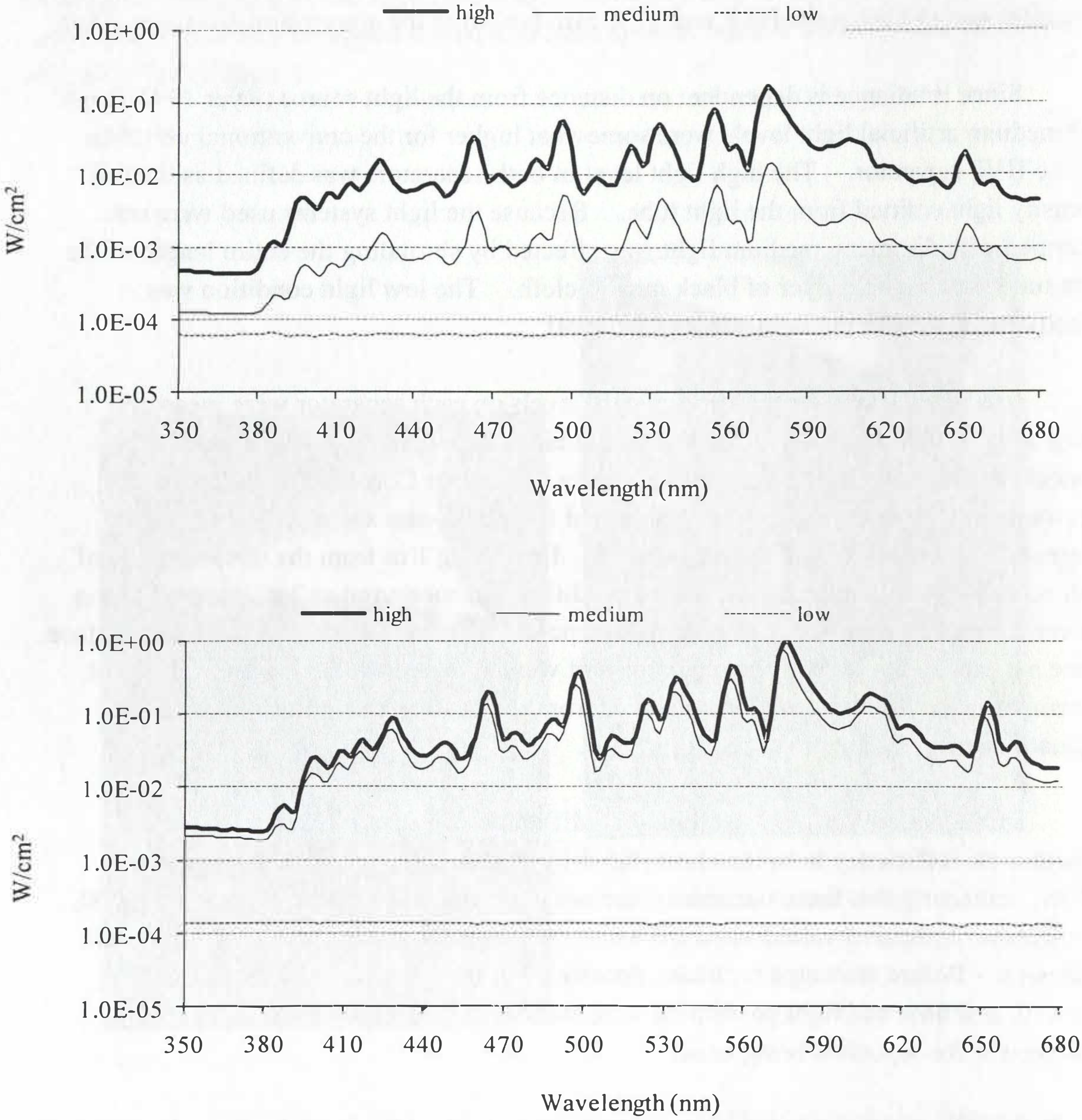

Figure 5. Spectral irradiance for high and medium artificial light and low natural light sources used with evaluation conventional and high-velocity flume wet separators during separation efficiency studies at McNary Dam, 2000.

The two conditions formed a block of six treatments with the order of treatments randomized within each block. Blocks were alternated between the two evaluation separators, so that one block was performed over a 3-d period on one separator, and the other separator unit was used over the next 3 d. One test series was completed using each separator during the spring migration and one during the summer migration, involving multiple blocks performed sequentially.

Results and Discussion

Over the 2000 spring migration, 22,114 smolts were included in evaluation of treatments using the McNary Dam evaluation separators. Yearling Chinook salmon and steelhead comprised 70.4% (15,560) and 14.1% (3,110) of the total catch, respectively. Coho, subyearling Chinook, and sockeye salmon together accounted for the remaining 15.1% of the catch, or 3,444 fish. During the summer migration, 115,467 subyearling Chinook salmon were handled, representing 96.5% of the total catch of 119,711 animals. Complete salmonid catch data for McNary Dam are presented by replicate in Appendix Table B7. Total catch for non-target incidental species are tabulated in Appendix Table B8.

In general, five replicates were completed for each treatment from 28 April to 7 June for the spring migration, and from 19 June to 28 July for the summer run (Table 5). Number of replicates varied somewhat during the spring migration due to delays in obtaining material, equipment malfunction, and maintenance outages for Turbine Unit 6.

The block experimental design was intended to be analyzed using a randomized block ANOVA. However, the assumption that fish seeded into the test gatewell (high density condition) would exit within the 4-h period of a test was not realized in several cases. In addition, the numbers of fish crossing the target separator during low density tests often exceeded the catch from high density tests, even when a majority of fish from the high density operation had exited as expected.

Rather than attempt to artificially assign high and low density status to replicates based on an arbitrary cut-off value, we analyzed the data using a single factor ANOVA with light intensity as the factor, combined across nominal density conditions. By species, smolt density was included in the analysis by using the natural logarithm of the catch (ln(catch)) as a covariate for each length group. The log transformation was used to create a linear relationship between the response variable (separation efficiency, separator exit efficiency or descaling, on a scale of 0-100%) and the log of the catch (scale 1-10). Note that catch for a given replicate ranged from 30 to nearly 8,000, depending on the species.

Table 5. Total number of replicates performed and smolt densities during each treatment on the two evaluation separators.

Treatment number	Light level	Smolt density	Conventional separator (replicates)	HVF separator (replicates)
			Spring migration	
1	low	low	5	5
2	medium	low	5	5
3	high	low	6	5
4	low	high	4	4
5	medium	high	5	3
6	high	high	4	5
			Summer migration	
1	low	low	5	5
2	medium	low	5	5
3	high	low	5	5
4	low	high	5	5
5	medium	high	5	5
6	high	high	5	5

Replicates with fewer than 30 fish (by species) in the catch were pooled across successive similar replicates to obtain a valid sample. For the spring migration, sufficient numbers of smolts were available from both evaluation separators for analysis of small, large, and total yearling Chinook salmon catch; large and total steelhead catch, the total small salmonid catch, the total large salmonid catch, and the total salmonid catch. Small subyearling Chinook salmon was the only group with adequate numbers for analysis from the summer migration.

Where tests were not pooled, sample date was also included as a covariate. Too few replicates were completed where sufficient numbers of steelhead were caught to correlate with date using either evaluation separator unit.

Separation Efficiency

Results of statistical analyses among treatments for all separation efficiency comparisons are included in Appendix Tables B9 and B10 for the evaluation conventional and HVF separators, respectively.

Conventional separator—There were significant differences in separation efficiency among all three light levels for small yearling Chinook salmon (F = 131.40, df = 2, $P = 0.000$) and for the total Chinook salmon catch (F = 79.32, df = 2, $P = 0.000$) using the conventional separator. For both groups the high light condition produced the highest mean separation efficiency, followed by medium and low light conditions (Table 5). Separation efficiency was statistically similar among light levels for the large Chinook salmon group. Density was not significantly related to separation efficiency for any Chinook salmon comparison during the spring run, but sample date was negatively correlated for small Chinook salmon (F = 7.95, df = 1, $P = 0.10$).

Table 5. Mean separation efficiency values (%) by light condition salmonid smolt length groups analyzed during separation efficiency studies using a conventional test separator during spring and summer Chinook salmon migrations at McNary Dam, 2000. Small fish were fish <180 mm fork length (FL). Large fish were ≥180 mm FL. Shaded cells indicate statistically different values in each column.

	Separation efficiency (%)								
	Spring								Summer
	Chinook salmon			Steelhead		Total salmonid catch			
Light condition	Small	Large	Small and large	Large	Total	Small	Large	Small and large	Subyearling Chinook salmon
high	74 (1.9)	71 (5.5)	73 (2.0)	93 (2.0)	88 (2.7)	73 (1.8)	85 (2.7)	75 (1.5)	90 (2.5)
medium	64 (1.8)	82 (5.1)	67 (1.9)	93 (2.0)	91 (2.5)	65 (1.7)	88 (2.6)	71 (1.5)	82 (2.3)
low	32 (1.9)	91 (5.6)	39 (2.0)	96 (2.1)	87 (2.6)	31 (1.8)	92 (2.9)	46 (1.5)	54 (2.3)*

* Interaction between light condition and total catch.

Mean separation efficiency was over 90% for all three light levels for the large steelhead group (Table 5), and not significantly different among the factors (F = 0.62, df = 2, *P* = 0.552) . Since 91% of steelhead were large fish, results for the total steelhead catch (F = 0.63, df = 2, *P* = 0.546) were similar. Density did not significantly effect the results for either group.

The total small fish group, representing all small salmonids sampled, displayed significantly higher separation efficiency with increasing light levels (F = 148.35, df = 2, *P* = 0.000), mirroring the result for small Chinook salmon (Table 5). For small fish, there was a significant interaction between separation efficiency and sample date (F = 8.57, df = 1, *P* = 0.008) indicating that separation efficiency decreased through the spring migration. Total large fish catch separation efficiency also decreased significantly (F = 22.91, df = 1, *P* = 0.000) through the migration, but light level and catch did not significantly effect separation efficiency for large fish using the conventional separator.

Interestingly, sample date did not effect separation efficiency when large and small total catch were combined into the total salmonid catch. However, light level was significantly correlated to separation (F = 100.89, df = 1, *P* = 0.000), so that separation efficiency for this group increased with light intensity (Table 5). Separation efficiency for the total catch decreased significantly as catch increased (F = 5.66, df = 1, *P* = 0.026) during the spring migration.

Separation efficiency for subyearling Chinook salmon during the summer migration revealed a real interaction (F = 8.75, df = 2, *P* = 0.001) with density. However, a plot of density against separation efficiency by light treatment shows a significant relationship for the low light factor, but not for high or medium light levels (Figure 6). Separation efficiency using the low light level was much lower than high or medium light conditions at low catch levels but approached separation for the lighted conditions at higher catches. Separation efficiency was significantly higher using high light than medium light.

High-velocity flume separator—As with the conventional separator, there were significant differences in mean separation efficiency values among all three light levels for small yearling Chinook salmon (F = 28.92, df = 2, *P* = 0.000) and for the total Chinook salmon catch (F = 15.78, df = 2, *P* = 0.000) using the evaluation HVF unit. For both groups the high light condition produced the highest mean separation efficiency, followed by medium and low light conditions (Table 6). Separation efficiency was statistically similar among light levels for the large Chinook salmon group (Table 6). Sample date was related to separation efficiency for small Chinook salmon (F = 16.81, df = 1, *P* = 0.001) and for the large Chinook salmon group (F = 9.53, df = 1, *P* = 0.005), but not for the total Chinook salmon catch. Density was not significant for any of the Chinook salmon groups.

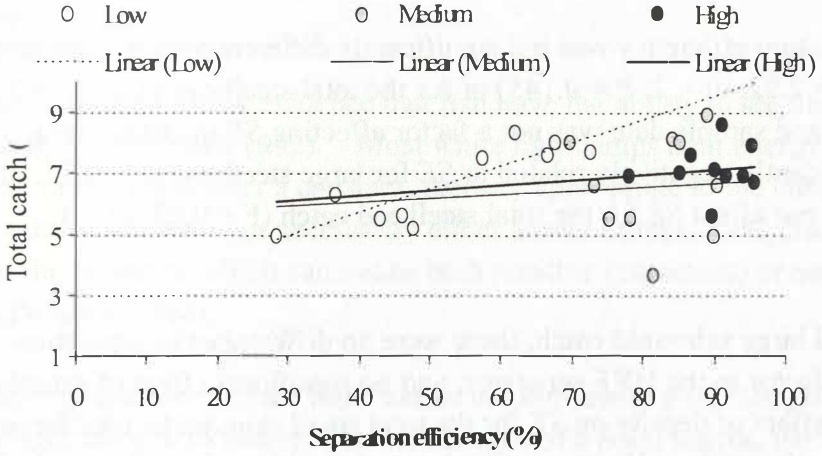

Figure 6. Scatter plot of natural logarithm of total subyearling Chinook salmon catch by light treatment as a function of separation efficiency using an evaluation conventional wet separator during separation efficiency evaluations at McNary Dam, 2000. The relationship between light factor and separation efficiency was significant only for the low light level (T = 3.78, df = 1, *P* = 0.001).

Table 6. Mean separation efficiency (standard errors in parentheses) by light condition for length groups analyzed during separation efficiency studies using an evaluation high-velocity flume wet separator during juvenile salmonid migrations at McNary Dam, 2000. Small fish were <180 mm FL; large fish were ≥180 mm FL. Shading indicates statistically significant differences.

	Separation efficiency (%)							
	Spring							
	Yearling Chinook		Steelhead		All salmonids			Summer subyearling Chinook salmon
Light condition	Small	Total	Large	Total	Total small catch	Total large catch	Total catch	
High	85 (2.6)	80 (2.8)	79 (2.3)	78 (3.2)	83 (2.6)	74 (3.8)	82 (1.8)	99 (1.3)
Medium	73 (2.8)	71 (3.1)	85 (2.9)	77 (3.8)	75 (2.9)	73 (4.1)	77 (2.0)	98 (1.3)
Low	55 (2.7)	57 (3.0)	86 (2.9)	86 (3.9)	58 (2.8)	85 (4.1)	64 (1.9)	84 (1.3)

Mean separation efficiency was not significantly different among light factors for large steelhead (F = 2.22, df = 2, $P = 0.145$) or for the total steelhead catch (F = 1.60, df = 2, $P = 0.232$), and sample date was not a factor affecting *SE* in either group. Density was significantly negatively related to *SE* for large steelhead (F = 4.75, df = 1, $P = 0.047$), but did not affect *SE* for the total steelhead catch (F = 0.07, df = 1, $P = 0.798$).

For the total large salmonid catch, there were no differences in separation efficiency by light factor in the HVF separator, and no significant effect of sample date. There was also no effect of density on *SE* for the total small salmonids, total large salmonids, or total salmonids. However, *SE* changed significantly with sample date for total small salmonids (F = 5.65, df = 1, $P = 0.027$) and total salmonids (F = 17.50, df = 1, $P = 0.000$). For total small and total salmonid groups, *SE* was significantly higher with increasing light levels (F = 21.69, df = 2, $P = 0.000$ and F = 21.70, df = 2, $P = 0.000$, respectively), suggesting the influence of small fish in the total salmonid sample during the spring migration (Table 6).

During the summer migration, subyearling Chinook salmon *SE* in the HVF separator was not significantly influenced by sample date or density. Mean *SE* was high for all three light conditions (Table 6) and was similar for high and medium light levels and significantly lower *SE* for the low light level (F = 38.16, df = 2, $P = 0.000$; Table 6).

To date, studies to improve size separation for salmonids in the Columbia River have centered on behavioral reaction to physical structure or hydraulic parameters of the separator. The inclusion of light is a departure from former work in that light is an external factor. However, light is always present in nature to a greater or lesser extent, and probably has significant impact on fish behavior and physiological response during the bypass process at hydroelectric facilities.

Of the extensive literature concerning visual systems in fish, the majority of work has centered on morphology and electrophysiology (Douglas and Hawryshyn 1990). The quality of light, including spectral range, intensity, diffusion, polarization, and impulse frequency (for artificial light), may influence varied behavioral responses. Absorption in juvenile salmonid fish photo-pigments has been shown to peak between 510 and 515 mμ (Wald 1941). Ali (1961) determined that the retinae and pigment of yearling Atlantic salmon *Salmo salar* are optimally light adapted to wavelengths between 3,060 and 6,900 angstroms (Å). He postulated that the visible spectrum for the species was between 3,640 Å and 6,900 Å. This is shifted toward the blue wavelengths, somewhat lower than the visible spectrum for humans, which ranges from 400 to 770 nm (Reyer 1997).

There is also a strong evidence that fish have the ability to see ultraviolet and polarized light (Hawryshyn 1992). Most white light lamps emit energy in the 400-700 nm range and deliver a constant intensity appropriate to the human eye. However, white light does not necessarily either attract or repel fish, since it may contain portions of the spectrum which can evoke both positive (attraction) or negative (repellent) reactions (Protasov 1968).

Intensity and focus of the light source are intuitively important, since point sources of light are rare in nature. In the absence of a point source, the entire surface of the retina can be illuminated evenly and the animal perceives diffuse, scattered light. Under these conditions, fish could be expected to seek a species and behavior specific optimal illumination. With these observations under consideration, it would may be beneficial to the separation process to illuminate the entire surface of the separator with diffuse light (as opposed to partially shadowed, for example) that has spectral qualities as near the natural condition as possible to evoke a natural sounding response.

Observations of psychophysical reactions of salmonid smolts to artificial light have been mixed. Nemeth and Anderson (1992) noted that both Chinook and coho salmon exhibited a fairly consistent avoidance to strobe and full-intensity mercury vapor lights. However, the response was different for each species, and depended on diel timing. During daytime, coho salmon most often hid when introduced to raceways with either light source, whereas Chinook salmon tended to swim actively. At night, exposure to mercury lamps increased swimming activity of both species. In a study directly related to size separation, Congleton and LaVoie (in prep) found no significant difference in Chinook salmon or steelhead separation efficiency with and without high intensity mercury vapor lamps trained on the upstream section of an operational separator at Lower Monumental Dam.

Behavioral reaction to perceived light stimuli can be modified by environmental factors such as annual timing (Cronly-Dillon and Scharma 1968), temperature (Thorpe 1973), and day length (Munz and Northmore 1973). In addition, physical attributes can influence a fishes psychophysical response. Many authors have noted that the age and size of an individual can affect visual acuity (for example Rahmann et al 1979, Neave 1984), as well as both absolute and spectral sensitivity (Douglas and Hawryshyn 1990). Ali (1961) compared sensitivity of salmonid fry species at low light intensities. Coho *O. kisutch*, chum *O. keta*, pink *O. gorbuscha*, and sockeye *O. nerka* salmon fry become dark adapted at 10^0 to 10^1 foot candles (ft-c).

Coho and sockeye salmon late fry were slightly more sensitive, remaining light adapted to 10^{-1} ft-c. These species were all less sensitive than Atlantic salmon fry, which remained light adapted at 10^{-3} ft-c. Salmonids have been shown to react differently depending on the prior state of adaptation (Ali 1962), related to the time required to change from one state to the other. Sockeye salmon, for example, require 20-25 min for light adaptation following acclimation to dark conditions, and 55 min to fully acclimate to dark after exposure to full light (Bret and Ali 1958). In bypass-system transport flumes, juvenile salmonids can pass between semi-darkness and full sunlight in far shorter time than the span required for light acclimation. This in turn may influence ability to react to visual cues.

Finally, continuity of perceived light or image may also play a role in behavioral reaction to a light source, dependent on the time period required for the organism to process an image. This is subject to the critical fusion frequency (CFF), which is the frequency below which individual retinal images can be separated (Douglas and Hawryshyn 1990). The CFF relates to motion detection, but may also be modified by flux frequency when an alternating current is used to power the light source (Protasov 1968). Protasov (1968) noted experimental evidence of fusion frequency in the range of 1/55 sec (0.0182 sec) for some species; thus it is possible that ordinary artificial light sources may appear to pulse for some fish species in much the same way that strobe lights do for humans.

Separator Exit Efficiency

Results of statistical analyses among treatments for separator exit efficiency comparisons are included in Appendix Table B11 for the evaluation conventional and Appendix Table B12 for the HVF separator.

Conventional Separator—Mean separator exit efficiency values for yearling Chinook salmon were significantly negatively correlated to sample date for small fish and for the total Chinook salmon catch using the conventional evaluation unit. Density did not significantly effect exit efficiency for any of the Chinook salmon groups analyzed from the spring migration. Separator exit efficiency (*EE*) was significantly different among light levels only for the small Chinook salmon contingent (F = 3.51, df = 2, *P* = 0.048), with *EE* higher for the low light level than for either the high or medium levels (Table 7). There was no difference in *EE* between medium and high light levels.

Table 7. Mean separator exit efficiency values (%) by light condition for salmonid smolt length groups analyzed during separation efficiency studies using an evaluation conventional wet separator during spring (Spring) and summer (Summer) Chinook salmon migrations at McNary Dam, 2000. Small fish were fish <180 mm fork length (FL). Large fish were ≥180 mm FL. Shaded cells indicate statistically different values within each column.

	Spring								Summer
	Yearling Chinook			Steelhead		All salmonids			
Light condition	Small	Large	Total	Large	Total	Total small catch	Total large catch	Total catch	subyearling Chinook salmon
High	96 (0.8)	97 (2.0)	96 (0.7)	94 (2.1)	94 (2.2)	96 (0.9)	96 (1.2)	96 (0.9)	90 (1.8)
Medium	96 (0.7)	98 (1.8)	96 (0.7)	93 (2.1)	92 (2.2)	95 (0.8)	96 (1.2)	96 (0.8)	91 (1.8)
Low	98 (0.8)	97 (2.0)	98 (0.7)	97 (2.1)	97 (2.3)	98 (0.8)	98 (1.3)	98 (0.8)	97 (1.8)

For the large steelhead and total steelhead groups, no significant differences in *EE* were observed among light levels, and density did not effect *EE* for either steelhead group.

Density did not significantly effect *EE* for small salmonids, large salmonids, or total catch of all salmonids. However, an effect of date was observed, with *EE* decreasing significantly through the spring migration for small salmonids, (F = 33.56, df = 1, *P* = 0.000), large salmonids (F = 9.56, df = 1, *P* = -0.006), and the total salmonid catch (F = 27.30, df = 1, *P* = 0.000). There was also a significant effect of light level on *EE* for small salmonids (F = 4.36, df = 2, *P* = 0.025), with significantly higher mean *EE* under low light than under high or medium light (Table 7).

During the summer migration, *EE* for subyearling Chinook salmon displayed no correlation with sample date, but there were significant differences among light level treatments (F = 4.51, df = 2, *P* = 0.021). The differences were similar to those seen in the small salmonid group, with low light producing higher *EE* than the medium and high light treatments (Table 7).

High-velocity flume—During the spring migration, there was a significant difference among mean *EE* values by light condition only for large steelhead (F = 6.29, df = 2, *P* = 0.011) using the HVF. For this group, *EE* was higher with the low light condition than for either lighted condition (Table 8). Exit efficiency was significantly negatively correlated to sample date for small Chinook salmon (F = 5.39, df = 1, *P* = 0.030) and for the total Chinook salmon catch (F = 4.93, df = 1, *P* = 0.043), and fish density (ln (catch)) had a significant positive effect on *EE* for large steelhead (F = 4.93, df = 1, *P* = 0.043). During the summer migration, *EE* for subyearling Chinook salmon displayed a positive correlation with density (F = 7.63, df = 1, *P* = 0.011) similar to that seen in the large steelhead group.

Table 8. Mean separator exit efficiency values (%, standard error in parentheses) by light condition for salmonid smolt length groups analyzed during separation efficiency studies using an evaluation high-velocity flume wet separator during spring and summer Chinook salmon migrations at McNary Dam, 2000. Small fish were fish <180 mm fork length (FL). Large fish were ≥180 mm FL. Shaded cells indicate statistically different values in each column.

	Spring							Summer
	Yearling Chinook		Steelhead		All salmonids			
Light condition	Small	Total	Large	Total	Total small catch	Total large catch	Total catch	subyearling Chinook salmon
High	94 (2.1)	95 (2.1)	89 (2.1)	89 (2.2)	94 (2.1)	90 (2.2)	93 (2.0)	98 (0.5)
Medium	96 (2.4)	96 (2.4)	85 (2.7)	88 (2.6)	94 (2.4)	91 (2.4)	94 (2.3)	99 (0.5)
Low	94 (2.3)	94 (2.3)	100 (2.7)	97 (2.6)	95 (2.3)	96 (2.5)	95 (2.2)	97 (0.5)

Overall, mean separator exit efficiency was over 90% using the conventional separator, and over 88% for the high-velocity flume unit, indicating that most fish readily exited both separators over the duration of a test replicate. An interesting behavioral pattern in these data implies that at low flows (as in the conventional unit), all fish exited well under low light (essentially dark) conditions, but smaller animals tended to linger in the separator under high or medium light. This may have resulted in part from the protection offered by the separation bar array for fish sounding between the bars, since exit efficiency was uniformly high for large fish restricted to the lighted area over the separation bars (Table 7).

Using higher flows in the HVF separator, small fish exited similarly regardless of light condition, but larger (and presumably stronger) steelhead tended to hold more easily during light treatments and exit the unit during dark replicates. One explanation for this behavior is that during lighted conditions salmonids are able to use visual cues in addition to the lateral line organ to remain on station. In the absence of visual cues, they are restricted to lateral line sensory input for orientation and direction. In the latter case, salmonid smolt migrants may be attuned to following acceptable flow patterns, resulting in a net movement out of the separator.

Fish Condition

Complete statistical analysis results for descaling comparisons are included in Appendix Tables B13-B14 for the conventional and HVF separators, respectively. In general, mean descaling values over the spring migration were higher than those encountered during similar studies over previous years. However, daily descaling was commensurate with values obtained by smolt monitoring personnel over the same period (Figure 7).

Conventional Separator—Mean yearling Chinook salmon descaling during the spring migration ranged from 2.1% (se = 0.7) to 7.2% (se = 2.1) across all three groups (Table 9). For the total Chinook salmon catch, there was a significant interaction between density and light treatment; however, the coefficients suggest that density was negatively correlated to descaling only for the medium light condition, and not related at all for the high and medium light conditions. Descaling using the low light condition was significantly lower than for the high light treatment. Differences in mean Chinook salmon descaling values for small and large fish groups were not significant.

Mean steelhead descaling was somewhat higher than for the Chinook salmon groups, ranging from 5.5% (se = 2.1) to 7.9% (se = 2.1). There were no significant differences in descaling among the three light levels for either steelhead group analyzed, and the results were not significantly effected by density.

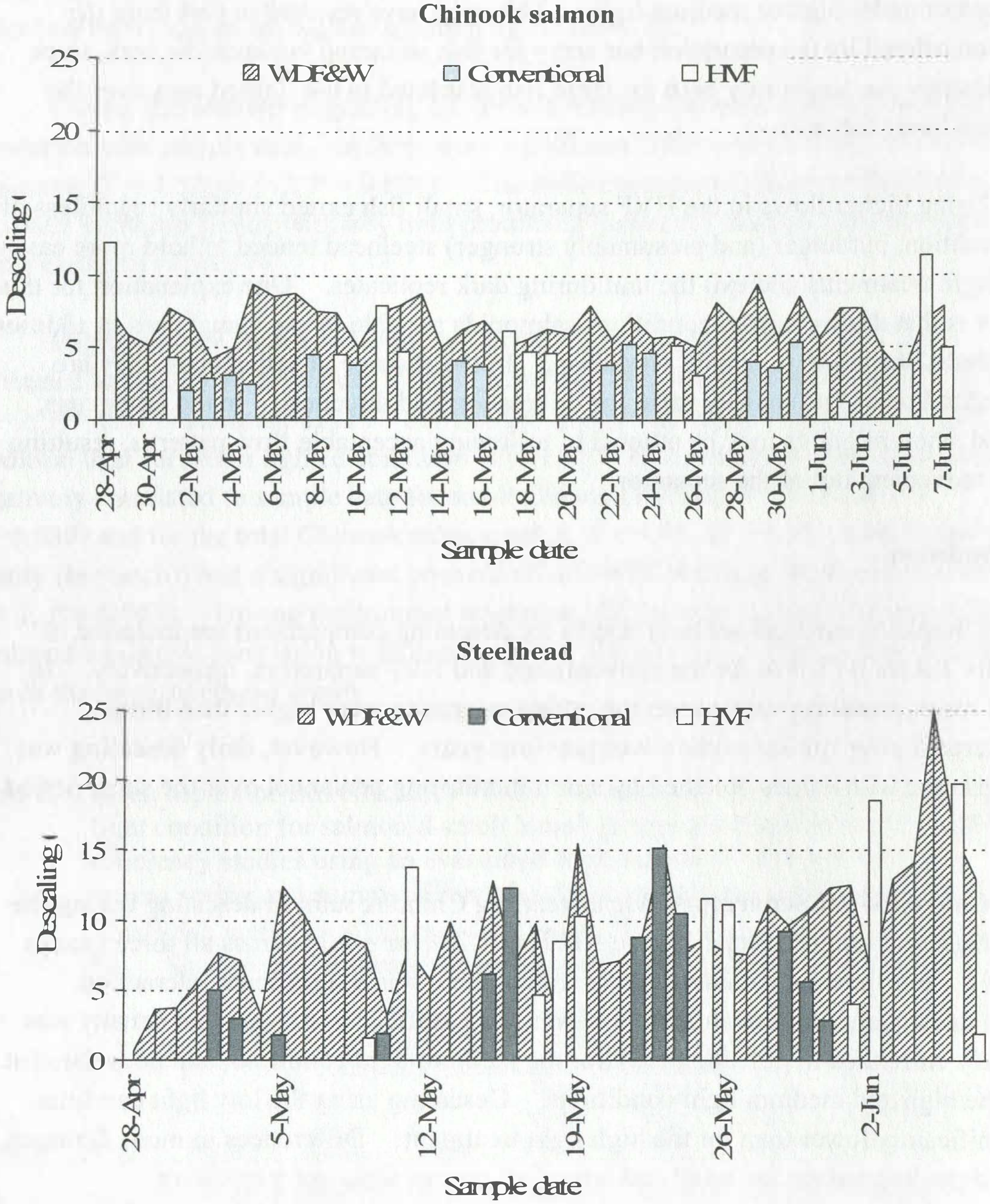

Figure 7. Daily descaling for yearling Chinook salmon and steelhead in juvenile bypass facility, conventional separator, and high-velocity flume (HVF) by sample date at McNary Dam, 2000. Bypass facility values are means for wild and hatchery fish combined from smolt monitoring samples obtained by Washington Department of Fish and Wildlife (WDFW) personnel. Separator values are means of all replicates per date during separation efficiency evaluations.

Table 9. Mean separator descaling values (%) by light condition for salmonid smolt length groups analyzed during separation efficiency studies using an evaluation conventional wet separator during spring and summer Chinook salmon migrations at McNary Dam, 2000. Small fish were fish <180 mm fork length (FL). Large fish were ≥180 mm FL. Values in each column with the same shading are statically similar. An asterisk indicates an interaction between light condition and total catch for the given value.

	Spring								Summer
	Yearling Chinook			Steelhead		All salmonids			
Light condition	Small	Large	Total	Large	Total	Total small catch	Total large catch	Total catch	subyearling Chinook salmon
High	4.3 (0.7)	4.7 (2.3)	4.5 (0.5)	5.9 (2.6)	5.5 (2.1)	4.3 (0.7)	5.1 (1.2)	4.6 (0.6)	0.4 (0.4)
Medium	4.2 (0.7)	7.2 (2.1)	4.6 (0.5)	7.4 (2.6)	7.9 (2.1)	4.3 (0.6)	7.3 (1.9)	4.7 (0.5)	1.4 (0.4)
Low	2.1 (0.7)	5.3 (2.3)	2.7 (0.5)	6.3 (2.7)	5.6 (2.1)	2.6 (0.7)	4.9 (1.3)	3.0 (0.6)	0.3 (0.4)

When all salmonid species were considered together mean descaling ranged from 2.6 (se = 0.7) to 7.3% (se = 1.9), and there was no real difference among light treatment descaling values for the small or large fish groups. For the total salmonid catch combined, there was a significant interaction between light level and density similar to that for the total Chinook salmon group. Density was negatively correlated to descaling, but only for the medium light condition. Density and descaling were not related for the high and medium light conditions. However, for the total salmonid catch, descaling between the low and high light conditions was equivalent.

Subyearling Chinook salmon descaling was typically low over the course of the summer migration, ranging from 0.3 (se = .04) to 1.4% (se = 0.4) across the three light conditions. There were no real differences in subyearling Chinook descaling values using the conventional evaluation separator.

High-velocity flume separator—There were no significant differences in descaling by light treatment for any group analyzed from data obtained using the high-velocity flume separator during the spring or summer migration periods. Descaling for the total salmonid catch ranged from 4.0 (se = 2.3) to 8.8% (se = 2.1) over the spring run, and 0.3 (se = 0.6) to 1.7% (se = 0.6) for subyearling Chinook salmon during the summer (Table 10).

During the spring migration, descaling for large fish did not appear to have been significantly affected by catch size. Length groups which included small fish, however, tended to display a negative relationship between density and condition. Descaling declined significantly with increasing catch for total yearling Chinook salmon (F = 4.89, df = 1 $P = 0.038$), the total salmonid small fish group (F = 4.42, df = 1, $P = 0.047$), and the total salmonid catch (F = 8.51, df = 1, $P = 0.008$), and was only barely not significant for yearling Chinook salmon small fish contingent (F = 4.28, df = 1, $P = 0.051$).

Table 10. Mean descaling values (%, standard error in parentheses) by light condition for salmonid smolt length groups analyzed during separation efficiency studies using a high-velocity flume wet separator during spring and summer Chinook salmon migrations at McNary Dam, 2000. Small fish were fish <180 mm fork length (FL). Large fish were ≥180 mm FL. No statistically significant differences were found among values in each column.

	Spring							Summer
	Yearling Chinook		Steelhead		All salmonids			
Light condition	Small	Total	Large	Total	Total small catch	Total large catch	Total catch	subyearling Chinook salmon
High	5.8 (1.2)	5.7 (1.1)	5.9 (1.9)	6.9	5.7 (0.7)	5.8 (1.9)	5.7 (0.8)	0.3 (0.6)
Medium	5.0 (1.3)	4.9 (1.3)	12.1 (2.5)	10.2	4.6 (0.8)	8.6 (2.0)	6.1 (0.9)	1.1 (0.6)
Low	5.2 (1.3)	5.5 (1.2)	8.6 (2.5)	8.9	4.0 (0.8)	8.8 (2.1)	4.9 (0.9)	1.7 (0.6)

An obvious rational for this result is that as fish numbers increased, personnel spent less time checking for descaling. However, similar relationships did not hold for the conventional separator during the spring or for either unit during the summer migration when numbers were substantially higher. Another possible explanation concerns differences in handling prior to entering the evaluation HVF separator. There appears to be a negative correlation between density and descaling for the total salmonid catch over replicates where the fish numbers were not augmented by fish from other gatewells.

Descaling for replicates over which fish were dipped from adjacent gatewells was consistent and independent of numbers exiting the test gatewell. It is possible that as density increases in the gatewell, a greater percentage of fish are more likely to find and readily exit through an orifice. The effect would act to reduce overall exposure to turbulent conditions in the gatewell, and be manifested in reduced descaling. The possibility of a relationship between descaling and fish density in the gatewell should be considered in future research.

CONCLUSIONS

1) In the prototype HVF test separator at Ice Harbor Dam, separation efficiency was statistically similar with parallel separation bars at 2 m/s velocity (80%) and angled separation bars at the 1 m/s velocity (79%).

   However, for total large salmonids, separation efficiency was significantly lower with the separation bars angled and water velocity at 1 m/s. This configuration also produced the lowest separator exit efficiencies for all groups analyzed. Results from this evaluation indicate that parallel separation bars submerged at 50 mm with a 2-m/s water velocity provided the most beneficial configuration in terms of separation efficiency and separator exit efficiency.

2) Descaling was significantly higher for the total catch using 2 m/s water velocity (8.1%) in the prototype HVF compared to 1 m/s velocity conditions (5.7%).

3) There was no apparent advantage to eliminating standing waves in the prototype HVF.

4) At 2 m/s, the test separator facility was capable of maintaining sustained separation bar submergences required for testing during 1999. Lowering the velocity to 1 m/s, however, 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 achieve lower velocity flows to meet separation evaluation objectives, the downstream end of the last separation-bar panel was lowered approximately 76 mm to intercept and divert flow into the upper flume. All separation evaluation replicates during 1999 were conducted with this adverse slope (approximately 1.5°) over the 3-m length of the downstream separation-bar panel.

5) Separation efficiency for the total salmonid catch displayed no significant interaction among treatment factors. By factor, mean values were higher at 2 m/s water velocity (72%, se = 1.15) than at 1 m/s (65%, se = 1.15), and using pedestal separation bars (71%, se = 1.15) as opposed to the non-pedestal condition (66%, se = 1.15). Separation was also higher using a 50-mm separation-bar submergence (71%, se = 1.15) than at 100 mm submergence (66%, se = 1.15). The highest mean separation efficiency, using pedestal separation bars submerged 50 mm with a 2-m/s water velocity, was 78.3% (se = 2.31).

6) An adult separator concept designed to be installed upstream from a juvenile salmonid separator, succeeded in removing all large adult salmonid and incidental fish except adult shad from juvenile fish. Separation efficiency for juvenile fish was higher using transport velocities of 3 m/s (98%) than at 2 m/s (90%). However, use of the prototype HVF separator to evaluate the adult separator concept probably limited juvenile separation efficiency. A proprietary adult separator design would eliminate these limitations, resulting in substantially higher juvenile separation.

7) Total catch separation efficiency using an evaluation conventional separator at McNary Dam was significantly higher for high light (75%) and medium light (71%) conditions compared to the low light (dark, 46%) condition during the spring migration. For subyearling Chinook salmon during the spring migration, separation efficiency using high (90%) and medium (82%) light were also statistically similar. There was a significant interaction between total catch and separation efficiency (54%) using the low light condition for subyearling Chinook salmon.

8) Using an evaluation HVF separator, total salmonid catch separation efficiency during the spring migration was significantly different among all three light levels. Mean separation efficiency values were 82% using high light, 77% using medium light and 64% with the low light condition. For subyearling Chinook salmon during the summer migration, mean separation efficiency using high light (99%) and medium light (98%) conditions were statistically similar and higher than using the low light (84%) condition.

9) Mean total salmonid catch separator exit efficiency using the conventional evaluation separator were over 96% during the spring migration and over 90% for subyearling Chinook salmon during the summer. Mean values for the spring and summer using the low light condition (98% and 97% , respectively) were significantly higher than using the high light (96% and 90%, respectively) or medium light (96% and 91%, respectively) conditions.

10) Using the evaluation HVF unit, total catch separator exit efficiency was over 93% during the spring migration and over 97% during the summer. There were no significant differences in mean exit efficiency values for any length group analyzed.

11) Using the evaluation conventional separator, mean total catch descaling values were similar under low light (3.0%) and high light (4.6%) conditions during the spring migration. Descaling using the medium light (4.7%) condition had a significant

negative interaction with total catch. There were no real differences among high light (0.4%), medium light (1.4%) and low light (0.3%) mean descaling values for subyearling Chinook salmon during the summer migration.

12) Mean descaling using the evaluation HVF during were statistically similar among all three light levels for the total salmonid catch during spring migration and for subyearling Chinook salmon during the summer. Respective mean descaling values for the high, medium and low light conditions were 5.7, 6.1, and 4.9% during the spring and 0.3, 1.1 and 1.7% during the spring.

ACKNOWLEDGMENTS

We express our appreciation to our seasonal employees for their interest and efforts in this project. We extend special thanks to Ms. Rebecca Kalamasz and Marvin Shutters of the Walla Walla District COE, and at Ice Harbor Dam to Mr. Bill Rose and Mark Plummer for their invaluable cooperation and support. We also extend special thanks to our support staff, especially Mr. Ira Brickey and Mr. Wayne Henry for their efforts and insight during this study.

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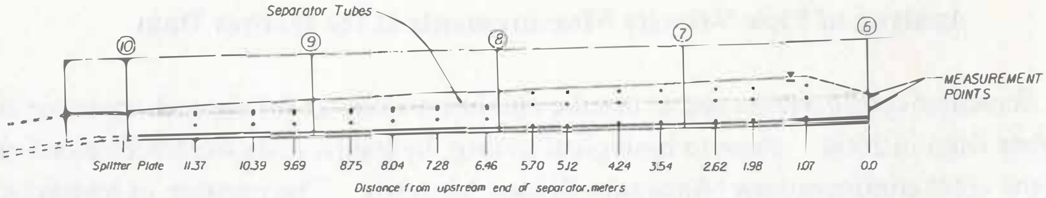
APPENDIX A

Analysis of Flow Velocity Measurements at Ice Harbor Dam

Separator configuration and hydraulic condition were set for the test separator at Ice Harbor Dam in 2000. Prior to biological testing, hydraulic tests were performed on four of the eight configurations (Appendix Tables A2-A10). The purpose of hydraulic tests was to set and record hydraulic conditions (including water depths and flow velocities) for the biological tests, and to assure repeatability.



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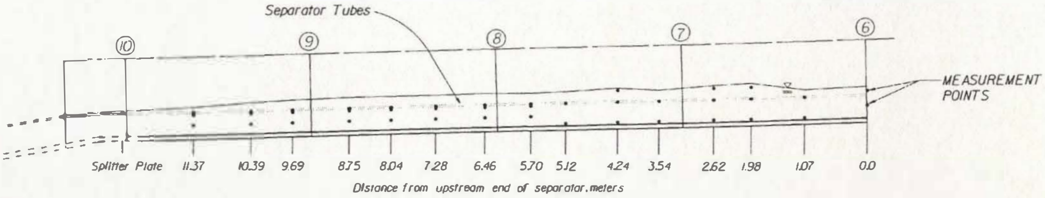
Description: 1 m/s, Sloping bars, Jump is 13' upstream of bars



Date: 3/4/00
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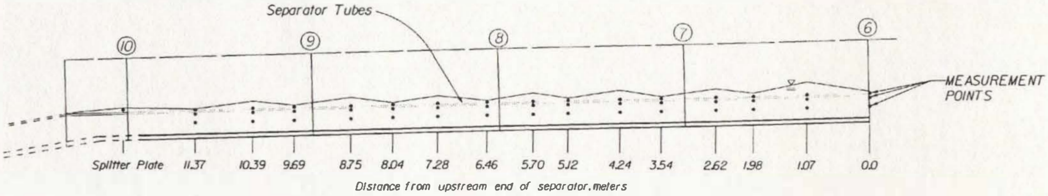
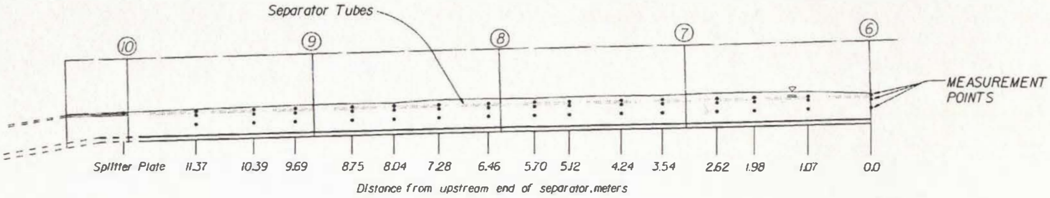


Date: 3/28/00
Description: 5 cm, 2 m/s



Date: 3/29/00
Description: 1 m/s, 5 cm depth condition

Appendix Figure A1. Cross-section of test separator with water surface profiles and velocity measurement points for 4 treatments.

ICE HARBOR EVALUATION SEPARATOR
2000 Field Work
Date: 3/29/00
Description: 1 m/s, 5-cm depth condition
Water Supply:

Appendix Table A2.

u/s invert el. = 417.1 fmsl
Column TOS = 417.05 fmsl
Length = 80 ft
d/s inv. to TOS = 6.5625 in
% Slope = -0.0063 ft/ft*

* positive slope is adverse.

Appendix Table A3.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
1												
2												
3	13.60	4.15	14.20	4.33	12.50	3.81	0.76	0.23	30.08	0.85	30.08	0.85
4	14.50	4.42	16.00	4.88	12.20	3.72	0.27	0.08	11.21	0.32	11.21	0.32
5	11.70	3.57	11.70	3.57	10.40	3.17	0.13	0.04	4.16	0.12	4.16	0.12
6											14.88	0.42
Upper	6.10	1.86	5.80	1.77	4.50	1.37	0.21	0.06	3.36	0.10		
Below bar 1 in. (0.025 m)	3.90	1.19	2.60	0.79	2.10	0.64	0.20	0.06	1.69	0.05		
Below bar 7 in. (0.178 m)	3.60	1.10	2.70	0.82	3.40	1.04	1.03	0.31	9.83	0.28		
3.5											14.84	0.42
Upper	4.80	1.46	3.00	0.91	3.20	0.98	0.31	0.09	3.34	0.09		
Below bar 1 in. (0.025 m)	2.80	0.85	2.80	0.85	2.60	0.79	0.20	0.06	1.61	0.05		
Below bar 7 in. (0.178 m)	3.00	0.91	3.00	0.91	3.00	0.91	1.12	0.34	9.89	0.28		
6.5											14.74	0.42
Upper	3.70	1.13	3.50	1.07	3.30	1.01	0.27	0.08	2.80	0.08		
Below bar 1 in. (0.025 m)	2.10	0.64	2.80	0.85	2.30	0.70	0.20	0.06	1.42	0.04		
Below bar 7 in. (0.178 m)	3.10	0.94	3.10	0.94	2.90	0.88	1.18	0.36	10.52	0.30		
8.6											14.98	0.42
Upper	3.60	1.10	3.30	1.01	2.80	0.85	0.25	0.08	2.39	0.07		
Below bar 1 in. (0.025 m)	2.70	0.82	2.40	0.73	2.30	0.70	0.20	0.06	1.46	0.04		
Below bar 7 in. (0.178 m)	3.10	0.94	3.20	0.98	3.00	0.91	1.22	0.37	11.14	0.32		

Appendix Table A3. Continued.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
11.6											14.31	0.41
Upper	2.90	0.88	3.10	0.94	2.10	0.64	0.21	0.06	1.66	0.05		
Below bar 1 in. (0.025 m)	2.40	0.73	2.10	0.64	2.20	0.67	0.20	0.06	1.32	0.04		
Below bar 7 in. (0.178 m)	3.20	0.98	3.30	1.01	3.30	1.01	1.18	0.36	11.33	0.32		
13.9											14.70	0.42
Upper	2.60	0.79	3.10	0.94	2.20	0.67	0.17	0.05	1.30	0.04		
Below bar 1 in. (0.025 m)	2.60	0.79	2.80	0.85	2.30	0.70	0.20	0.06	1.52	0.04		
Below bar 7 in. (0.178 m)	3.20	0.98	3.20	0.98	3.20	0.98	1.26	0.38	11.89	0.34		
16.8											14.90	0.42
Upper	2.40	0.73	2.90	0.88	2.10	0.64	0.19	0.06	1.37	0.04		
Below bar 1 in. (0.025 m)	2.10	0.64	2.40	0.73	2.40	0.73	0.20	0.06	1.36	0.04		
Below bar 7 in. (0.178 m)	3.30	1.01	3.40	1.04	3.30	1.01	1.24	0.38	12.18	0.34		
18.7											14.86	0.42
Upper	2.50	0.76	3.00	0.91	2.50	0.76	0.17	0.05	1.31	0.04		
Below bar 1 in. (0.025 m)	2.40	0.73	2.60	0.79	2.40	0.73	0.20	0.06	1.46	0.04		
Below bar 7 in. (0.178 m)	3.30	1.01	3.50	1.07	3.30	1.01	1.22	0.37	12.09	0.34		
21.2											15.49	0.44
Upper	2.90	0.88	3.20	0.98	3.00	0.91	0.23	0.07	2.05	0.06		
Below bar 1 in. (0.025 m)	2.20	0.67	2.00	0.61	1.90	0.58	0.20	0.06	1.20	0.03		
Below bar 7 in. (0.178 m)	3.50	1.07	3.50	1.07	3.40	1.04	1.20	0.36	12.24	0.35		

Appendix Table A3. Continued.

Station	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
23.9											14.96	0.42
Upper	2.40	0.73	2.60	0.79	2.50	0.76	0.25	0.08	1.85	0.05		
Below bar 1 in. (0.025 m)	2.40	0.73	2.20	0.67	2.10	0.64	0.20	0.06	1.32	0.04		
Below bar 7 in. (0.178 m)	3.50	1.07	3.30	1.01	3.40	1.04	1.18	0.36	11.80	0.33		
26.4											14.55	0.41
Upper	2.70	0.82	3.10	0.94	2.70	0.82	0.17	0.05	1.39	0.04		
Below bar 1 in. (0.025 m)	2.40	0.73	2.20	0.67	2.20	0.67	0.20	0.06	1.34	0.04		
Below bar 7 in. (0.178 m)	3.50	1.07	3.40	1.04	3.50	1.07	1.15	0.35	11.81	0.33		
28.7											14.78	0.42
Upper	2.30	0.70	2.60	0.79	2.50	0.76	0.23	0.07	1.67	0.05		
Below bar 1 in. (0.025 m)	2.30	0.70	2.30	0.70	2.50	0.76	0.20	0.06	1.40	0.04		
Below bar 7 in. (0.178 m)	3.60	1.10	3.50	1.07	3.60	1.10	1.11	0.34	11.72	0.33		
31.8											15.27	0.43
Upper	2.30	0.70	3.20	0.98	2.60	0.79	0.21	0.06	1.66	0.05		
Below bar 1 in. (0.025 m)	2.60	0.79	2.00	0.61	2.20	0.67	0.20	0.06	1.34	0.04		
Below bar 7 in. (0.178 m)	3.60	1.10	3.70	1.13	3.70	1.13	1.13	0.35	12.27	0.35		
34.1											14.81	0.42
Upper	2.30	0.70	2.80	0.85	2.50	0.76	0.19	0.06	1.40	0.04		
Below bar 1 in. (0.025 m)	2.60	0.79	2.50	0.76	2.40	0.73	0.20	0.06	1.48	0.04		
Below bar 7 in. (0.178 m)	3.70	1.13	3.50	1.07	3.70	1.13	1.11	0.34	11.94	0.34		

Appendix Table A3. Continued.

	Measured velocity (looking downstream)											
	Left		Middle		Right		Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
37.3											14.28	0.40
Upper	2.40	0.73	2.60	0.79	2.50	0.76	0.17	0.05	1.23	0.03		
Below bar 1 in. (0.025 m)												
	2.60	0.79	2.50	0.76	2.80	0.85	0.20	0.06	1.56	0.04		
Below bar 7 in. (0.178 m)												
	3.60	1.10	3.40	1.04	3.70	1.13	1.09	0.33	11.50	0.33		
Splitter Plate											1.28	0.04
(Upper)	2.90	0.88	2.60	0.79	2.30	0.70	0.17	0.05	1.28	0.04		
11											13.95	0.40
Upper												
Lower	15.00	4.57	16.50	5.03	14.90	4.54	0.46	0.14	13.95	0.40		

ICE HARBOR EVALUATION SEPARATOR
2000 Field Work
Date: 3/4/00
Description: 2 m/s, sloping bars, Jump is 6' into separator

Appendix Table A4.

u/s invert el. = 417.097 fmsl
Column TOS = 417.055 fmsl
Length = 80 ft
d/s inv. to TOS = in
% Slope = -0.001 ft/ft*
* positive slope is adverse.

Appendix Table A5.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
1												
2												
3	13.30	4.05	14.30	4.36	12.00	3.66	0.79	0.24	30.86	0.87	30.86	0.87
4	13.90	4.24	15.30	4.66	13.00	3.96	0.55	0.17	22.93	0.65	22.93	0.65
5	12.90	3.93	13.10	3.99	12.70	3.87	0.46	0.14	17.46	0.49	17.46	0.49
6											29.91	0.85
Upper	12.30	3.75	13.00	3.96	11.70	3.57	0.46	0.14	16.69	0.47		
Lower	7.00	2.13	6.50	1.98	6.40	1.95	0.88	0.27	13.22	0.37		
3.5											22.74	0.64
Upper, at bar	10.40	3.17	11.30	3.44	11.10	3.38	0.38	0.11	12.11	0.34		
Lower, 1.5" above floor	5.90	1.80	6.70	2.04	6.60	2.01	0.94	0.29	10.63	0.30		
6.5											24.80	0.70
Upper, 7.25" above bar	6.00	1.83	10.00	3.05	7.50	2.29	0.83	0.25	15.09	0.43		
Upper, at bar	3.10	0.94	3.50	1.07	6.70	2.04				0.00		
Lower, 1.5" above floor	3.80	1.16	4.30	1.31	4.20	1.28	1.64	0.50	9.71	0.28		
8.6											21.09	0.60
Upper, 7.25" above bar	6.80	2.07	10.90	3.32	6.90	2.10	0.77	0.23	14.49	0.41		
Upper, at bar	4.50	1.37	5.10	1.55	4.00	1.22	0.77	0.23		0.00		
Lower, 1.5" above floor	3.10	0.94	3.00	0.91	3.10	0.94	1.50	0.46	6.60	0.19		
11.6											21.50	0.61
Upper, at bar	7.00	2.13	8.50	2.59	6.00	1.83	0.54	0.17	11.46	0.32		
Lower, 1.5" above floor	3.40	1.04	3.50	1.07	3.30	1.01	1.54	0.47	10.04	0.28		

Appendix Table A5. Continued.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
13.9											21.64	0.61
Upper, 7.25" above bar	6.50	1.98	10.30	3.14	6.80	2.07	0.73	0.22	14.75	0.42		
Upper, at bar	5.30	1.62	6.50	1.98	5.70	1.74	0.73	0.22		0.00		
Lower, 1.5" above floor	2.60	0.79	2.80	0.85	2.60	0.79	1.60	0.49	6.89	0.20		
16.8											19.21	0.54
Upper, at bar	6.50	1.98	7.30	2.22	5.70	1.74	0.58	0.18	11.20	0.32		
Lower, 1.5" above floor	2.80	0.85	3.00	0.91	2.70	0.82	1.54	0.47	8.02	0.23		
18.7											20.07	0.57
Upper, at bar	6.90	2.10	7.90	2.41	6.60	2.01	0.54	0.17	11.41	0.32		
Lower, 1" under bar	3.70	1.13	4.60	1.40	3.60	1.10	1.48		2.34	0.07		
Lower 7" under bar	2.80	0.85	3.10	0.94	2.80	0.85	1.48	0.45	6.32	0.18		
21.2											20.14	0.57
Upper, at bar	6.30	1.92	6.30	1.92	6.40	1.95	0.60	0.18	11.30	0.32		
Lower, 1" under bar	2.50	0.76	3.00	0.91	2.50	0.76	1.63	0.50	1.57	0.04		
Lower 7" under bar	2.90	0.88	3.30	1.01	2.80	0.85	1.63	0.50	7.27	0.21		
23.9											19.82	0.56
Upper, at bar	6.20	1.89	6.80	2.07	6.10	1.86	0.56	0.17	10.57	0.30		
Lower, 1" under bar	3.80	1.16	3.70	1.13	3.30	1.01	1.60	0.49	2.13	0.06		
Lower 7" under bar	2.80	0.85	3.20	0.98	2.60	0.79	1.60	0.49	7.12	0.20		

Appendix Table A5. Continued.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
26.4											20.44	0.58
Upper, at bar	6.50	1.98	5.90	1.80	6.50	1.98	0.54	0.17	10.08	0.29		
Lower, 1" under bar	3.50	1.07	3.00	0.91	2.80	0.85	1.75	0.53	1.83	0.05		
Lower 7" under bar	2.80	0.85	3.20	0.98	2.60	0.79	1.75	0.53	8.54	0.24		
28.7											19.86	0.56
Upper, at bar	5.80	1.77	5.60	1.71	5.90	1.80	0.54	0.17	9.22	0.26		
Lower, 1" under bar	3.60	1.10	3.80	1.16	3.50	1.07	1.78	0.54	2.15	0.06		
Lower 7" under bar	2.70	0.82	3.10	0.94	2.50	0.76	1.78	0.54	8.49	0.24		
31.8											20.24	0.57
Upper, at bar	6.60	2.01	6.50	1.98	6.60	2.01	0.48	0.15	9.29	0.26		
Lower, 1" under bar	2.90	0.88	2.80	0.85	3.00	0.91	1.67	0.51	1.71	0.05		
Lower 7" under bar	3.10	0.94	3.40	1.04	3.00	0.91	1.67	0.51	9.23	0.26		
34.1											23.19	0.66
Upper, at bar	6.60	2.01	6.40	1.95	6.60	2.01	0.44	0.13	8.44	0.24		
Lower, 1" under bar	4.40	1.34	4.00	1.22	4.00	1.22	1.65	0.50	2.44	0.07		
Lower 7" under bar	4.40	1.34	4.00	1.22	4.00	1.22	1.65	0.50	12.31	0.35		
37.3											23.51	0.67
Upper, at bar	7.60	2.32	8.10	2.47	7.40	2.26	0.23	0.07	5.21	0.15		
Lower, 1" under bar	5.90	1.80	5.80	1.77	5.40	1.65	1.52	0.46	3.37	0.10		
Lower 7" under bar	4.70	1.43	4.70	1.43	4.50	1.37	1.52	0.46	14.94	0.42		

Appendix Table A5. Continued.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
Splitter Plate											3.10	0.09
(Upper)	7.20	2.19	7.70	2.35	6.70	2.04	0.15	0.04	3.10	0.09		
11											21.49	0.61
Upper												
Lower	17.60	5.36	19.80	6.03	16.80	5.12	0.60	0.18	21.49	0.61		

ICE HARBOR EVALUATION SEPARATOR

2000 Field Work
Date:3/3/00
Description:1 m/s, sloping bars, Jump is 13' upstream of bars

Appendix Table A6.

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u/s invert el. = 417.1 fmsl
Column TOS = 417.05 fmsl
Length = 80 ft
d/s inv. to TOS = in
% Slope = 0.0005 ft/ft*

* positive slope is adverse.

Appendix Table A7.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
1												
2												
3	13.90	4.24	14.10	4.30	12.40	3.78	0.79	0.24	31.48	0.89	31.48	0.89
4	14.10	4.30	15.40	4.69	13.40	4.08	0.42	0.13	17.59	0.50	17.59	0.50
5	15.10	4.60	14.40	4.39	13.60	4.15	0.27	0.08	11.49	0.33	11.49	0.33
6												
Upper	2.30	0.70	1.70	0.52	1.60	0.49		0.00	0.00	0.00		
Lower	3.90	1.19	3.60	1.10	3.60	1.10		0.00	-0.20	-0.01		
3.5											13.58	0.38
Upper, 7.25" above bar	2.90	0.88	2.50	0.76	2.90	0.88	1.13	0.34	8.42	0.24		
Upper, at bar	2.20	0.67	2.20	0.67	2.50	0.76	1.13	0.34		0.00		
Lower, 1.5" above floor	2.70	0.82	3.20	0.98	3.10	0.94	1.71	0.52	5.17	0.15		
6.5											13.87	0.39
Upper, 7.25" above bar	3.00	0.91	2.70	0.82	2.90	0.88	1.08	0.33	8.58	0.24		
Upper, at bar	2.50	0.76	2.50	0.76	2.50	0.76	1.08	0.33		0.00		
Lower, 1.5" above floor	2.90	0.88	2.90	0.88	2.80	0.85	1.71	0.52	5.29	0.15		
8.6											13.45	0.38
Upper, 7.25" above bar	2.80	0.85	2.90	0.88	2.90	0.88	1.04	0.32	8.46	0.24		
Upper, at bar	2.60	0.79	2.60	0.79	2.70	0.82	1.04	0.32		0.00		
Lower, 1.5" above floor	2.60	0.79	2.60	0.79	2.40	0.73	1.71	0.52	4.99	0.14		

Appendix Table A7. Continued.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
Station	V (ft/s)	(m/s)	V (ft/s)	(m/s)	V (ft/s)	(m/s)	D (ft)	(m)	Q (ft^2/s)	(m^2/s)	Q (ft^2/s)	(m^2/s)
11.6											13.97	0.40
Upper, 7.25" above bar	2.90	0.88	3.10	0.94	3.20	0.98	0.95	0.29	8.21	0.23		
Upper, at bar	2.80	0.85	2.70	0.82	2.90	0.88	0.95	0.29		0.00		
Lower, 1.5" above floor	2.60	0.79	2.60	0.79	2.50	0.76	1.71	0.52	5.76	0.16		
13.9											13.20	0.37
Upper, 7.25" above bar	3.10	0.94	3.00	0.91	3.20	0.98	0.88	0.27	7.66	0.22		
Upper, at bar	2.80	0.85	2.70	0.82	3.00	0.91	0.88	0.27		0.00		
Lower, 1.5" above floor	2.40	0.73	2.40	0.73	2.30	0.70	1.67	0.51	5.53	0.16		
16.8											13.37	0.38
Upper, 7.25" above bar	3.30	1.01	3.10	0.94	3.10	0.94	0.84	0.26	7.68	0.22		
Upper, at bar	2.80	0.85	3.00	0.91	3.20	0.98	0.84	0.26		0.00		
Lower, 1.5" above floor	2.50	0.76	2.50	0.76	2.40	0.73	1.63	0.50	5.69	0.16		
18.7											13.32	0.38
Upper, 7.25" above bar	3.30	1.01	3.20	0.98	3.10	0.94	0.81	0.25	7.56	0.21		
Upper, at bar	3.00	0.91	3.00	0.91	3.30	1.01	0.81	0.25		0.00		
Lower, 1.5" above floor	2.50	0.76	2.40	0.73	2.30	0.70	1.63	0.50	5.76	0.16		

Appendix Table A7. Continued.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
21.2											13.38	0.38
Upper, at bar	3.40	1.04	3.20	0.98	3.50	1.07	0.69	0.21	6.83	0.19		
Lower, 1" under bar	1.70	0.52	1.90	0.58	1.70	0.52	1.60	0.49	1.04	0.03		
Lower, 7" under bar	2.60	0.79	2.70	0.82	2.50	0.76	1.60	0.49	5.50	0.16		
23.9											13.20	0.37
Upper, at bar	3.20	0.98	3.00	0.91	3.20	0.98	0.71	0.22	6.55	0.19		
Lower, 1" under bar	2.20	0.67	2.10	0.64	2.20	0.67	1.65	0.50	1.28	0.04		
Lower, 7" under bar	2.50	0.76	2.50	0.76	2.40	0.73	1.65	0.50	5.37	0.15		
26.4											13.54	0.38
Upper, at bar	3.40	1.04	3.30	1.01	3.40	1.04	0.63	0.19	6.21	0.18		
Lower, 1" under bar	1.90	0.58	2.00	0.61	1.70	0.52	1.65	0.50	1.10	0.03		
Lower, 7" under bar	2.60	0.79	2.60	0.79	2.50	0.76	1.65	0.50	6.22	0.18		
28.7											13.32	0.38
Upper, at bar	3.40	1.04	3.20	0.98	3.40	1.04	0.56	0.17	5.54	0.16		
Lower, 1" under bar	2.10	0.64	2.20	0.67	2.10	0.64	1.65	0.50	1.26	0.04		
Lower, 7" under bar	2.60	0.79	2.50	0.76	2.40	0.73	1.65	0.50	6.52	0.18		

Appendix Table A7. Continued.

	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
Station	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
31.8											13.72	0.39
Upper, at bar	3.60	1.10	3.40	1.04	3.70	1.13	0.50	0.15	5.27	0.15		
Lower, 1" under bar	2.10	0.64	2.20	0.67	2.00	0.61	1.58	0.48	1.24	0.04		
Lower, 7" under bar	2.80	0.85	2.80	0.85	2.70	0.82	1.58	0.48	7.22	0.20		
34.1											13.65	0.39
Upper, at bar	3.70	1.13	3.60	1.10	3.70	1.13	0.40	0.12	4.29	0.12		
Lower, 1" under bar	2.60	0.79	2.60	0.79	2.60	0.79	1.48	0.45	1.54	0.04		
Lower, 7" under bar	3.00	0.91	3.10	0.94	2.90	0.88	1.48	0.45	7.82	0.22		
37.3											14.62	0.41
Upper, at bar	4.40	1.34	4.30	1.31	4.40	1.34	0.29	0.09	3.76	0.11		
Lower, 1" under bar	3.10	0.94	3.10	0.94	3.00	0.91	1.31	0.40	1.81	0.05		
Lower, 7" under bar	3.80	1.16	3.70	1.13	3.70	1.13	1.31	0.40	9.05	0.26		
Splitter Plate											1.07	0.03
(Upper)	4.60	1.40	3.80	1.16	4.60	1.40	0.08	0.03	1.07	0.03		
11											12.20	0.35
Upper												
Lower	16.00	4.88	17.30	5.27	16.30	4.97	0.38	0.11	12.20	0.35		

ICE HARBOR EVALUATION SEPARATOR

2000 Field Work
Date: 3/28/00
Description: 5 cm, 2 m/s

Appendix Table A8.

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u/s invert el. = 417.097 fmsl
Column TOS = 417.054 fmsl
Length = 80 ft
d/s inv. to TOS = in
% Slope = 0.0005373 ft/ft*

* positive slope is adverse.

Appendix Table A9.

Station	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V (ft/s)	(m/s)	V (ft/s)	(m/s)	V (ft/s)	(m/s)	D (ft)	(m)	Q (ft^2/s)	(m^2/s)	Q (ft^2/s)	(m^2/s)
1												
2												
3	12.70	3.87	13.50	4.11	11.30	3.44	0.79	0.24	29.22	0.83	29.22	0.83
4	14.10	4.30	14.30	4.36	12.80	3.90	0.33	0.10	13.52	0.38	13.52	0.38
5	13.00	3.96	11.80	3.60	11.90	3.63	0.17	0.05	6.02	0.17	6.02	0.17
6											16.94	0.48
Upper	8.00	2.44	8.10	2.47	7.30	2.22	0.17	0.05	3.84	0.11		
Below bar 1 in. (0.025 m)	7.00	2.13	6.00	1.83	7.50	2.29	0.20	0.06	4.04	0.11		
Below bar 7 in. (0.178 m)	6.60	2.01	5.80	1.77	6.10	1.86	0.50	0.15	9.07	0.26		
3.5											16.49	0.47
Upper	2.90	0.88	3.00	0.91	1.80	0.55	0.79	0.24	6.00	0.17		
Below bar 1 in. (0.025 m)	5.60	1.71	5.20	1.58	5.10	1.55	0.20	0.06	3.13	0.09		
Below bar 7 in. (0.178 m)	5.80	1.77	5.10	1.55	5.50	1.68	0.46	0.14	7.36	0.21		
6.5											17.03	0.48
Upper	6.20	1.89	6.40	1.95	5.00	1.52	0.24	0.07	4.15	0.12		
Below bar 1 in. (0.025 m)	5.10	1.55	5.20	1.58	5.40	1.65	0.20	0.06	3.09	0.09		
Below bar 7 in. (0.178 m)	6.50	1.98	6.30	1.92	6.00	1.83	0.53	0.16	9.79	0.28		
8.6											16.84	0.48
Upper	3.40	1.04	3.50	1.07	3.50	1.07	0.51	0.16	5.22	0.15		
Below bar 1 in. (0.025 m)	5.90	1.80	5.30	1.62	4.90	1.49	0.20	0.06	3.17	0.09		
Below bar 7 in. (0.178 m)	6.00	1.83	6.00	1.83	5.80	1.77	0.48	0.15	8.45	0.24		

Appendix Table A9. Continued.

Station	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V (ft/s)	(m/s)	V (ft/s)	(m/s)	V (ft/s)	(m/s)	D (ft)	(m)	Q (ft^2/s)	(m^2/s)	Q (ft^2/s)	(m^2/s)
11.6											16.20	0.46
Upper	6.30	1.92	6.80	2.07	6.00	1.83	0.17	0.05	3.13	0.09		
Below bar 1 in. (0.025 m)	5.20	1.58	5.10	1.55	5.00	1.52	0.20	0.06	3.01	0.09		
Below bar 7 in. (0.178 m)	6.70	2.04	6.60	2.01	6.20	1.89	0.52	0.16	10.06	0.28		
13.9											18.52	0.52
Upper	3.60	1.10	3.20	0.98	3.80	1.16	0.55	0.17	5.76	0.16		
Below bar 1 in. (0.025 m)	3.30	1.01	5.50	1.68	5.50	1.68	0.20	0.06	2.81	0.08		
Below bar 7 in. (0.178 m)	6.40	1.95	6.30	1.92	6.20	1.89	0.53	0.16	9.94	0.28		
16.8											17.22	0.49
Upper	6.00	1.83	6.60	2.01	6.00	1.83	0.20	0.06	3.62	0.10		
Below bar 1 in. (0.025 m)	5.00	1.52	4.70	1.43	5.00	1.52	0.20	0.06	2.89	0.08		
Below bar 7 in. (0.178 m)	6.60	2.01	6.50	1.98	6.30	1.92	0.56	0.17	10.70	0.30		
18.7											17.86	0.51
Upper	3.20	0.98	3.20	0.98	3.80	1.16	0.52	0.16	5.23	0.15		
Below bar 1 in. (0.025 m)	3.40	1.04	5.20	1.58	3.30	1.01	0.20	0.06	2.34	0.07		3.60
Below bar 7 in. (0.178 m)	6.50	1.98	6.10	1.86	6.40	1.95	0.55	0.17	10.29	0.29		

Appendix Table A9. Continued.

Station	Measured velocity (looking downstream)						Measured depth		Computed discharge (upper/lower)		Computed discharge (combined)	
	Left		Middle		Right							
	V		V		V		D		Q		Q	
	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft/s)	(m/s)	(ft)	(m)	(ft^2/s)	(m^2/s)	(ft^2/s)	(m^2/s)
21.2											16.74	0.47
Upper	5.90	1.80	6.50	1.98	6.20	1.89	0.17	0.05	3.05	0.09		
Below bar 1 in. (0.025 m)	5.80	1.77	4.80	1.46	4.80	1.46	0.20	0.06	3.03	0.09		
Below bar 7 in. (0.178 m)	6.60	2.01	6.30	1.92	6.60	2.01	0.56	0.17	10.66	0.30		
23.9											15.86	0.45
Upper	3.40	1.04	3.50	1.07	3.50	1.07	0.48	0.15	4.90	0.14		
Below bar 1 in. (0.025 m)	0.06	0.02	2.60	0.79	2.20	0.67	0.20	0.06	0.96	0.03		
Below bar 7 in. (0.178 m)	6.60	2.01	6.30	1.92	6.30	1.92	0.53	0.16	10.00	0.28		
26.4											16.77	0.48
Upper	5.80	1.77	6.20	1.89	5.70	1.74	0.18	0.05	3.09	0.09		
Below bar 1 in. (0.025 m)	4.70	1.43	5.00	1.52	4.80	1.46	0.20	0.06	2.85	0.08		
Below bar 7 in. (0.178 m)	6.80	2.07	6.70	2.04	6.90	2.10	0.54	0.16	10.83	0.31		
28.7											15.60	0.44
Upper	3.10	0.94	3.20	0.98	3.50	1.07	0.51	0.16	4.92	0.14		
Below bar 1 in. (0.025 m)	1.70	0.52	2.60	0.79	1.50	0.46	0.20	0.06	1.14	0.03		
Below bar 7 in. (0.178 m)	6.80	2.07	6.60	2.01	6.90	2.10	0.48	0.15	9.53	0.27		
31.8											15.60	0.44
Upper	6.00	1.83	6.50	1.98	5.90	1.80	0.16	0.05	2.83	0.08		
Below bar 1 in. (0.025 m)	5.40	1.65	5.50	1.68	5.20	1.58	0.20	0.06	3.17	0.09		
Below bar 7 in. (0.178 m)	7.00	2.13	6.90	2.10	7.00	2.13	0.47	0.14	9.60	0.27		

Appendix Table A9. Continued.

Station	Measured velocity (looking downstream) Left V (ft/s)	Left V (m/s)	Middle V (ft/s)	Middle V (m/s)	Right V (ft/s)	Right V (m/s)	Measured depth D (ft)	Measured depth D (m)	Computed discharge (upper/lower) Q (ft^2/s)	Computed discharge (upper/lower) Q (m^2/s)	Computed discharge (combined) Q (ft^2/s)	Computed discharge (combined) Q (m^2/s)
34.1											15.20	0.43
Upper	3.60	1.10	3.40	1.04	3.60	1.10	0.47	0.14	4.89	0.14		
Below bar 1 in. (0.025 m)	2.00	0.61	1.90	0.58	0.09	0.03	0.20	0.06	0.79	0.02		
Below bar 7 in. (0.178 m)	6.90	2.10	6.80	2.07	6.80	2.07	0.47	0.14	9.52	0.27		
37.3											14.55	0.41
Upper	6.10	1.86	6.00	1.83	6.30	1.92	0.10	0.03	1.89	0.05		
Below bar 1 in. (0.025 m)	5.10	1.55	5.60	1.71	5.80	1.77	0.20	0.06	3.25	0.09		
Below bar 7 in. (0.178 m)	7.50	2.29	7.50	2.29	7.50	2.29	0.43	0.13	9.41	0.27		
Splitter Plate											2.99	0.08
(Upper)	3.30	1.01	4.20	1.28	3.50	1.07	0.28	0.08	2.99	0.08		
11											0.00	0.00
Upper												
Lower	15.50	4.72	15.80	4.82	15.30	4.66		0.00	0.00	0.00		

APPENDIX B

Data Tables

Appendix Table B1. Total catch, by species, for individual test replicates using a prototype high-velocity flume wet separator at Ice Harbor Dam, 2000.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 1, April 25										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: parallel										
Tanks: separated			21		2	6				
non-separated			70	13		98				
Separator: separated						1				
non-separated										
Replicate 2, Treatment 1, May 3										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: parallel										
Tanks: separated			18		3	4				
non-separated			20		7	114				
Separator: separated			4		2	3				
non-separated			4			5				
Replicate 3, Treatment 1, May 5										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: parallel										
Tanks: separated			13	1	2					
non-separated			40	3	6	55				
Separator: separated			4		3					
non-separated			4	1		4				
Replicate 4, Treatment 1, May 10										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: parallel										
Tanks: separated			22		2	1				
non-separated			47	2		108				
Separator: separated			1		1	1				
non-separated			2			9				
Replicate 5, Treatment 1, May 17										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: parallel										
Tanks: separated			16							
non-separated			15			17				
Separator: separated			7		1					
non-separated			1			1				
Replicate 6, Treatment 1, May 22										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: parallel										
Tanks: separated	1		24		4	2				
non-separated			27		4	42			1	
Separator: separated			2		1	2				
non-separated			2		1	5				

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 7, Treatment 1, May 25										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: parallel										
Tanks: separated			17		2	2				
non-separated			25	1	7	94				
Separator: separated										
non-separated										
Replicate 1, Treatment 2, April 26										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			43	1		1				
non-separated			39	7	2	49				
Separator: separated			2			1				
non-separated										
Replicate 1, Treatment 2, May 1										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			15		1	4				
non-separated			24	3	5	96				
Separator: separated			2		1					
non-separated			1		3	3				
Replicate 1, Treatment 2, May 3										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			30	1	5	2				
non-separated			45	3	5	127			1	
Separator: separated										
non-separated			1			5				
Replicate 1, Treatment 2, May 11										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			36		4	5				
non-separated			14	2	2	34				
Separator: separated			3							
non-separated						2				
Replicate 1, Treatment 2, May 15										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			28	1	1	4			1	
non-separated			12	2	3	34			1	
Separator: separated										
non-separated			1			3				
Replicate 1, Treatment 2, May 23										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated	1		19		2	3				
non-separated			6		1	39			1	
Separator: separated			4							
non-separated						1				

Appendix Table B1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 2, May 26										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated	4		13		4	2				
non-separated	1		3			33				
Separator: separated	1		1							
non-separated										
Replicate 1, Treatment 3, April 25										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			5		1					
non-separated			5	2	1	29				
Separator: separated			2			1				
non-separated										
Replicate 1, Treatment 3, April 28										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			42	2	6	5				
non-separated										
Separator: separated			34		4	5				
non-separated			2	3	2	39				
Replicate 1, Treatment 3, May 8										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			10		2					
non-separated			24	1		14				
Separator: separated			27		3	5				
non-separated			2			34				
Replicate 1, Treatment 3, May 9										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			11		3	1				
non-separated			18	1	1	22				
Separator: separated			21		4	8				
non-separated			2		1	51				
Replicate 1, Treatment 3, May 17										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			6			2				
non-separated			4			5				
Separator: separated			12		2					
non-separated						15				
Replicate 1, Treatment 3, May 17										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			13			2				
non-separated			24	1		20				
Separator: separated			24	1	1	1				
non-separated						14				

Appendix Table B1. Continued.

Source	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 3, May 31										
Separation-bar support style: flat, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated	2		3	2	5					
non-separated	3		6		4	41				
Separator: separated			2	3	2					
non-separated					1	12				
Replicate 1, Treatment 4, April 26										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			76		3	2				
non-separated			51	6	2	34				
Separator: separated										
non-separated										
Replicate 1, Treatment 4, May 1										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			38		2	3				
non-separated			50	1	4	80				
Separator: separated			14	1	1	5				
non-separated			1			2				
Replicate 1, Treatment 4, May 8										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			9	1	2	2				
non-separated			36	1	8	60				
Separator: separated			6		2	2				
non-separated			3			2				
Replicate 1, Treatment 4, May 10										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			8		2					
non-separated			28	1	1	26				
Separator: separated			4		1	1				
non-separated						1				
Replicate 1, Treatment 4, May 11										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			15	1	1					
non-separated			22			38				
Separator: separated			6		1					
non-separated			4			1				
Replicate 1, Treatment 4, May 24										
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			11		2	2				
non-separated			14		2	46				
Separator: separated			7		1					
non-separated			2		1	5				

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 4, June 2											
Separation-bar support style: flat, water velocity: 2 m/s, flow orientation: angled											
Tanks:	separated	2				2					
	non-separated	5		2		2	28	1			
Separator:	separated										
	non-separated										
Replicate 1, Treatment 5, April 27											
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: parallel											
Tanks:	separated			15		6	1				
	non-separated			48	2	5	60				
Separator:	separated										
	non-separated										
Replicate 1, Treatment 5, May 2											
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: parallel											
Tanks:	separated			30		3	7				
	non-separated			39	5	5	102				
Separator:	separated			3		1					
	non-separated			4		1	1				
Replicate 1, Treatment 5, May 5											
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: parallel											
Tanks:	separated			73		2	3				
	non-separated			46	4	4	44				
Separator:	separated						1				
	non-separated			3			6				
Replicate 1, Treatment 5, May 8											
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: parallel											
Tanks:	separated			56		4	2				
	non-separated			27	2	4	114				
Separator:	separated			5		2	2				
	non-separated						1				
Replicate 1, Treatment 5, May 15											
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: parallel											
Tanks:	separated			7							
	non-separated			7			15				
Separator:	separated			2	1		1				
	non-separated						1				
Replicate 1, Treatment 5, May 18											
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: parallel											
Tanks:	separated			22		2					
	non-separated			14		1	23				
Separator:	separated			1			1				
	non-separated			1			2				

Appendix Table B1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 5, May 30										
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: parallel										
Tanks: separated	4		5		1	2				
non-separated			5		4	44				
Separator: separated			2							
non-separated			1			4				
Replicate 1, Treatment 6, April 27										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			36	1	10	2				
non-separated			36	8	9	85				
Separator: separated					1					
non-separated										
Replicate 1, Treatment 6, May 1										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			59	1	1	4				
non-separated			26	3	3	53				
Separator: separated			3		1	1				
non-separated					2	5				
Replicate 1, Treatment 6, May 4										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			44		2	4				
non-separated			33	3	3	93				
Separator: separated			5		3	2				
non-separated			1			6				
Replicate 1, Treatment 6, May 10										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			34		2	3				
non-separated			19	1	1	57				
Separator: separated			5							
non-separated			1			3				
Replicate 1, Treatment 6, May 15										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			25		7	2				
non-separated			11		3	31				
Separator: separated			4							
non-separated						2				
Replicate 1, Treatment 6, May 18										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			27		3	2				
non-separated			27		1	62				
Separator: separated						2				
non-separated			1			2				

Appendix Table B1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 6, June 1										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: parallel										
Tanks: separated			3		3					
non-separated					1	53				
Separator: separated			1							
non-separated						1				
Replicate 1, Treatment 7, April 27										
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			25		2	4				
non-separated			36	3	1	26				
Separator: separated			3		1	3				
non-separated			1			8				
Replicate 1, Treatment 7, April 28										
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			101	1	11	5				
non-separated			57	7		95				
Separator: separated										
non-separated										
Replicate 1, Treatment 7, May 5										
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			13		1	2				
non-separated			26	1		25				
Separator: separated			19		4	4				
non-separated			6	2		61				
Replicate 1, Treatment 7, May 11										
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			5		2	1				
non-separated			9	1	3	19				
Separator: separated			20		6	4				
non-separated			2	1		54				
Replicate 1, Treatment 7, May 16										
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			4		3					
non-separated			15		1	7				
Separator: separated			14		2	5				
non-separated			3			19				
Replicate 1, Treatment 7, May 19										
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			5		2					
non-separated			6	1	2	14				
Separator: separated			5			1				
non-separated					1	29				

Appendix Table B1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 7, June 1										
Separation-bar support style: round, water velocity: 1 m/s, flow orientation: angled										
Tanks: separated			4			1				
non-separated			3			17				
Separator: separated						1				
non-separated						5				
Replicate 1, Treatment 8, April 26										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			49		7	1				
non-separated			26	9	5	41				
Separator: separated										
non-separated										
Replicate 1, Treatment 8, May 3										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			10	1	1	1				
non-separated			40	1	3	78				
Separator: separated			4		3	1				
non-separated			3		1	2				
Replicate 1, Treatment 8, May 4										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			20			1				
non-separated			22	4	1	52				
Separator: separated			3	1	2	3				
non-separated			2			3				
Replicate 1, Treatment 8, May 11										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			16							
non-separated			21			49				
Separator: separated			7			1				
non-separated						3				
Replicate 1, Treatment 8, May 12										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			21		2					
non-separated			34		5	50				
Separator: separated			5			1				
non-separated						3				
Replicate 1, Treatment 8, May 24										
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: angled										
Tanks: separated			16							
non-separated			22		1	60				
Separator: separated			5			1				
non-separated			1			5				

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, May 31											
Separation-bar support style: round, water velocity: 2 m/s, flow orientation: angled											
Tanks:	separated										
	non-separated	1		4		5	88			2	
Separator:	separated										
	non-separated						1				

Appendix Table B2. Incidental species captured during separation efficiency studies using a prototype high-velocity flume wet separator at Ice Harbor Dam, 25 April-2 June, 2000. Species are listed in order of total capture frequency.

Common name	Scientific name	Total catch
channel catfish	*Ictalurus punctatus*	62
crappie	*Proxomus* spp.	31
sucker	*Catostomus* spp.	17
lamprey	*Entosphenus tridentata*	12
mountain whitefish	*Prosopium williamsoni*	10
yellow perch	*Perca flavescens*	4
sand roller	*Columbia transmontanus*	4
peamouth	*Mylocheilus caurinus*	1
redside shiner	*Richardsonius balteatus*	1
white sturgeon	*Acipenser transmontanus*	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, 2000. Asterisks indicate significant differences ($\alpha = 0.05$) among treatment factors.

Group	Treatment conditions	Calculated statistic F	df	*P*	
yearling Chinook salmon <180 mm	date	2.25	1	0.143	
	wave height, separation-bar style	0.16	1	0.687	
	water velocity	0.13	1	0.725	
	separation-bar array orientation	0.09	1	0.770	
	style vs. velocity	0.09	1	0.771	
	style vs. orientation	2.39	1	0.131	
	velocity vs. orientation	16.77	1	0.000	*
	style vs. velocity vs. orientation	2.33	1	0.135	
yearling Chinook salmon total catch	date	0.89	1	0.353	
	wave height, separation-bar style	0.21	1	0.647	
	water velocity	0.11	1	0.737	
	separation-bar array orientation	0.00	1	0.976	
	style vs. velocity	0.07	1	0.797	
	style vs. orientation	1.61	1	0.213	
	velocity vs. orientation	16.29	1	0.000	*
	style vs. velocity vs. orientation	1.94	1	0.172	
steelhead ≥180 mm	date	2.62	1	0.113	
	wave height, separation-bar style	0.35	1	0.555	
	water velocity	3.01	1	0.090	
	separation-bar array orientation	1.79	1	0.189	
	style vs. velocity	1.32	1	0.257	
	style vs. orientation	0.08	1	0.773	
	velocity vs. orientation	8.85	1	0.005	*
	style vs. velocity vs. orientation	0.00	1	0.985	
steelhead, total catch	date	2.65	1	0.111	

Appendix Table B3. Continued.

Group	Treatment conditions	Calculated statistic			
		F	df	*P*	
steelhead, total catch	wave height, separation-bar style	0.26	1	0.612	
	water velocity	1.17	1	0.284	
	separation-bar array orientation	0.00	1	0.994	
	style vs. velocity	0.85	1	0.363	
	style vs. orientation	0.06	1	0.814	
	velocity vs. orientation	1.69	1	0.200	
	style vs. velocity vs. orientation	0.00	1	0.948	
total salmonid catch <180 mm	date	0.82	1	0.371	
	wave height, separation-bar style	0.11	1	0.742	
	water velocity	0.60	1	0.442	
	separation-bar array orientation	0.15	1	0.696	
	style vs. velocity	0.25	1	0.617	
	style vs. orientation	2.46	1	0.125	
	velocity vs. orientation	17.31	1	0.000	*
	style vs. velocity vs. orientation	1.31	1	0.260	
total salmonid catch ≥180 mm	date	1.17	1	0.285	
	wave height, separation-bar style	1.43	1	0.238	
	water velocity	3.85	1	0.056	
	separation-bar array orientation	3.14	1	0.084	
	style vs. velocity	0.76	1	0.389	
	style vs. orientation	0.70	1	0.409	
	velocity vs. orientation	11.36	1	0.002	*
	style vs. velocity vs. orientation	0.17	1	0.683	
total salmonid catch	date	17.41	1	0.000	*
	wave height, separation-bar style	1.23	1	0.273	
	water velocity	0.06	1	0.814	
	separation-bar array orientation	0.30	1	0.587	
	style vs. velocity	1.96	1	0.168	
	style vs. orientation	0.11	1	0.739	
total salmonid catch	velocity vs. orientation	16.76	1	0.000	*
	style vs. velocity vs. orientation	3.42	1	0.071	

Appendix Table B4. Statistical analysis results of comparisons among mean separator exit efficiency values by group for treatments evaluated using a prototype high-velocity flume wet separator at Ice Harbor Dam, 2000. Asterisks indicate significant differences (α = 0.05) among treatment factors.

Group	Treatment conditions	Calculated statistic F	df	P	
yearling Chinook salmon <180 mm	date	7.15	1	0.011	*
	wave height, separation-bar style	2.33	1	0.136	
	water velocity	20.98	1	0.000	*
	separation-bar array orientation	39.99	1	0.000	*
	style vs. velocity	0.89	1	0.352	
	style vs. orientation	2.30	1	0.138	
	velocity vs. orientation	16.08	1	0.000	*
	style vs. velocity vs. orientation	0.33	1	0.571	
yearling Chinook salmon, total catch	date	7.74	1	0.010	*
	wave height, separation-bar style	2.39	1	0.131	
	water velocity	21.51	1	0.000	*
	separation-bar array orientation	41.07	1	0.000	*
	style vs. velocity	0.92	1	0.344	
	style vs. orientation	2.47	1	0.125	
	velocity vs. orientation	15.90	1	0.000	*
	style vs. velocity vs. orientation	0.34	1	0.561	
steelhead ≥180 mm	date	0.49	1	0.487	
	wave height, separation-bar style	0.00	1	0.962	
	water velocity	27.14	1	0.000	*
	separation-bar array orientation	25.73	1	0.000	*
	style vs. velocity	0.03	1	0.871	
	style vs. orientation	0.03	1	0.866	
	velocity vs. orientation	23.26	1	0.000	*
	style vs. velocity vs. orientation	0.00	1	0.994	
steelhead, total catch	date	0.03	1	0.585	
	wave height, separation-bar style	0.00	1	0.997	

Appendix Table B4. Continued.

Group	Treatment conditions	Calculated statistic F	 df	 *P*	
steelhead, total catch	water velocity	29.25	1	0.000	*
	separation-bar array orientation	28.41	1	0.000	*
	style vs. velocity	0.09	1	0.762	
	style vs. orientation	0.02	1	0.877	
	velocity vs. orientation	24.68	1	0.000	*
	style vs. velocity vs. orientation	0.00	1	0.971	
total salmonid catch <180 mm	date	2.80	1	0.103	
	wave height, separation-bar style	2.35	1	0.134	
	water velocity	18.51	1	0.000	*
	separation-bar array orientation	32.38	1	0.000	*
	style vs. velocity	1.35	1	0.253	
	style vs. orientation	1.29	1	0.263	
	velocity vs. orientation	13.08	1	0.001	*
	style vs. velocity vs. orientation	0.22	1	0.645	
total salmonid catch ≥180 mm	date	0.69	1	0.410	
	wave height, separation-bar style	0.00	1	0.981	
	water velocity	27.89	1	0.000	*
	separation-bar array orientation	26.63	1	0.000	*
	style vs. velocity	0.02	1	0.878	
	style vs. orientation	0.04	1	0.834	
	velocity vs. orientation	23.21	1	0.000	*
	style vs. velocity vs. orientation	0.00	1	0.999	
total salmonid catch	date	0.54	1	0.465	
	wave height, separation-bar style	0.30	1	0.589	
	water velocity	26.68	1	0.000	*
	separation-bar array orientation	28.83	1	0.000	*
	style vs. velocity	0.22	1	0.642	
	style vs. orientation	0.23	1	0.631	
	velocity vs. orientation	19.57	1	0.000	*
	style vs. velocity vs. orientation	0.01	1	0.916	

Appendix Table B5. 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, 2000. Asterisks indicate significant differences (α = 0.05) among treatment factors.

		Calculated statistic			
Group	Treatment conditions	F	df	*P*	
yearling Chinook salmon <180 mm	date	0.39	1	0.538	
	wave height, separation-bar style	0.10	1	0.755	
	water velocity	6.36	1	0.016	*
	separation-bar array orientation	0.05	1	0.816	
	style vs. velocity	1.16	1	0.288	
	style vs. orientation	0.32	1	0.576	
	velocity vs. orientation	0.12	1	0.726	
	style vs. velocity vs. orientation	0.01	1	0.939	
yearling Chinook salmon, total catch	date	0.03	1	0.866	
	wave height, separation-bar style	0.08	1	0.773	
	water velocity	6.29	1	0.017	*
	separation-bar array orientation	0.07	1	0.789	
	style vs. velocity	1.01	1	0.322	
	style vs. orientation	0.18	1	0.670	
	velocity vs. orientation	0.08	1	0.778	
	style vs. velocity vs. orientation	0.01	1	0.928	
steelhead ≥180 mm	date	18.45	1	0.000	*
	wave height, separation-bar style	0.14	1	0.708	
	water velocity	0.09	1	0.730	
	separation-bar array orientation	0.23	1	0.636	
	style vs. velocity	0.04	1	0.851	
	style vs. orientation	0.04	1	0.850	
	velocity vs. orientation	3.25	1	0.079	
	style vs. velocity vs. orientation	0.00	1	0.958	
steelhead, total catch	date	19.19	1	0.000	*
	wave height, separation-bar style	0.01	1	0.939	

Appendix Table B5. Continued.

Group	Treatment conditions	Calculated statistic F	 df	 *P*	
steelhead, total catch	water velocity	0.05	1	0.827	
	separation-bar array orientation	0.74	1	0.394	
	style vs. velocity	0.06	1	0.802	
	style vs. orientation	0.06	1	0.806	
	velocity vs. orientation	3.02	1	0.089	
	style vs. velocity vs. orientation	0.02	1	0.887	
total salmonid catch <180 mm	date	1.13	1	0.296	
	wave height, separation-bar style	0.14	1	0.710	
	water velocity	7.09	1	0.012	*
	separation-bar array orientation	0.02	1	0.884	
	style vs. velocity	0.93	1	0.340	
	style vs. orientation	0.30	1	0.588	
	velocity vs. orientation	0.07	1	0.786	
	style vs. velocity vs. orientation	0.03	1	0.866	
total salmonid catch ≥180 mm	date	19.46	1	0.000	*
	wave height, separation-bar style	0.131	1	0.725	
	water velocity	0.000.36	1	0.958	
	separation-bar array orientation	0.36	1	0.552	
	style vs. velocity	0.05	1	0.822	
	style vs. orientation	0.22	1	0.645	
	velocity vs. orientation	3.06	1	0.088	
	style vs. velocity vs. orientation	0.01	1	0.931	
total salmonid catch	date	0.01	1	0.933	
	wave height, separation-bar style	0.12	1	0.757	
	water velocity	6.86	1	0.012	*
	separation-bar array orientation	0.11	1	0.744	
	style vs. velocity	0.60	1	0.443	
	style vs. orientation	0.24	1	0.629	
	velocity vs. orientation	0.77	1	0.384	
	style vs. velocity vs. orientation	0.05	1	0.826	

Appendix Table B6. Total catch, by species, for individual separation efficiency test replicates using a conventional evaluation separator at McNary Dam, 2000.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 1, 2 May										
Light level low, density low										
Tanks: separated				16	8					1
non-separated				25	15	1	12	1		2
Separator: separated										
non-separated										
Replicate 2, Treatment 1, 8 May										
Light level low, density low										
Tanks: separated				38	1					1
non-separated				55	18	4	36	1		4
Separator: separated				1						
non-separated										
Replicate 3, Treatment 1, 15 May										
Light level low, density low										
Tanks: separated		1		241	1		1			8
non-separated				413	64	7	76	1		6
Separator: separated				5			3			
non-separated				1						
Replicate 4, Treatment 1, 23 May										
Light level low, density low										
Tanks: separated		4		55			3			
non-separated		4		254	67	13	82	5		5
Separator: separated				4						
non-separated				8	1	1	1			
Replicate 5, Treatment 1, 31 May										
Light level low, density low										
Tanks: separated	11		43				11		3	
non-separated	35		182	8	2	75	54	2	4	1
Separator: separated					8				11	
non-separated	2			5	1		2	3		
Replicate 6, Treatment 1, 19 June										
Light level low, density low										
Tanks: separated	100									
non-separated	130		11	2		5	3	1		
Separator: separated	6									
non-separated	10									

Appendix Table B6. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 7, Treatment 1, 29 June										
Light level low, density low										
Tanks: separated	2044		66							
non-separated	983		33	3			5			
Separator: separated	4									
non-separated										
Replicate 8, Treatment 1, 6 July										
Light level low, density low										
Tanks: separated		1087		9						
non-separated		800		17	1		1	1		
Separator: separated		4								
non-separated		5								
Replicate 9, Treatment 1, 17 July										
Light level low, density low										
Tanks: separated	105		2							
non-separated	139		4	1					5	
Separator: separated	14									
non-separated										
Replicate 10, Treatment 1, 24 July										
Light level low, density low										
Tanks: separated	185									
non-separated	329		8			2			1	
Separator: separated	8									
non-separated	2									
Replicate 1, Treatment 2, 3 May										
Light level medium, density low										
Tanks: separated				101	19		1			7
non-separated				57	41		32			
Separator: separated										
non-separated										
Replicate 2, Treatment 2, 5 May										
Light level medium, density low										
Tanks: separated				77	8		2			3
non-separated				28	5		23			1
Separator: separated				3			1			
non-separated						1	1	1		
Replicate 3, Treatment 2, 10 May										
Light level medium, density low										
Tanks: separated				65	3	1	4			4
non-separated				24	17		34			2
Separator: separated										
non-separated										

Appendix Table B6. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 4, Treatment 2, 22 May										
Light level medium, density low										
Tanks: separated	1			26		1				2
non-separated				27	14	1	21			1
Separator: separated				6						
non-separated										
Replicate 5, Treatment 2, 29 May										
Light level medium, density low										
Tanks: separated	74		442	2	6	4	115		24	
non-separated	35		312	41	7	55	69		12	
Separator: separated	3			33	1	1		27		1
non-separated				4		1	7	2		
Replicate 6, Treatment 2, 21 June										
Light level medium, density low										
Tanks: separated		2006		31						
non-separated		874		35	4		4	6		
Separator: separated		21		3						
non-separated		9		2						
Replicate 7, Treatment 2, 27June										
Light level medium, density low										
Tanks: separated	2567		77	1						
non-separated	513		13	5		2	2			
Separator: separated	150		1							
non-separated	1			1						
Replicate 8, Treatment 2, 5 July										
Light level medium, density low										
Tanks: separated	591		11							
non-separated	69		3			1	1			
Separator: separated	76		2							
non-separated	1									
Replicate 9, Treatment 2, 17 July										
Light level medium, density low										
Tanks: separated	31								1	
non-separated	7									1
Separator: separated										
non-separated										
Replicate 10, Treatment 2, 21 July										
Light level medium, density low										
Tanks: separated	149									
non-separated	56		4							
Separator: separated	28									
non-separated	2									

Appendix Table B6.   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 3, 2 May										
Light level high, density low										
Tanks: separated				50	15		1			5
non-separated				14	27		14			
Separator: separated										
non-separated										
Replicate 2, Treatment 3, 2 May										
Light level high, density low										
Tanks: separated				111	30		4			14
non-separated				36	32	2	31			5
Separator: separated				4	2		3			1
non-separated										1
Replicate 3, Treatment 3, 4 May										
Light level high, density low										
Tanks: separated				38	1					
non-separated				15	7		23			1
Separator: separated										
non-separated										
Replicate 4, Treatment 3, 16 May										
Light level high, density low										
Tanks: separated				75	2		3			
non-separated				20	12	1	21	1		
Separator: separated				4						1
non-separated							2			
Replicate 5, Treatment 3, 24 May										
Light level high, density low										
Tanks: separated	2			6						
non-separated					7		4			
Separator: separated										
non-separated										
Replicate 6, Treatment 3, 30 May										
Light level high, density low										
Tanks: separated	11		95		1		8			1
non-separated	1			47	7	4	30	18		2
Separator: separated				10		3	1	6		
non-separated				1				3		
Replicate 7, Treatment 3, 20 June										
Light level high, density low										
Tanks: separated	1540		118		1		6			1
non-separated	252		15			3	6			
Separator: separated	135		1				1			
non-separated	2									

Appendix Table B6. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 8, Treatment 3, 28 June										
Light level high, density low										
Tanks: separated		4749		152				1		
non-separated		488		47	4		1			
Separator: separated		364		14	1					
non-separated		11			1					
Replicate 9, Treatment 3, 7 July										
Light level high, density low										
Tanks: separated	799		6				1		5	
non-separated	86		7	2			2		1	
Separator: separated	136		3	2			1		1	
non-separated										
Replicate 10, Treatment 3, 14 July										
Light level high, density low										
Tanks: separated	734		21						7	
non-separated	35			1			2		2	
Separator: separated	54		3						3	
non-separated										
Replicate 11, Treatment 3, 25 July										
Light level high, density low										
Tanks: separated	696		6							
non-separated	198		6							
Separator: separated	65									
non-separated	15									
Replicate 1, Treatment 4, 5 May										
Light level low, density high										
Tanks: separated				17	1					
non-separated				41	4	11	18			1
Separator: separated										
non-separated										
Replicate 2, Treatment 4, 15 May										
Light level low, density high										
Tanks: separated				64	2	1	1			1
non-separated	2			143	36	5	38			5
Separator: separated				3						
non-separated					1					
Replicate 3, Treatment 4, 22 May										
Light level low, density high										
Tanks: separated	2			132	8	2	18	2		4
non-separated	1			241	22	7	67	12		8
Separator: separated				4						
non-separated				12	2	2	6	1		1

Appendix Table B6. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 4, Treatment 4, 30 May										
Light level low, density high										
Tanks: separated	36		235	1	2	1	41		4	
non-separated	45		561	16	5	70	153		19	
Separator: separated	1			20		1		7		
non-separated				11	3		3	3		1
Replicate 5, Treatment 4, 21 June										
Light level low, density high										
Tanks: separated	1589		95	1			2			
non-separated	596		26			2	6			
Separator: separated	2									
non-separated										
Replicate 6, Treatment 4, 28 June										
Light level low, density high										
Tanks: separated	2566		111							
non-separated	1583		69	7		3				
Separator: separated	18									
non-separated										
Replicate 7, Treatment 4, 5 July										
Light level low, density high										
Tanks: separated	1319		10				1			
non-separated	669		10	1		1				
Separator: separated	8									
non-separated										
Replicate 8, Treatment 4, 14 July										
Light level low, density high										
Tanks: separated	86		2							
non-separated	92		4				1		3	
Separator: separated	1									
non-separated	3									
Replicate 9, Treatment 4, 26 July										
Light level low, density high										
Tanks: separated	27		3							
non-separated	92									
Separator: separated	11									
non-separated	4									
Replicate 1, Treatment 5, 3 May										
Light level medium, density high										
Tanks: separated				114	22		1			8
non-separated				72	79		15			2
Separator: separated										
non-separated										

Appendix Table B6. 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, 4 May										
Light level medium, density high										
Tanks: separated				61	5		2			9
non-separated				26	15	1	7			
Separator: separated				2						
non-separated				3						
Replicate 3, Treatment 5, 16 May										
Light level medium, density high										
Tanks: separated	1			512	3	6	3	2		18
non-separated				228	45	2	30			4
Separator: separated										
non-separated										
Replicate 4, Treatment 5, 24 May										
Light level medium, density high										
Tanks: separated	4			59	1		2	5		3
non-separated	1			30	10		31	5		
Separator: separated				5		1		1		
non-separated				2	1		4			
Replicate 5, Treatment 5, 29 May										
Light level medium, density high										
Tanks: separated	33		184	1	1		55		20	
non-separated	18		222	40		41	52		11	
Separator: separated	6			62	3		3	26		9
non-separated				2	2		7	2		
Replicate 6, Treatment 5, 20 June										
Light level medium, density high										
Tanks: separated	530		37							
non-separated	195		4	5		13	8			
Separator: separated	2									
non-separated										
Replicate 7, Treatment 5, 29 June										
Light level medium, density high										
Tanks: separated	2333		76						1	
non-separated	442		21	1		1			1	
Separator: separated	203		1							
non-separated										
Replicate 8, Treatment 5, 7 July										
Light level medium, density high										
Tanks: separated	5823		91				1		7	
non-separated	640		24	17		3	1		13	
Separator: separated	708		12				2		2	
non-separated	160		5	3		1			1	

Appendix Table B6. 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, 13 July										
Light level medium, density high										
Tanks: separated	99		5						1	
non-separated	14		2			1			4	
Separator: separated	25		3							
non-separated										
Replicate 10, Treatment 5, 24 July										
Light level medium, density high										
Tanks: separated	133		2						3	
non-separated	47		5	2		2	5	1	1	
Separator: separated	54								1	
non-separated	5			1						
Replicate 1, Treatment 6, 8 May										
Light level high, density high										
Tanks: separated				222	23		3			14
non-separated				60	33		27	2		2
Separator: separated				1						
non-separated				7						
Replicate 2, Treatment 6, 10 May										
Light level high, density high										
Tanks: separated				364	10	3	1	2		3
non-separated				151	30	2	40	2		5
Separator: separated				16			2			
non-separated					1		4			
Replicate 3, Treatment 6, 23 May										
Light level high, density high										
Tanks: separated	1			154	3	7	1	2		
non-separated	1			60	19	8	34	3		1
Separator: separated				12						
non-separated				2	2		2			
Replicate 4, Treatment 6, 31 May										
Light level high, density high										
Tanks: separated	58		182		2	3	24		8	
non-separated	10		97	7	1	87	41	1	6	
Separator: separated	16		88			1	26		3	
non-separated				12	2		4	3		
Replicate 5, Treatment 6, 19 June										
Light level high, density high										
Tanks: separated	1130		48				4			
non-separated	124		3			2	10			
Separator: separated	5			1				1		
non-separated	1									

Appendix Table B6. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 6, Treatment 6, 27 June Light level high, density high										
Tanks: separated	2295		101	1			1	1		
non-separated	127		19	1		2	3			
Separator: separated	254		18				2			
non-separated										
Replicate 7, Treatment 6, 6 July, Light level high, density high										
Tanks: separated	793		11	1					1	
non-separated	57		2	1			2	1	1	
Separator: separated	107		1							
non-separated										
Replicate 8, Treatment 6, 14 July Light level high, density high										
Tanks: separated	179		4						1	
non-separated	27		1				1		1	
Separator: separated	64		1				1		2	
non-separated	1									1
Replicate 9, Treatment 6, 21 July Light level high, density high										
Tanks: separated	873		1							
non-separated	136		5							
Separator: separated	38									
non-separated	22		2							

Appendix Table B7. Total catch, by species, for individual separation efficiency test replicates using a High-velocity flume wet separator at McNary Dam, 1999.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 1, 20 April										
Bar spacing 17 mm, diel										
Tanks: separated			203	83	2	9			2	
non-separated			31	56	2	38			1	
Separator: separated										
non-separated										
Replicate 2, Treatment 1, 22 April										
Bar spacing 17 mm, diel										
Tanks: separated			327	34	3	13			6	
non-separated			104	47		50				
Separator: separated										
non-separated										
Replicate 3, Treatment 1, 26 April										
Bar spacing 17 mm, diel										
Tanks: separated			156	15	6	21			6	
non-separated			31	16	1	99			2	
Separator: separated										
non-separated										
Replicate 4, Treatment 1, 28 April										
Bar spacing 17 mm, diel										
Tanks: separated			165	11	5	7	2		17	
non-separated			44	14	3	40			4	
Separator: separated			2							
non-separated										
Replicate 5, Treatment 1, 3 May										
Bar spacing 17 mm, diel										
Tanks: separated			669	16	18	24	2		181	
non-separated			47	45		45			31	
Separator: separated						2				
non-separated										
Replicate 6, Treatment 1, 6 May										
Bar spacing 17 mm, diel										
Tanks: separated			768	63	22	58			392	
non-separated			162	107	5	71			105	
Separator: separated									1	
non-separated				1						
Replicate 7, Treatment 1, 11 May										
Bar spacing 17 mm, diel										
Tanks: separated			1664	46	30	140	2		1244	10
non-separated			260	76	12	173	1		246	
Separator: separated			9	3	2	2				
non-separated										

Appendix Table B7. 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, 13 May										
Bar spacing 17 mm, diel										
Tanks: separated			2657	61	48	111	21		532	
non-separated			443	39	2	111	5		182	
Separator: separated			4			3				
non-separated						2				
Replicate 9, Treatment 1, 14 May										
Bar spacing 17 mm, diel										
Tanks: separated			3514	110	84	157	51		562	
non-separated			615	93	30	249	7		194	
Separator: separated			7			2			1	
non-separated			3			1			2	
Replicate 10, Treatment 1, 18 May										
Bar spacing 17 mm, diel										
Tanks: separated			1613	60	11	60	26		320	
non-separated			263	19	4	38	11		95	
Separator: separated			2							
non-separated										
Replicate 11 , Treatment 1, 24 May										
Bar spacing 17 mm, diel										
Tanks: separated			1196	31	25	68	86	2	338	
non-separated			81	36	2	63	9		40	1
Separator: separated			10		1		2		1	
non-separated			1							
Replicate 12, Treatment 1, 31 May										
Bar spacing 17 mm										
Tanks: separated	257		74		21	54	65		47	
non-separated	31		14	6	16	205	13		7	
Separator: separated	2		2		1	2	1		1	
non-separated										
Replicate 13, Treatment 1, 3 June										
Bar spacing 17 mm, diel										
Tanks: separated	991		61	4	20	15	105	7	55	
non-separated	152		40	8	6	35	32	2	28	
Separator: separated	1		2		1		1			
non-separated										
Replicate 14, Treatment 1, 22 June										
Bar spacing 17 mm, diel										
Tanks: separated	2699		157		3	7	55		1	
non-separated	309		38	4		17	13			
Separator: separated	1					3				
non-separated										

Appendix Table B7. 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 15, Treatment 1, 25 June Bar spacing 17 mm, diel											
Tanks:	separated	3912		107	2		2	20		1	
	non-separated	728		21	2		12	5	1		
Separator:	separated	1				1					
	non-separated										
Replicate 16, Treatment 1, 28 June Bar spacing 17 mm, diel											
Tanks:	separated	3878		9				38			
	non-separated	398		2			1	3		1	
Separator:	separated	7									
	non-separated										
Replicate 17, Treatment 1, 2 July Bar spacing 17 mm, diel											
Tanks:	separated	1092		4			2	93			
	non-separated	78		3				8			1
Separator:	separated										
	non-separated										
Replicate 18, Treatment 1, 9 July Bar spacing 17 mm, diel											
Tanks:	separated	2053		44			3	108			
	non-separated	172		10	1		7	13			
Separator:	separated										
	non-separated										
Replicate 19, Treatment 1, 12 July Bar spacing 17 mm, diel											
Tanks:	separated	939		18				23		1	
	non-separated	59		2	1		1				
Separator:	separated										
	non-separated										
Replicate 20, Treatment 1, 15 July Bar spacing 17 mm, diel											
Tanks:	separated	583		31				23			
	non-separated	57		3			2				1
Separator:	separated	2									
	non-separated										
Replicate 21, Treatment 1, 19 July Bar spacing 17 mm, diel											
Tanks:	separated	2294		81				69		1	
	non-separated	99		8			3	11			
Separator:	separated	1									
	non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 22, Treatment 1, 23 July **Bar spacing 17 mm, diel**										
Tanks: separated	816		17				28			
non-separated	127		4				9			
Separator: separated	1									
non-separated										
Replicate 23, Treatment 1, 27 July **Bar spacing 17 mm, diel**										
Tanks: separated	806		7				22			
non-separated	61		5							
Separator: separated										
non-separated										
Replicate 24, Treatment 1, 30 July **Bar spacing 17 mm, diel**										
Tanks: separated	480		2							
non-separated	79		2			2				
Separator: separated	2									
non-separated										
Replicate 1, Treatment 2, 5 May **Bar spacing 17 mm, Short Duration**										
Tanks: separated			99	7	9	37			21	
non-separated			16	9	1	33			2	
Separator: separated										
non-separated										
Replicate 2, Treatment 2, 5 May **Bar spacing 17 mm, Short duration**										
Tanks: separated			36		3	10			18	
non-separated			6	6		20			7	
Separator: separated										
non-separated										
Replicate 3, Treatment 2, 5 May **Bar spacing 17 mm, Short duration**										
Tanks: separated			111	5		5			35	
non-separated			7	5		13	1		15	
Separator: separated										
non-separated										
Replicate 4, Treatment 2, 12 May **Bar spacing 17 mm, Short duration**										
Tanks: separated			137	4	2	15	1		29	
non-separated			15	7		12			3	
Separator: separated										
non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 5, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			160	15	1	11			85	
non-separated			34	5		7			42	
Separator: separated			4							
non-separated						1				
Replicate 6, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			64		1				61	
non-separated			19	1					36	
Separator: separated			1							
non-separated										
Replicate 7, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			86			1			124	
non-separated			37	2		1			63	
Separator: separated										
non-separated										
Replicate 8, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			225	6	2	12	8		10	
non-separated			35	1	2	9	2			
Separator: separated										
non-separated										
Replicate 9, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			424	21	1	10	5		147	
non-separated			40	1	1	4			38	
Separator: separated			2							
non-separated										
Replicate 10, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			131	2		1			52	
non-separated			12	2					8	
Separator: separated										
non-separated										
Replicate 11, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			89	1					342	
non-separated			14						6	
Separator: separated									1	
non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 12, Treatment 2, 26 May Bar spacing 17 mm, Short duration										
Tanks: separated			419	16	15	147	144	4	153	
non-separated	2		64	5	7	77	17		16	
Separator: separated										
non-separated										
Replicate 13, Treatment 2, 26 May Bar spacing 17 mm, Short duration										
Tanks: separated			63		1	13	32		14	
non-separated			10			17	4	1	3	
Separator: separated										
non-separated										
Replicate 14, Treatment 2, 26 May Bar spacing 17 mm, Short duration										
Tanks: separated			22		2	1	31		125	
non-separated			13	1	5	6	16		67	
Separator: separated			5	1	2	3	1			
non-separated										
Replicate 15, Treatment 2, 1 June Bar spacing 17 mm, Short duration										
Tanks: separated	24		11	1	7	3	10		22	
non-separated	3		3	2	1	11	7		16	
Separator: separated					3	5			1	
non-separated						5				
Replicate 16, Treatment 2, 2 June Bar spacing 17 mm, Short duration										
Tanks: separated	51		7			6	10	1	2	
non-separated	17		4			17	5		1	
Separator: separated										
non-separated										
Replicate 17, Treatment 2, 2 June Bar spacing 17 mm, Short duration										
Tanks: separated	72		15	2	4	6	11	2	4	
non-separated	2					1	1			
Separator: separated					1	1				
non-separated										
Replicate 18, Treatment 2, 23 June Bar spacing 17 mm, Short duration										
Tanks: separated	961		2			2	5		2	
non-separated	56					6				1
Separator: separated										
non-separated										

Appendix Table B7. 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 19, Treatment 2, 23 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	661					2	2			
non-separated	75					1	2			
Separator: separated										
non-separated										
Replicate 20, Treatment 2, 23 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	116				1		1			
non-separated	31									
Separator: separated										
non-separated										
Replicate 21, Treatment 2, 30 June										
Bar spacing17 mm, Short duration										
Tanks: separated	956		1				16			
non-separated	55					1				
Separator: separated										
non-separated										
Replicate 22, Treatment 2, 30 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	516						30	1		
non-separated	31						2			
Separator: separated										
non-separated										
Replicate 23, Treatment 2, 30 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	336		6		1		3			
non-separated	23									
Separator: separated										
non-separated										
Replicate 24, Treatment 2, 30 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	86									
non-separated	27									
Separator: separated	2									
non-separated										

Appendix Table B7. Continued.

Source	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 25, Treatment 2, 1 July Bar spacing 17 mm, Short duration										
Tanks: separated	77						5			
non-separated	15									
Separator: separated										
non-separated										
Replicate 26, Treatment 2, 1 July Bar spacing 17 mm, Short duration										
Tanks: separated	68						2			
non-separated	11									
Separator: separated										
non-separated										
Replicate 27, Treatment 2, 6 July Bar spacing 17 mm, Short duration										
Tanks: separated	1862		78		1		140			
non-separated	144		9			1	23			
Separator: separated										
non-separated										
Replicate 28, Treatment 2, 7 July Bar spacing 17 mm, Short duration										
Tanks: separated	430						31		1	
non-separated	24						2			
Separator: separated										
non-separated										
Replicate 29, Treatment 2, 7 July Bar spacing 17 mm, Short duration										
Tanks: separated	170		7				7			
non-separated	5									
Separator: separated										
non-separated										
Replicate 30, Treatment 2, 7 July Bar spacing 17 mm, Short duration										
Tanks: separated	156		5				3			
non-separated	14		1			2	1			
Separator: separated	1									
non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 31, Treatment 2, 13 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	171		2							
non-separated	14									
Separator: separated										
non-separated										
Replicate 32, Treatment 2, 13 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	98									
non-separated	11					2				
Separator: separated										
non-separated										
Replicate 33, Treatment 2, 14 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	232		11				24			
non-separated	15		2				1			
Separator: separated										
non-separated										
Replicate 34, Treatment 2, 14 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	170		6				13			
non-separated	8						1			
Separator: separated										
non-separated										
Replicate 35, Treatment 2, 14 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	1126		10				2			
non-separated	82		1			1	1			
Separator: separated										
non-separated										
Replicate 36, Treatment 2, 21 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	53		4				4			
non-separated	7		3							
Separator: separated										
non-separated										

Appendix Table B7. 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 37, Treatment 2, 21 July Bar spacing 17 mm, Short duration										
Tanks: separated	31						2			
non-separated	5									
Separator: separated										
non-separated										
Replicate 38, Treatment 2, 21 July Bar spacing 17 mm, Short duration										
Tanks: separated	50									
non-separated	8									
Separator: separated										
non-separated										
Replicate 39, Treatment 2, 21 July Bar spacing 17 mm, Short duration										
Tanks: separated	28									
non-separated	3									
Separator: separated										
non-separated										
Replicate 40, Treatment 2, 28 July Bar spacing 17 mm, Short duration										
Tanks: separated	63									
non-separated	5									
Separator: separated										
non-separated										
Replicate 41, Treatment 2, 28 July Bar spacing 17 mm, Short duration										
Tanks: separated	51									
non-separated	4									
Separator: separated										
non-separated										
Replicate 42, Treatment 2, 28 July Bar spacing 17 mm, Short duration										
Tanks: separated	307		3				16			
non-separated	4					1	3			
Separator: separated										
non-separated										

Appendix Table B7. 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 43, Treatment 2, 28 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	47									
non-separated	12					1				
Separator: separated	5									
non-separated										
Replicate 1, Treatment 3, 21 April										
Bar spacing 19 mm, diel										
Tanks: separated			176	54	5	11			2	
non-separated			21	17	1	7			1	
Separator: separated						1				
non-separated										
Replicate 2, Treatment 3, 23 April										
Bar spacing 19 mm, diel										
Tanks: separated			277	20	6	30			9	
non-separated			73	15		30			4	
Separator: separated			1			1				
non-separated										
Replicate 3, Treatment 3, 27 April										
Bar spacing 19 mm, diel										
Tanks: separated			325	66	10	46			4	
non-separated			44	16		49			1	
Separator: separated										
non-separated										
Replicate 4, Treatment 3, 29 April										
Bar spacing 19 mm, diel										
Tanks: separated			215	26	6	26			18	
non-separated			71	6	2	24			3	
Separator: separated										
non-separated										
Replicate 5, Treatment 3, 30 April										
Bar spacing 19 mm, diel										
Tanks: separated			987	108	14	61	5		75	
non-separated			104	43	5	40	1	1	21	
Separator: separated			11	3		6			1	
non-separated				1		3			1	

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 6, Treatment 3, 4 May										
Bar spacing 19 mm, diel										
Tanks: separated			854	70	25	126	3	2	329	
non-separated			74	20	1	55			51	
Separator: separated			2		2					
non-separated										
Replicate 7, Treatment 3, 10 May										
Bar spacing 19 mm, diel										
Tanks: separated			1062	48	33	196	7	2	918	
non-separated			129	20	1	97	1		143	
Separator: separated										
non-separated										
Replicate 8, Treatment 3, 17 May										
Bar spacing 19 mm, diel										
Tanks: separated			1352	36	27	114	14	2	244	
non-separated			130	24	9	46	2		58	
Separator: separated			4	1	4	3			1	
non-separated										
Replicate 9, Treatment 3, 20 May										
Bar spacing 19 mm, diel										
Tanks: separated			844	30	22	80	58	2	243	
non-separated			153	37	3	76	12	1	71	
Separator: separated					2					
non-separated										
Replicate 10, Treatment 3, 25 May										
Bar spacing 19 mm, diel										
Tanks: separated			1165	18	16	132	115	3	560	
non-separated			117	10	2	52	10	2	32	
Separator: separated			3	2	1	2			1	
non-separated										
Replicate 11, Treatment 3, 27 May										
Bar spacing 19 mm, diel										
Tanks: separated	22		192	3	25	122	184	5	185	
non-separated	5		71	3	9	97	62		50	
Separator: separated			1		4	3	4			
non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 12, Treatment 3, 28 May										
Bar spacing 19 mm, diel										
Tanks: separated	68		578	12	48	189	428	3	119	
non-separated	10		93	5	3	138	96	1	21	
Separator: separated			30	4	1	6	7		1	
non-separated						2	1			
Replicate 13, Treatment 3, 4 June										
Bar spacing 19 mm, diel										
Tanks: separated	682		96	15	27	47	182	2	49	
non-separated	129		25	7	1	27	48		27	
Separator: separated			4		1	4	3			
non-separated										
Replicate 14, Treatment 3, 21 June										
Bar spacing 19 mm, diel										
Tanks: separated	1469		88		4	2	10		2	
non-separated	106		7	1		6			1	
Separator: separated	3		4							
non-separated										
Replicate 15, Treatment 3, 24 June										
Bar spacing 19 mm, diel										
Tanks: separated	2587		46			2	2			1
non-separated	325		9			2				
Separator: separated										
non-separated										
Replicate 16, Treatment 3, 29 June										
Bar spacing 19 mm, diel										
Tanks: separated	5387		29			1	124	1		
non-separated	406		2	1		1	6			
Separator: separated	5									
non-separated										
Replicate 17, Treatment 3, 5 July										
Bar spacing 19 mm, diel										
Tanks: separated	1797		37		1		137		2	
non-separated	134		9				15			
Separator: separated										
non-separated										

Appendix Table B7. Continued.

Source		Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
		<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 18, Treatment 3, 8 July											
Bar spacing 19 mm, diel											
Tanks:	separated	664		51			1	44		1	
	non-separated	26		2			2	2			
Separator:	separated										
	non-separated										
Replicate 19, Treatment 3, 16 July											
Bar spacing 19 mm, diel											
Tanks:	separated	1129		9				42			
	non-separated	41		4	1			2			
Separator:	separated	3									
	non-separated										
Replicate 20, Treatment 3, 20 July											
Bar spacing 19 mm, diel											
Tanks:	separated	1336		45	2			63			
	non-separated	42		1				14			
Separator:	separated										
	non-separated										
Replicate 21, Treatment 3, 22 July											
Bar spacing 19 mm, diel											
Tanks:	separated	820		22	1			55			
	non-separated	58		4				5			
Separator:	separated										
	non-separated										
Replicate 22, Treatment 3, 26 July											
Bar spacing 19 mm, diel											
Tanks:	separated	716		9				21			
	non-separated	37		3				1			
Separator:	separated	1									
	non-separated										
Replicate 23, Treatment 3, 29 July											
Bar spacing 19 mm, diel											
Tanks:	separated	666		5			1	5			
	non-separated	67		2							
Separator:	separated	2									
	non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 4, Bar spacing 19 mm, Short duration										
Tanks: separated			48	12	4	27			17	
non-separated			2	3	1	13			4	
Separator: separated						1				
non-separated										
Replicate 2, Treatment 4, Bar spacing 19 mm, Short duration										
Tanks: separated			46	4	1	3			10	
non-separated			10	11		9			1	
Separator: separated										
non-separated										
Replicate 3, Treatment 4, 5 May Bar spacing 19 mm, Short duration										
Tanks: separated			81	6	6	9			45	
non-separated			40	13	4	18			24	
Separator: separated				1		4				
non-separated										
Replicate 4, Treatment 4, 12 May Bar spacing 19 mm, Short duration										
Tanks: separated			148	4	5	15	2		47	
non-separated			10	2		4			6	
Separator: separated										
non-separated										
Replicate 5, Treatment 4, 12 May Bar spacing 19 mm, Short duration										
Tanks: separated			104	1					87	
non-separated			7						36	
Separator: separated			2							
non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 6, Treatment 4, 12 May Bar spacing 19 mm, Short duration										
Tanks: separated			66	2					104	
non-separated			16			1			39	
Separator: separated										
non-separated										
Replicate 7, Treatment 4, 12 May Bar spacing 19 mm, Short duration										
Tanks: separated			82	1	3	2			143	
non-separated			78	1	1	4			98	
Separator: separated			5							
non-separated										
Replicate 8, Treatment 4, 12 May Bar spacing 19 mm, Short duration										
Tanks: separated			192	4	8	13	2	1	74	
non-separated			25	4		8			8	
Separator: separated										
non-separated										
Replicate 9, Treatment 4, 19 May Bar spacing 19 mm, Short duration										
Tanks: separated			473	10	13	48	14		205	
non-separated			59	14	1	14	1		15	
Separator: separated										
non-separated										
Replicate 10, Treatment 4, 19 May Bar spacing 19 mm, Short duration										
Tanks: separated			112	5		4	4	1	8	
non-separated			15	5		4			1	
Separator: separated										
non-separated										
Replicate 11, Treatment 4, 19 May Bar spacing 19 mm, Short duratiion										
Tanks: separated			62	1					48	
non-separated			3	1		1	1		4	
Separator: separated			1							
non-separated										

Appendix Table B7. Continued.

Source	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 12, Treatment 4, 19 May Bar spacing 19 mm, Short duration										
Tanks: separated			116		1	2				
non-separated			4			1				
Separator: separated										
non-separated										
Replicate 13, Treatment 4, 19 May Bar spacing 19 mm, Short duration										
Tanks: separated			80	1	2	1			46	
non-separated			8			1			7	
Separator: separated						1				
non-separated										
Replicate 14, Treatment 4, 26 May Bar spacing 19 mm, Short duration										
Tanks: separated			166	2	7	46	55	3	10	
non-separated			10			19	3		3	
Separator: separated										
non-separated										
Replicate 15, Treatment 4, 26 May Bar spacing 19 mm, Short duration										
Tanks: separated	17		296	12	6	22	34		280	
non-separated	1		16			7	2		29	
Separator: separated							1			
non-separated										
Replicate 16, Treatment 4, 1 June Bar spacing 19 mm, Short duration										
Tanks: separated	225		93	7	22	115	76	3	23	
non-separated	29		5	1	2	38	8		3	
Separator: separated										
non-separated										
Replicate 17, Treatment 4, 2 June Bar spacing 19 mm, Short duration										
Tanks: separated	58		8	4	1	40	25	1	24	
non-separated	5		2	1	2	21	2		2	
Separator: separated										
non-separated										

Appendix Table B7. Continued.

Source		Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
		<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 18, Treatment 4, 2 June											
Bar spacing 19 mm, Short duration											
Tanks:	separated	114		7	1	1	2	6			1
	non-separated	11		3	1	4	2	12		1	
Separator:	separated										
	non-separated										
Replicate 19, Treatment 4, 2 June											
Bar spacing 19 mm, Short duration											
Tanks:	separated	98		11	1	1	1	8		9	
	non-separated	12		2		1	1	1		4	
Separator:	separated					2		1			
	non-separated										
Replicate 20, Treatment 4, 23 June											
Bar spacing 19 mm, Short duration											
Tanks:	separated	691		2			1	4		1	
	non-separated				129	1		1			
Separator:	separated										
	non-separated										
Replicate 21, Treatment 4, 23 June											
Bar spacing 19 mm, Short duration											
Tanks:	separated	481					1	2		1	
	non-separated	31					1				
Separator:	separated										
	non-separated										
Replicate 22, Treatment 4, 23 June											
Bar spacing 19 mm, Short duration											
Tanks:	separated	557		475	2		6	14		1	
	non-separated	115		43			2				
Separator:	separated										
	non-separated										
Replicate 23, Treatment 4, 30 June											
Bar spacing 19 mm, Short duration											
Tanks:	separated	876		6				14			
	non-separated	17		1							
Separator:	separated										
	non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 24, Treatment 4, 30 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	408						22			
non-separated	24						1			
Separator: separated										
non-separated										
Replicate 25, Treatment 4, 30 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	51									
non-separated										
Separator: separated	2									
non-separated										
Replicate 26, Treatment 4, 1 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	78						5			
non-separated	9									
Separator: separated	1									
non-separated										
Replicate 27, Treatment 4, 1 July										
Bar spacing mm										
Tanks: separated	81						2			
non-separated	9									
Separator: separated										
non-separated										
Replicate 28, Treatment 4, 1 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	89						2			
non-separated	27									
Separator: separated										
non-separated										
Replicate 29, Treatment 4, 6 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	67									
non-separated	8						2			
Separator: separated	3									
non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 30, Treatment 4, 7 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	231		29		1	1	24			
non-separated	15		1	1						
Separator: separated										
non-separated										
Replicate 31, Treatment 4, 7 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	54		4				4			
non-separated	3		1							
Separator: separated										
non-separated										
Replicate 32, Treatment 4, 13 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	959		27			2	38			
non-separated	30						1			
Separator: separated										
non-separated										
Replicate 33, Treatment 4, 13 July										
Bar spacing 19 mm, Short duration										
Tanks: separated				182	1					
non-separated	4									
Separator: separated										
non-separated										
Replicate 34, Treatment 4, 13 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	258		1							
non-separated	25									
Separator: separated	5					1				
non-separated										
Replicate 35, Treatment 4, 14 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	183		5				15			
non-separated	6									
Separator: separated										
non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 36, Treatment 4, 14 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	170		6	1			6			
non-separated	17		1				2			
Separator: separated										
non-separated										
Replicate 37, Treatment 4, 14 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	78									
non-separated	17									
Separator: separated										
non-separated										
Replicate 38, Treatment 4, 21 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	60		6							
non-separated	6		5							
Separator: separated										
non-separated										
Replicate 39, Treatment 4, 21 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	451		21				41			
non-separated	38						4	2		
Separator: separated	1									
non-separated										
Replicate 40, Treatment 4, 21 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	33									
non-separated	1									
Separator: separated										
non-separated										
Replicate 41, Treatment 4, 28 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	64									
non-separated	7									
Separator: separated										
non-separated										

Appendix Table B7. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 42, Treatment 4, 28 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	66									
non-separated	13		1							
Separator: separated										
non-separated										
Replicate 43, Treatment 4, 28 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	143									
non-separated	9		1							
Separator: separated										
non-separated										

Appendix Table B8. Incidental species captured during separation efficiency studies using a conventional separator and a high-velocity flume wet separator at McNary Dam, 28 April-28 July, 2000. Species are listed in order of total capture frequency.

Common name	Scientific name	Total catch
shad	*Alosa sapidissima*	28
mountain whitefish	*Prosopium williamsoni*	26
lamprey	*Entosphenus tridentata*	10
yellow perch	*Perca flavescens*	9
sucker	*Catostomus* spp.	7
peamouth	*Mylocheilus caurinus*	4
channel catfish	*Ictalurus punctatus*	1
chiselmouth	*Acrochelius alutaceus*	1
crappie	*Proxomus* spp.	1

Appendix Table B9. Statistical analysis results of comparisons among mean separation efficiency values by group for treatments evaluated using an evaluation conventional wet separator at McNary Dam, 2000. Asterisks indicate significant differences (α = 0.05) among treatment factors.

		Calculated statistic			
Group	Treatment conditions	F	df	*P*	
Yearling Chinook salmon					
<180 mm	date	7.95	1	0.010	*
	density	0.09	1	0.765	
	light level	131.40	2	0.000	*
≥180 mm	density	0.04	1	0.854	
	light level	3.20	2	0.077	
Total catch	date	3.86	1	0.062	
	density	0.49	1	0.493	
	light level	79.32	2	0.000	*
Steelhead					
≥180 mm	density	0.13	1	0.721	
	light level	0.62	2	0.552	
Total catch	density	0.33	1	0.573	
	light level	0.63	2	0.546	
All salmonids					
<180 mm	date	8.57	1	0.008	*
	density	0.59	1	0.450	
	light level	148.35	2	0.000	*
≥180 mm	date	22.91	1	0.000	*
	density	2.98	1	0.099	
	light level	1.71	2	0.204	
Total catch, all salmonids	date	1.20	1	0.285	
	density	5.66	1	0.026	*
	light level	100.89	2	0.000	*
Subyearling Chinook salmon catch					
	date	1.16	1	0.292	
	density	3.10	1	0.092	
	light level	18.65	2	0.000	*
	density vs. light level	8.75	2	0.001	*

Appendix Table B10. Statistical analysis results of comparisons among mean separation efficiency values by group for treatments evaluated using an evaluation high-velocity flume wet separator at McNary Dam, 2000. Asterisks indicate significant differences (α = 0.05) among treatment factors.

Group	Treatment conditions	Calculated statistic			
		F	df	*P*	
Yearling Chinook salmon					
<180 mm	date	16.81	1	0.001	*
	density	0.26	1	0.616	
	light level	28.92	2	0.000	*
Total catch	date	9.53	1	0.005	*
	density	2.17	1	0.155	
	light level	15.78	2	0.000	*
Steelhead					
≥180 mm	density	4.75	1	0.047	*
	light level	2.22	2	0.145	
Total catch	density	0.07	1	0.798	
	light level	1.60	2	0.2322	
All salmonids					
<180 mm	date	5.65	1	0.027	*
	density	1.60	1	0.219	
	light level	21.69	2	0.000	*
≥180 mm	date	0.98	1	0.336	
	density	0.32	1	0.583	
	light level	2.15	2	0.148	
Total catch all salmonids	date	17.50	1	0.000	*
	density	0.000	1	0.993	
	light level	21.70	2	0.000	*
Subyearling Chinook salmon					
	date	1.42	1	0.245	
	density	0.01	1	0.907	
	light level	38.16	2	0.000	*

Appendix Table B11. Statistical analysis results of comparisons among mean separator exit efficiency values by group for treatments evaluated using an evaluation conventional wet separator at McNary Dam, 2000. Asterisks indicate significant differences (α = 0.05) among treatment factors.

Group	Treatment conditions	Calculated statistic F	df	*P*	
Yearling Chinook salmon					
<180 mm	date	32.88	1	0.000	*
	density	3.11	1	0.092	
	light level	3.51	2	0.048	*
≥180 mm	density	0.48	1	0.502	
	light level	0.07	2	0.932	
Total catch	date	34.98	1	0.000	*
	density	2.02	1	0.169	
	light level	2.98	2	0.071	
Steelhead					
steelhead ≥180 mm	density	0.27	1	0.609	
	light level	1.35	2	0.286	
steelhead, total catch	density	0.09	1	0.769	
	light level	1.09	2	0.359	
All salmonids					
<180 mm	date	33.56	1	0.000	*
	density	2.41	1	0.135	
	light level	4.36	2	0.025	*
≥180 mm	date	9.56	1	0.006	*
	density	0.50	1	0.489	
	light level	1.20	2	0.320	
Total catch all salmonids	date	27.30	1	0.000	*
	density	0.69	1	0.413	
	light level	3.78	2	0.039	*
Subyearling Chinook salmon					
	date	3.47	1	0.074	
	density	0.57	1	0.457	
	light level	4.51	2	0.021	*

Appendix Table B12. Statistical analysis results of comparisons among mean separator exit efficiency values by group for treatments evaluated using an evaluation high-velocity flume wet separator at McNary Dam, 2000. Asterisks indicate significant differences ($\alpha = 0.05$) among treatment factors.

		Calculated statistic			
Group	Treatment conditions	F	df	*P*	
Yearling Chinook salmon					
<180 mm	date	5.39	1	0.030	*
	density	0.31	1	0.585	
	light level	0.13	2	0.879	
Total catch	date	5.29	1	0.031	*
	density	0.31	1	0.581	
	light level	0.12	2	0.887	
Steelhead					
≥180 mm	density	4.93	1	0.043	*
	light level	6.29	2	0.011	*
Total catch	density	1.72	1	0.207	
	light level	3.16	2	0.070	
All salmonids					
<180 mm	date	3.45	1	0.077	
	density	0.05	1	0.833	
	light level	0.01	2	0.985	
≥180 mm	date	3.75	1	0.070	
	density	0.63	1	0.437	
	light level	1.64	2	0.222	
Total catch all salmonids	date	3.53	1	0.074	
	density	0.10	1	0.754	
	light level	0.11	2	0.893	
Subyearling Chinook salmon					
	date	1.09	1	0.306	
	density	7.63	1	0.011	*
	light level	2.92	2	0.072	

Appendix Table B13. Statistical analysis results of comparisons among mean descaling values by group for treatments evaluated using an evaluation conventional wet separator at McNary Dam, 2000. Asterisks indicate significant differences ($\alpha = 0.05$) among treatment factors.

Group	Treatment conditions	Calculated statistic			
		F	df	*P*	
Yearling Chinook salmon					
<180 mm	date	4.19	1	0.052	
	density	0.01	1	0.092	
	light level	2.04	2	0.153	
≥180 mm	density	2.53	1	0.151	
	light level	0.36	2	0.703	
Total catch	date	8.25	1	0.009	*
	density	0.11	1	0.744	
	light level	9.40	2	0.001	*
	density vs. light level	9.15	2	0.001	*
Steelhead					
≥180 mm	density	0.17	1	0.687	
	light level	0.09	2	0.911	
Total catch	density	0.01	1	0.941	
	light level	0.44	2	0.650	
All salmonids					
<180 mm	date	5.16	1	0.033	*
	density	0.20	1	0.663	
	light level	2.08	2	0.147	
≥180 mm	date	7.78	1	0.011	*
	density	0.10	1	0.750	
	light level	1.21	2	0.319	
Total catch all salmonids	date	10.12	1	0.004	*
	density	0.02	1	0.892	
	light level	4.32	2	0.027	*
	density vs. light level	4.20	2	0.029	*
Subyearling Chinook salmon					
	date	1.96	1	0.173	
	density	3.33	1	0.080	
	light level	2.59	2	0.095	

Appendix Table B14. Statistical analysis results of comparisons among mean descaling values by group for treatments evaluated using an evaluation high-velocity flume wet separator at McNary Dam, 2000. Asterisks indicate significant differences ($\alpha = 0.05$) among treatment factors.

Group	Treatment conditions	Calculated statistic F	df	*P*	
Yearling Chinook salmon					
<180 mm	date	0.03	1	0.8873	
	density	4.28	1	0.051	
	light level	0.10	2	0.903	
Total catch	date	0.00	1	0.956	
	density	4.89	1	0.038	*
	light level	0.12	2	0.891	
Steelhead					
≥180 mm	density	0.51	1	0.488	
	light level	2.22	2	0.145	
Total catch	density	0.18	1	0.680	
	light level	0.67	2	0.525	
All salmonids					
<180 mm	date	0.14	1	0.709	
	density	4.42	1	0.047	*
	light level	1.18	2	0.327	
≥180 mm	date	1.69	1	0.211	
	density	0.27	1	0.612	
	light level	0.71	2	0.505	
Total catch, all salmonids	date	0.02	1	0.876	
	density	8.51	1	0.008	*
	light level	0.42	2	0.663	
Subyearling Chinook salmon					
	date	0.85	1	0.365	
	density	3.30	1	0.081	
	light level	1.18	2	0.342	