

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

R. Lynn McComas, Cynthia D. Magie, Benjamin P. Sandford, John W. Ferguson,
and Daniel M. Katz

Report of research by

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

and

Hydrology Department, Walla Walla District
U.S. Army Corps of Engineers
201 North Third Avenue
Walla Walla, Washington 99326-1876

for

Walla Walla District
U.S. Army Corps of Engineers
201 North Third Avenue
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.

CONTENTS

| | |
|---|-----|
| EXECUTIVE SUMMARY | iii |
| INTRODUCTION | 1 |
| 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 | 5 |
| Methods..... | 5 |
| Results and Discussion | 10 |
| Separation Efficiency..... | 10 |
| Separator Exit Efficiency | 12 |
| Fish Condition..... | 13 |
| OBJECTIVE 2: Evaluate an in-flume adult separator for removing adult salmonids and other large incidental species upstream from the primary wet separator..... | 15 |
| Approach..... | 15 |
| Results and Discussion | 17 |
| 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..... | 19 |
| Approach..... | 19 |
| Results and Discussion | 25 |
| Separation Efficiency..... | 27 |
| Separator Exit Efficiency | 33 |
| Fish Condition..... | 35 |
| CONCLUSIONS..... | 39 |
| ACKNOWLEDGMENTS | 42 |
| REFERENCES | 43 |
| APPENDIX A: Analysis of Flow Velocity Measurements at Ice Harbor Dam | 47 |
| APPENDIX B: Data Tables..... | 69 |

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.

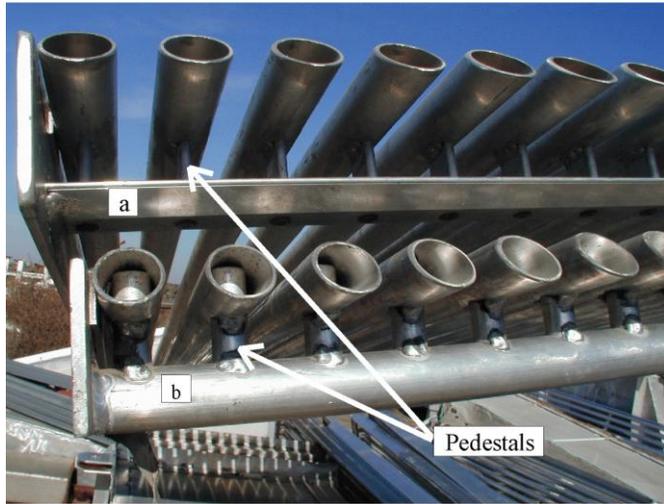
Volitional separation efficiency, separator exit efficiency, and fish condition were evaluated using 12-m separation-bar arrays oriented parallel to the water surface. Separation bars were made of 25.4-mm (1-in) untreated aluminum tubing with a 32 mm (1.25-in) outside diameter. Spacing, or gap, between 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.



Cross section
of lateral
supports



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 (\geq 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 *SEs* 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 *SEs* 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.

| Wave condition (separation-bar support type) | Exit efficiency (%) | | | | | | |
|--|----------------------------|----------------------------|--------------------|--------------------|----------------------------------|----------------------------------|----------------------------|
| | 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.

| Bar orientation, water velocity | Exit efficiency (%) | | | | | | |
|------------------------------------|----------------------------|----------------------------|--------------------|--------------------|----------------------------------|----------------------------------|----------------------------|
| | 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).

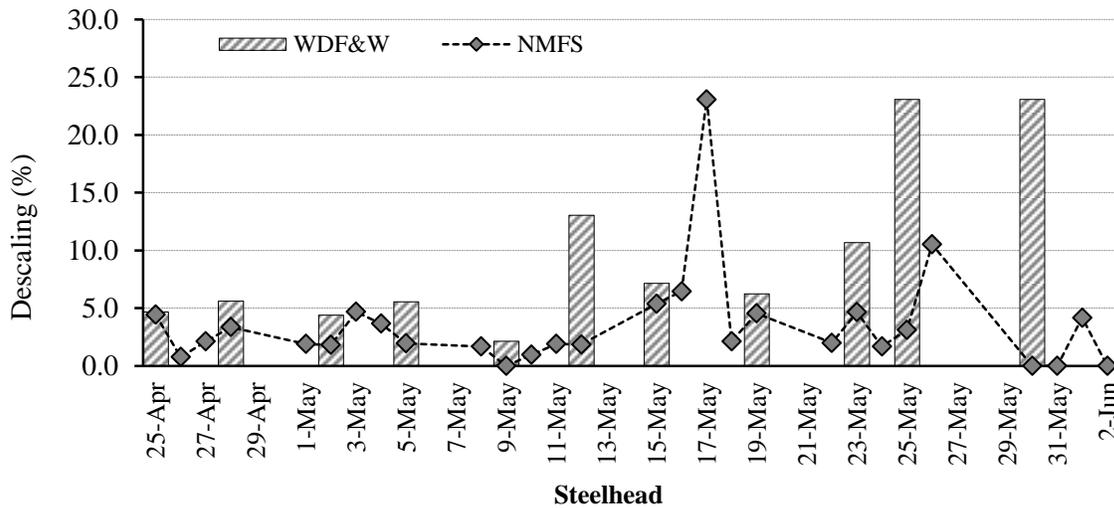
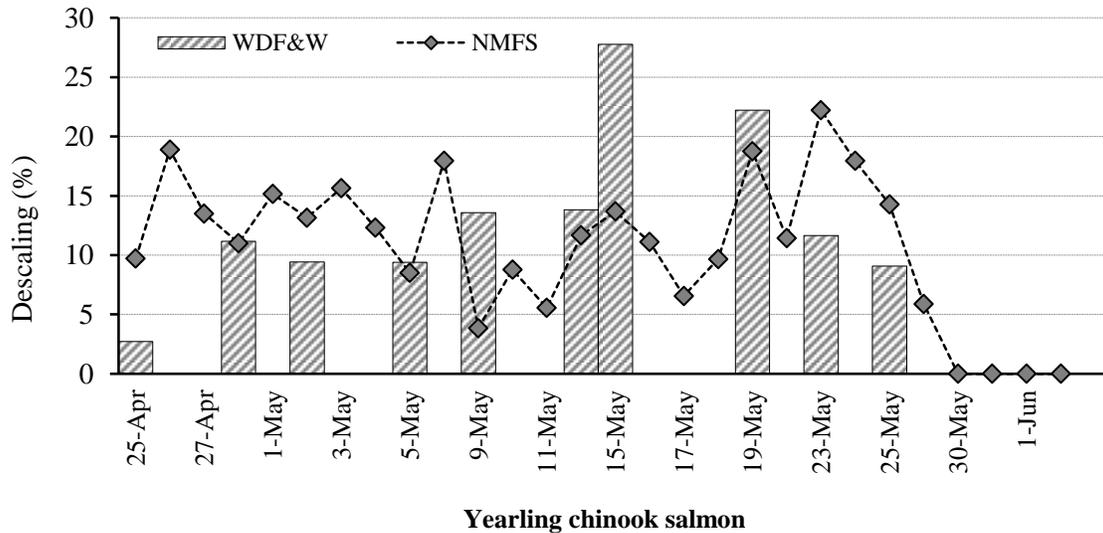


Figure 2. Yearling Chinook salmon and steelhead descaling values obtained from the Ice Harbor Dam juvenile bypass and test separator facilities by sample date, 2000. WDFW values are means from the bypass facility smolt-monitoring samples of wild and hatchery fish combined obtained by Washington State 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 m² (55 ft²), or approximately 85% of the total area available in the upstream section of an operational conventional separator (5.85 m², 65 ft²).

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 gateway 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 gateway was seeded with fish obtained by netting fish from adjacent (A and C) gateways 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 gateway and released into the test gateway without interim transfer to, and release from, another container. For the high-density evaluation, all smolts were removed from adjacent gateways and placed in the test gateway prior to beginning the replicate. A low-density test was defined as the number of fish exiting the unseeded test gateway 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 gateway 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 Corporation¹, called a Light Pipe®. This system consisted of a 1000-W metal halide lamp directed

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).

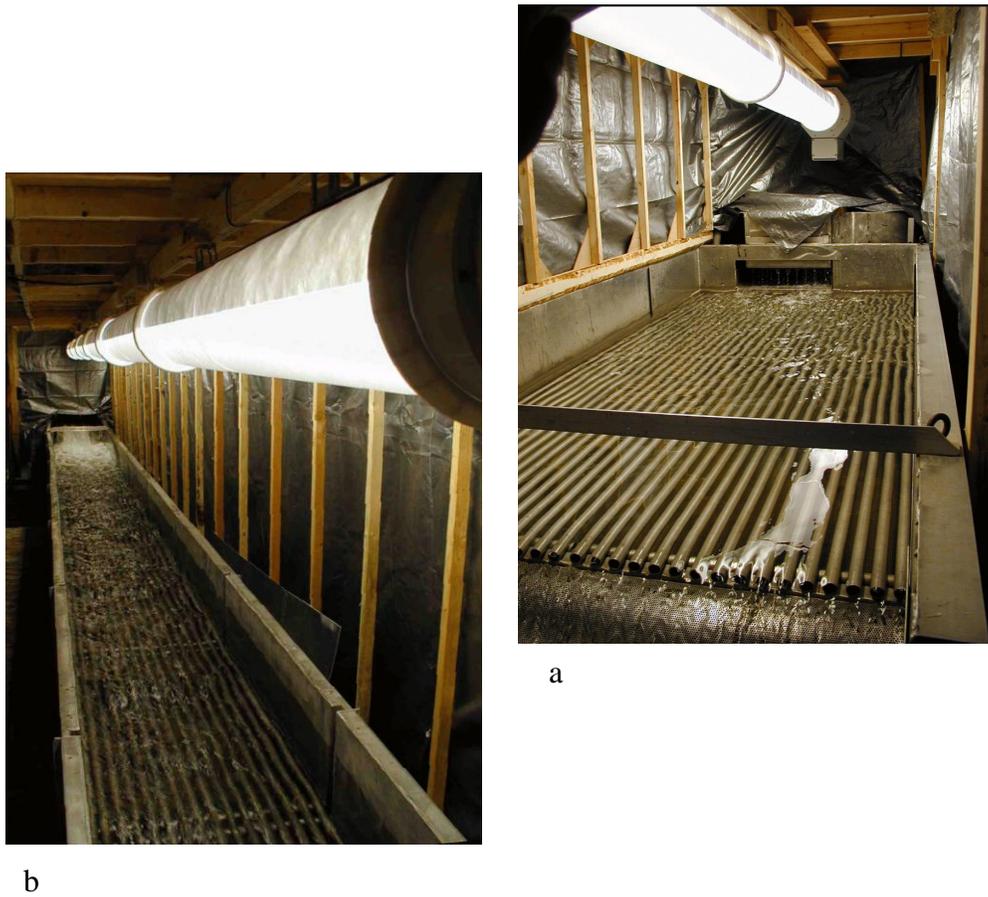


Figure 4. Artificial illumination of (a) conventional and (b) high-velocity flume wet separators studied at McNary Dam, 2000. Both light sources are 1000-W metal halide light, and both photographs show the high light condition.

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 of 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 gateway, 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 gateway 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.

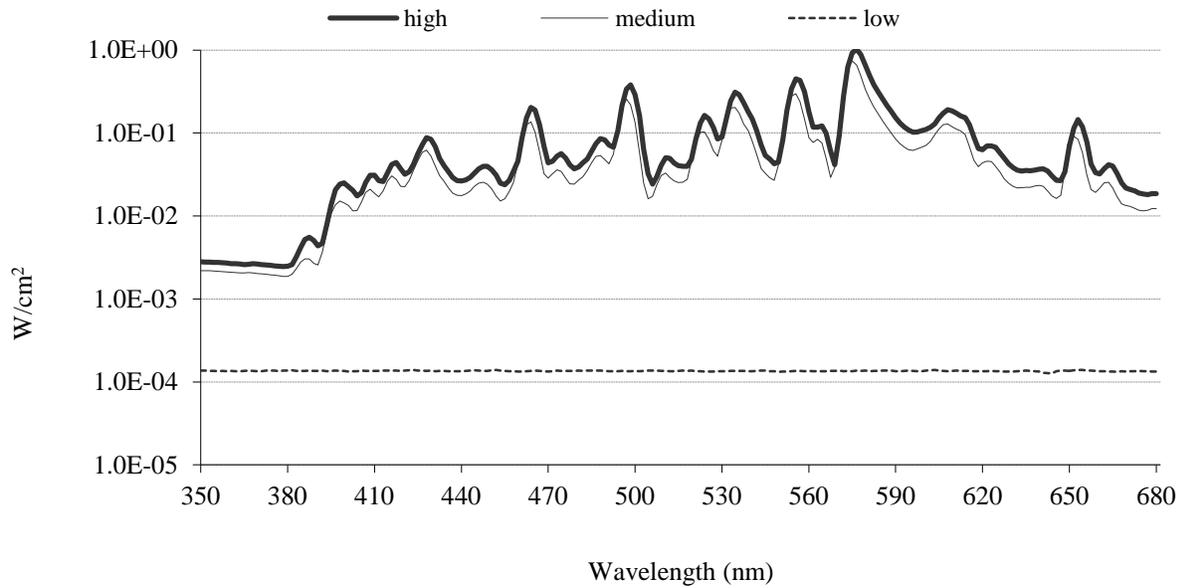
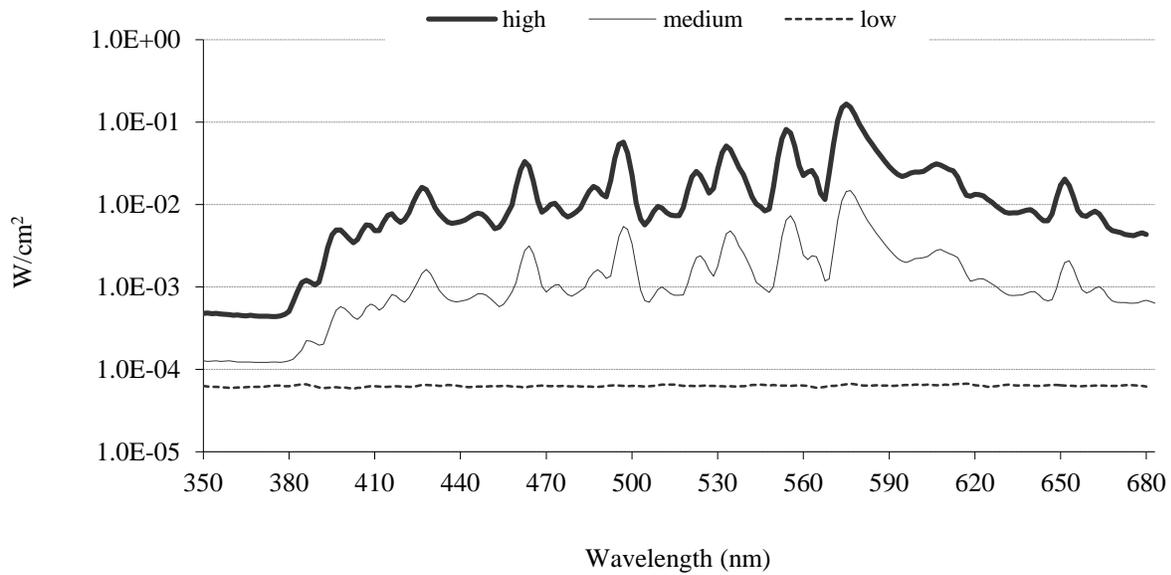


Figure 5. Spectral irradiance for high and medium artificial light and low natural light sources used with evaluation conventional and high-velocity flume wet separators during separation efficiency studies at McNary Dam, 2000.

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 ($\ln(\text{catch})$) 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 of 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.

| Light condition | Separation efficiency (%) | | | | | | | | |
|-----------------|---------------------------|----------|-----------------|-----------|----------------------|----------|----------|-----------------|--|
| | Spring | | | | | | | | Summer Subyearling Chinook salmon |
| | Chinook salmon | | | Steelhead | Total salmonid catch | | | | |
| | Small | Large | Small and large | Large | Total | Small | Large | Small and large | |
| 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.

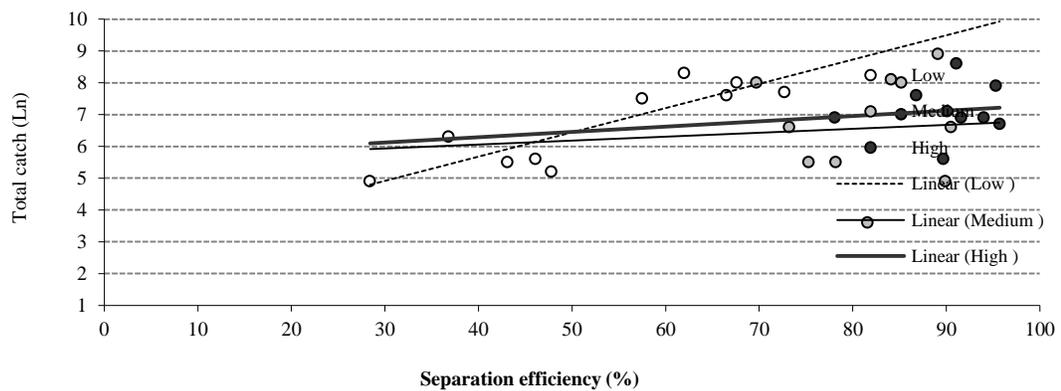


Figure 6. Scatter plot of natural logarithm of total subyearling Chinook salmon catch by light treatment as a function of separation efficiency using an evaluation conventional wet separator during separation efficiency evaluations at McNary Dam, 2000. The relationship between light factor and separation 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 | | | | | | | | |
| Light condition | Yearling Chinook | | Steelhead | | All salmonids | | | Summer subyearling Chinook salmon |
| | 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 m μ (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 (\AA). He postulated that the visible spectrum for the species was between 3,640 \AA and 6,900 \AA . 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.

| Light condition | Spring | | | | | | | | Summer subyearling Chinook salmon |
|-----------------|------------------|----------|----------|-----------|----------|-------------------|-------------------|-------------|-----------------------------------|
| | Yearling Chinook | | | Steelhead | | All salmonids | | | |
| | Small | Large | Total | Large | Total | Total small catch | Total large catch | Total catch | |
| 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 ($\ln(\text{catch})$) 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.

| Light condition | Spring | | | | | | | Summer |
|-----------------|------------------|----------|-----------|----------|-------------------|-------------------|-------------|----------------------------|
| | Yearling Chinook | | Steelhead | | All salmonids | | | subyearling Chinook salmon |
| | Small | Total | Large | Total | Total small catch | Total large catch | Total catch | |
| 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.

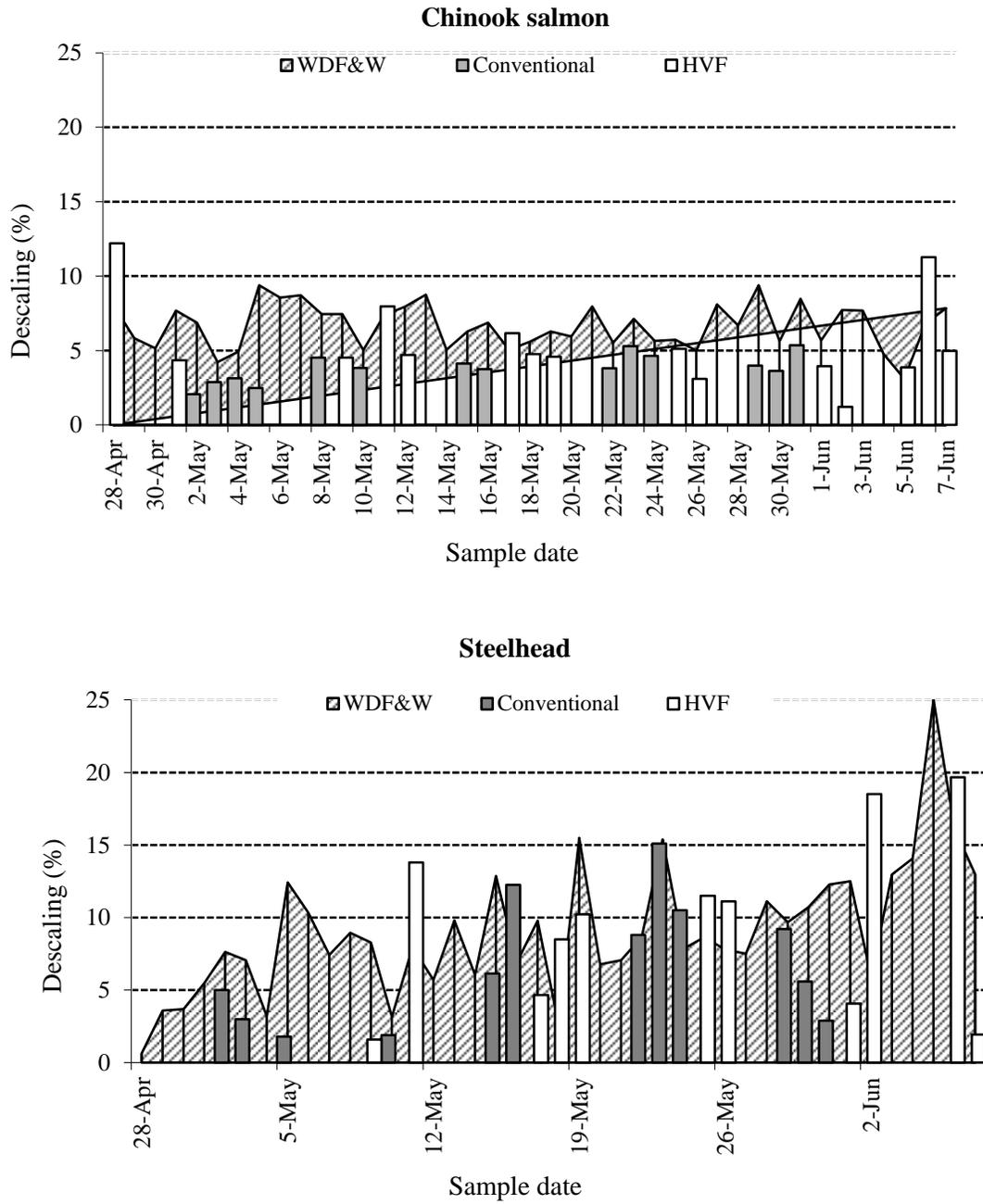


Figure 7. Daily descaling for yearling Chinook salmon and steelhead in juvenile bypass facility, conventional separator, and high-velocity flume (HVF) by sample date at McNary Dam, 2000. Bypass facility values are means for wild and hatchery fish combined from smolt monitoring samples obtained by Washington 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.

| Light condition | Spring | | | | | | | | Summer subyearling Chinook salmon |
|-----------------|------------------|-----------|-----------|-----------|-----------|-------------------|-------------------|-------------|-----------------------------------|
| | Yearling Chinook | | | Steelhead | | All salmonids | | | |
| | Small | Large | Total | Large | Total | Total small catch | Total large catch | Total catch | |
| 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.

| Light condition | Spring | | | | | | | Summer subyearling Chinook salmon |
|-----------------|------------------|-----------|------------|-------|-------------------|-------------------|-------------|-----------------------------------|
| | Yearling Chinook | | Steelhead | | All salmonids | | | |
| | Small | Total | Large | Total | Total small catch | Total large catch | Total catch | |
| 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 rationale 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.

REFERENCES

- Ali, M. A. 1961. Histological studies on the juvenile Atlantic salmon (*Salmo salar*) retina II: Responses to light intensities, wavelengths, temperatures, and continuous light or dark. *Canadian Journal of Zoology* 39:511-526.
- Ali, M. A. 1962. Light preference of control, light-, or dark-adapted sockeye salmon (*Oncorhynchus nerka*) juveniles. *American Zoologist* 2:385.
- Brett, J. R., and M. A. Ali. 1958. Some observations on the structure and photomechanical responses of the Pacific salmon retina. *Journal of the Fisheries Research Board of Canada* 15:815-829.
- Ceballos, J. R., S. W. Pettit, and J. L. McKern. 1992. Fish Transportation Oversight Team. Annual Report-1991. Transportation operations on the Columbia and Snake Rivers. NOAA Technical Memorandum NMFS F/NWR-29.
- Congleton, J. L., W. J. LaVoie, C. B. Schreck, L. E. Davis, H. Lorz, M. Beck, D. G. Elliot, R. J. Pascho, D. M. Chase, C. L. McKibbin, and L. J. Applegate. In press. Evaluation of procedures for collection, bypass, and downstream passage of outmigrating salmonids, Annual Report 1995. Report to U.S. Army Corps of Engineers, Walla Walla District.
- Cronly-Dillon, J. R., and S. C. Sharma. 1968. Effects of season and sex on the photopic spectral sensitivity of the goldfish and the clawed tadpole under photopic conditions. *Journal of Experimental Biology* 42:481-493.
- Gessel, M. H., W. E. Farr, and C. W. Long. 1985. Underwater separation of juvenile salmonids by size. *Marine Fisheries Review* 47(3):38-42.
- Hawryshyn, G. W. 1992. Polarization in fish. *American Scientist* 80:164-175.
- Hawryshyn, G. W., and R. H. Douglas. 1990. Behavioral studies of fish vision: an analysis of visual capabilities. Pages 374-318 in R. H. Douglas and M. B. A. Djamgoz, editors. *The Visual System In Fish*. Chapman and Hall Ltd., London.
- Katz, Daniel M. 1996. Juvenile fish separator design. Pages 47-52 in Chenchayya Bathala, editor. *Conference Proceedings, North American Water and Environment Congress & Destructive Water*. New York, NY.

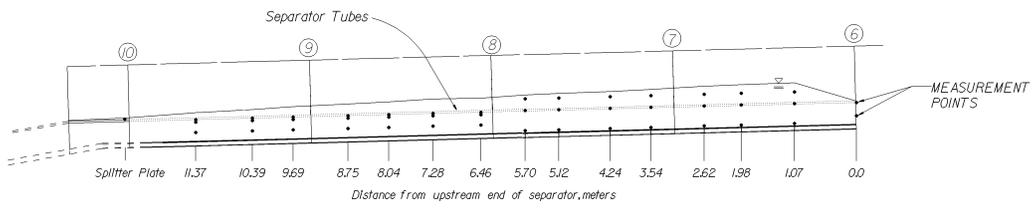
- Katz, Daniel M., R. L. McComas, and L. Swenson. 1999. Juvenile fish separator design. Pages 173-183 *in* C. Bathala, editor. Proceedings of the American Society of Civil Engineers, North American Water and Environment Congress and Destructive Water, Anaheim, California, June 22-28, 1996.
- McCabe, G. T., Jr., C. W. Long, and D. L. Park. 1979. Barge transportation of juvenile salmonids on the Columbia and Snake Rivers, 1977. *Marine Fisheries Review* 41(7):28-34.
- McComas, R. L., B. P. Sandford, C. D. Magie and J. W. Ferguson. 2003a. Biological design criteria for fish passage facilities: high-velocity flume development and improved wet-separator efficiency, McNary Dam 1999. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla District.
- McComas, R. L., B. P. Sandford, C. D. Magie and J. W. Ferguson. 2003b. Evaluation of a prototype high-velocity flume separator at Ice Harbor Dam, 1999. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla District.
- McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 1998. Studies to establish biological design criteria for wet separators, 1996. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla District.
- McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 2000. Biological design criteria for improved wet-separator efficiency and high velocity flume development, 1997. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla District.
- McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 2001. Studies to establish biological design criteria for fish passage facilities: improved wet-separator efficiency and high velocity flume development, 1998. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla District.
- Munz, F. W. 1971. Vision: visual pigments. Pages 1-32 *in* W. S. Hoar and D. J. Randall, editors. *Fish Physiology*, Vol. 5. Academic Press, New York.
- Neave, D. A. 1984. The development of visual acuity in larval plaice (*Pleuronectes platessa* L.) and turbot (*Scophthalmus maximus* L.). *Journal of Experimental Marine Biology and Ecology* 78:167-175.

- Nemeth R. S., and J. J. Anderson. 1992. Response of juvenile coho and Chinook salmon to strobe and mercury vapor lights. *North American Journal of Fisheries Management* 12:648-692
- Protasov, V. R. 1968. Vision and Near Orientation of Fish. Academy of Sciences of the U.S.S.R. Seveitsov Institute of Animal Evolutionary Morphology. Moscow . Pages 132-144 *in* Vision and Near Orientation of Fish, Translation by Israel Program for Scientific Translation, Jerusalem, 1970.
- Rahmann, H., G. Jeserich, and I. Zeutzius. 1979. Ontogeny of visual acuity of rainbow trout under normal conditions and light deprivation. *Behavior* 68:315-322.
- Reyer, A. D. 1997. Light measurement Handbook. International Light Technical Publications Dept., Newburyport, MA.
- Sager, D. R., and C. H. Hocutt. 1985. Preferred wavelengths of visible light for juvenile Atlantic menhaden. *North American Journal of Fisheries Management* 5:72-77.
- Schreck, C. B., L. E Davis, L. Burtis, P. A. Wood, J. Congleton, T. Mosey, S. Rocklage, and B. Sun. In prep. Evaluation of facilities for collection and transport of outmigrating Chinook salmon, Annual Report 1994. Report to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla District.
- Thorpe, S. A. 1973. Effects of temperature on the psychophysical and electroretinographic spectral sensitivity of the chromatically-adapted goldfish. *Vision Research* 13:59-72.
- Wald, G. 1941. The visual systems of euryhaline fishes. *Journal of General Physiology* 25: 235-245.

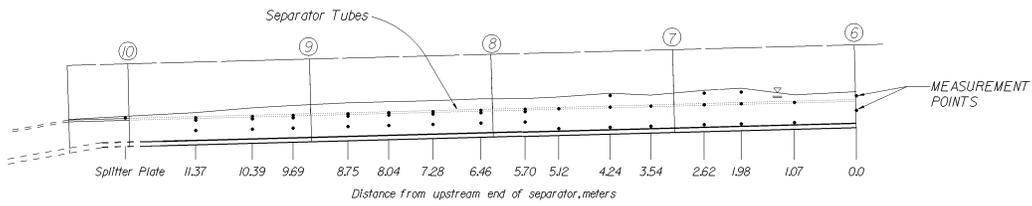
APPENDIX A

Analysis of Flow Velocity Measurements at Ice Harbor Dam

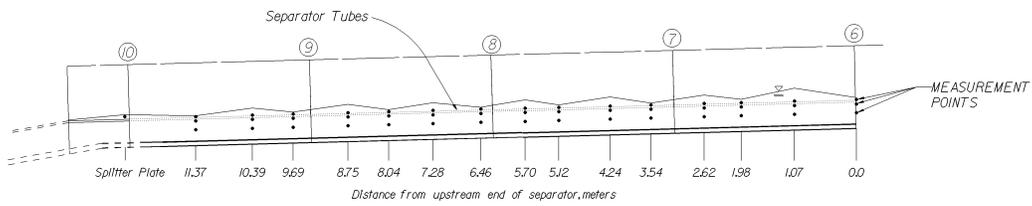
Separator configuration and hydraulic condition were set for the test separator at Ice Harbor Dam in 2000. Prior to biological testing, hydraulic tests were performed on four of the eight configurations (Appendix Tables A2-A10). The purpose of hydraulic tests was to set and record hydraulic conditions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



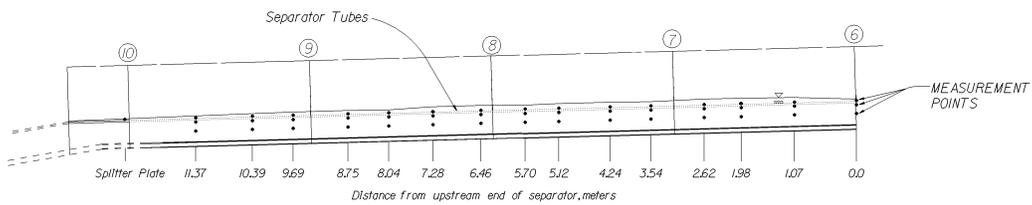
Date: 3/3/00
 Description: 1 m/s, Sloping bars, Jump 1s 13' upstream of bars



Date: 3/4/00
 Description: 2 m/s, Sloping bars, Jump 1s 6' into separator



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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge (upper/lower) | | Computed discharge (combined) | |
|---------------------------|---|------------|-------------|------------|-------------|------------|-------------------|----------|--|---------------------|-------------------------------------|---------------------|
| | Left | | Middle | | Right | | | | Q | Q | Q | Q |
| | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | D (ft) | D (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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge (upper/lower) | | Computed discharge (combined) | |
|---------------------------|---|-------|-------------|-------|-------------|-------|-------------------|------|--|---------------------|-------------------------------------|---------------------|
| | Left | | Middle | | Right | | | | Q | | Q | |
| | V (ft/s) | (m/s) | V (ft/s) | (m/s) | V (ft/s) | (m/s) | D (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 | | | | Q | | Q | |
| | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | D (ft) | D (m) | Q (ft ² /s) | Q (m ² /s) | Q (ft ² /s) | Q (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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge (upper/lower) | | Computed discharge (combined) | |
|---------------------------|---|------------|-------------|------------|-------------|------------|----------------|------|-------------------------------------|---------------------|----------------------------------|---------------------|
| | Left | | Middle | | Right | | D | | Q | | Q | |
| | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | V (ft/s) | V (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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth D (ft) | Computed discharge (upper/lower) | | Computed discharge (combined) | | |
|-------------------------|---|-------|-------------|-------|-------------|-------|--------------------------------|--|---------------------|-------------------------------------|---------------------|------|
| | Left | | Middle | | Right | | | Q | | Q | | |
| | V (ft/s) | (m/s) | V (ft/s) | (m/s) | V (ft/s) | (m/s) | | (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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge (upper/lower) | | Computed discharge (combined) | |
|-------------------------|---|-------|-------------|-------|-------------|-------|-------------------|------|--|---------------------|-------------------------------------|---------------------|
| | Left | | Middle | | Right | | | | Q | | Q | |
| | V (ft/s) | (m/s) | V (ft/s) | (m/s) | V (ft/s) | (m/s) | D (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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth D (ft) (m) | Computed discharge (upper/lower) Q (ft ² /s) (m ² /s) | | Computed discharge (combined) Q (ft ² /s) (m ² /s) | | |
|---------------------|---|-------|-------------|-------|-------------|-------|------------------------------------|---|-------|--|-------|------|
| | Left | | Middle | | Right | | | | | | | |
| | V (ft/s) | (m/s) | V (ft/s) | (m/s) | V (ft/s) | (m/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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge (upper/lower) | | Computed discharge (combined) | |
|---------------------------|---|------------|-------------|------------|-------------|------------|-------------------|------|--|---------------------|-------------------------------------|---------------------|
| | Left | | Middle | | Right | | D | | Q | | Q | |
| | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | (ft) | (m) | (ft ² /s) | (m ² /s) | (ft ² /s) | (m ² /s) |
| Splitter Plate (Upper) | 7.20 | 2.19 | 7.70 | 2.35 | 6.70 | 2.04 | 0.15 | 0.04 | 3.10 | 0.09 | 3.10 | 0.09 |
| 11 Upper | | | | | | | | | | | 21.49 | 0.61 |
| 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.

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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge | | Computed discharge | |
|-------------------------|---|-------|-------------|-------|-------------|-------|-------------------|------|---------------------------|---------------------|---------------------------|---------------------|
| | Left | | Middle | | Right | | | | (upper/lower) | | (combined) | |
| | 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 | 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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge (upper/lower) | | Computed discharge (combined) | |
|-------------------------|---|-------|-------------|-------|-------------|-------|----------------|------|-------------------------------------|---------------------|----------------------------------|---------------------|
| | Left | | Middle | | Right | | D | | Q | | Q | |
| | V (ft/s) | (m/s) | V (ft/s) | (m/s) | V (ft/s) | (m/s) | (ft) | (m) | (ft ² /s) | (m ² /s) | (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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge | | Computed discharge | |
|---------------------|---|-------|-------------|-------|-------------|-------|-------------------|------|---------------------------|---------------------|---------------------------|---------------------|
| | Left | | Middle | | Right | | | | (upper/lower) | | (combined) | |
| | 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) |
| 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.

| Station | Measured velocity (looking downstream) | | | | | | Measured depth | | Computed discharge | | Computed discharge | |
|---------------------------|---|------------|-------------|------------|-------------|------------|-------------------|----------|---------------------------|--------------------------|---------------------------|--------------------------|
| | Left | | Middle | | Right | | | | (upper/lower) | | (combined) | |
| | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | V (ft/s) | V (m/s) | D (ft) | D (m) | Q (ft ² /s) | Q (m ² /s) | Q (ft ² /s) | Q (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 (Upper) | | | | | | | | | | | 1.07 | 0.03 |
| | 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.

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 | | Computed discharge | |
|---------------------------|---|-------|-------------|-------|-------------|-------|-------------------|------|---------------------------|---------------------|---------------------------|---------------------|
| | Left | | Middle | | Right | | | | (upper/lower) | | (combined) | |
| | 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 | | Computed discharge | |
|---------------------------|---|-------|-------------|-------|-------------|-------|-------------------|------|---------------------------|---------------------|---------------------------|---------------------|
| | Left | | Middle | | Right | | | | (upper/lower) | | (combined) | |
| | 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 | | Computed discharge | |
|---------------------------|---|-------|-------------|-------|-------------|-------|-------------------|------|---------------------------|---------------------|---------------------------|---------------------|
| | Left | | Middle | | Right | | | | (upper/lower) | | (combined) | |
| | 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) |
| 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) | | | | | | Measured depth | | Computed discharge | | Computed discharge | |
|---------------------------|---|-------|-------------|-------|-------------|-------|-------------------|------|---------------------------|---------------------|---------------------------|---------------------|
| | Left | | Middle | | Right | | | | (upper/lower) | | (combined) | |
| | 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) |
| 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 (Upper) | | | | | | | | | | | 2.99 | 0.08 |
| | 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.

| Source | Subyearling | | Yearling | | Steelhead | | Coho | | Sockeye | |
|--|-------------|------|----------|------|-----------|------|------|------|---------|------|
| | <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 | | Yearling Chinook | | Steelhead | | Coho | | Sockeye | |
|--|---------------------|------|------------------|------|-----------|------|------|------|---------|------|
| | <180 | ≥180 | <180 | ≥180 | <180 | ≥180 | <180 | ≥180 | <180 | ≥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 | |
| Separator: | separated | | | | | | | | 1 | |
| | 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 | |
| | non-separated | | 12 | | 2 | | 3 | | 34 | |
| 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 | |
| Separator: | separated | | 4 | | | | | | | |
| | non-separated | | | | | | 1 | | | |

Appendix Table B1. Continued.

| Source | Subyearling | | Yearling | | Steelhead | | Coho | | Sockeye | |
|--|-------------|------|----------|------|-----------|------|------|------|---------|------|
| | <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 | | | | | 1 |
| 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 | | Yearling | | Steelhead | | Coho | | Sockeye | |
|---|---------------|------|----------|------|-----------|------|------|------|---------|------|
| | <180 | ≥180 | <180 | ≥180 | <180 | ≥180 | <180 | ≥180 | <180 | ≥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.

| Source | Subyearling Chinook | | Yearling Chinook | | Steelhead | | Coho | | Sockeye | |
|---|------------------------|------|---------------------|------|-----------|------|------|------|---------|------|
| | <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.

| Source | Subyearling | | Yearling | | Steelhead | | Coho | | Sockeye | |
|---|---------------|------|----------|------|-----------|------|------|------|---------|------|
| | <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.

| Source | Subyearling Chinook | | Yearling Chinook | | Steelhead | | Coho | | Sockeye | |
|---|------------------------|------|---------------------|------|-----------|------|------|------|---------|------|
| | <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 | | Yearling Chinook | | Steelhead | | Coho | | Sockeye | |
|---|------------------------|------|---------------------|------|-----------|------|------|------|---------|------|
| | <180 | ≥180 | <180 | ≥180 | <180 | ≥180 | <180 | ≥180 | <180 | ≥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 | <i>Ictalurus punctatus</i> | 62 |
| crappie | <i>Proxomus</i> spp. | 31 |
| sucker | <i>Catostomus</i> spp. | 17 |
| lamprey | <i>Entosphenus tridentata</i> | 12 |
| mountain whitefish | <i>Prosopium williamsoni</i> | 10 |
| yellow perch | <i>Perca flavescens</i> | 4 |
| sand roller | <i>Columbia transmontanus</i> | 4 |
| peamouth | <i>Mylocheilus caurinus</i> | 1 |
| redside shiner | <i>Richardsonius balteatus</i> | 1 |
| white sturgeon | <i>Acipenser transmontanus</i> | 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 \geq 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 \geq 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 ($\alpha = 0.05$) 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 \geq 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 \geq 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 ($\alpha = 0.05$) among treatment factors.

| Group | Treatment conditions | Calculated statistic | | |
|--------------------------------------|------------------------------------|----------------------|----|---------|
| | | 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 \geq 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 \geq 180 mm | date | 19.46 | 1 | 0.000 * |
| | wave height, separation-bar style | 0.131 | 1 | 0.725 |
| | water velocity | 0.000.361 | | 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.

| Source | Subyearling Chinook | | Yearling Chinook | | Steelhead | | Coho | | Sockeye | |
|--|---------------------|------|------------------|------|-----------|------|------|------|---------|------|
| | <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 |
| 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.

| Source | Subyearling Chinook <180≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <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 |
| non-separated | | 24 | 17 | 34 | 2 |
| Separator: separated | | | | | |
| non-separated | | | | | |

Appendix Table B6. Continued.

| Source | Subyearling Chinook | Yearling Chinook | Steelhead | | Coho | | Sockeye | |
|---|------------------------|---------------------|-----------|----------|----------|----------|----------|----------|
| | <180≥180 | <180≥180 | <180≥180 | <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, 27 June | | | | | | | | |
| 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≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <180≥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 |
| 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 |
| 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 |
| 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.

| Source | Subyearling Chinook | Yearling Chinook | Steelhead | | Coho | | Sockeye |
|---|------------------------|---------------------|-----------|----------|----------|----------|----------|
| | <180≥180 | <180≥180 | <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.

| Source | Subyearling Chinook | Yearling Chinook | | Steelhead | | Coho | | Sockeye |
|--|------------------------|---------------------|------|-----------|------|------|------|----------|
| | <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 | Yearling Chinook | Steelhead | | Coho | | Sockeye |
|--|------------------------|---------------------|-----------|----------|----------|----------|----------|
| | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥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 | Yearling Chinook | Steelhead | | Coho | | Sockeye |
|---|------------------------|---------------------|-----------|----------|----------|----------|----------|
| | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥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 |
| 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.

| Source | Subyearling Chinook | Yearling Chinook | | Steelhead | Coho | | Sockeye |
|---|------------------------|---------------------|------|-----------|------|------|----------|
| | <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.

| Source | Subyearling Chinook | | Yearling Chinook | | Steelhead | | Coho | | Sockeye | | |
|---|---------------------|------|------------------|------|-----------|------|------|------|---------|------|----|
| | <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 | Yearling Chinook | Steelhead | | Coho | | Sockeye |
|---|------------------------|---------------------|-----------|----------|----------|----------|----------|
| | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥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 | Yearling Chinook | Steelhead | Coho | Sockeye |
|---|------------------------|---------------------|-----------|----------|----------|
| | <180≥180 | <180≥180 | <180≥180 | <180≥180 | <180≥180 |
| Replicate 15, Treatment 1, 25 June | | | | | |
| Bar spacing 17 mm, diel | | | | | |
| Tanks: separated | 3912 | 107 | 2 | 20 | 1 |
| non-separated | 728 | 21 | 2 | 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 | | |
| 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.

| Source | Subyearling Chinook <180≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <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.

| Source | Subyearling Chinook | Yearling Chinook | Steelhead | | Coho | Sockeye | |
|--|------------------------|---------------------|-----------|----------|----------|----------|-----|
| | <180≥180 | <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.

| Source | Subyearling Chinook | Yearling Chinook | Steelhead | | Coho | | Sockeye |
|---|------------------------|---------------------|-----------|----------|----------|----------|----------|
| | <180≥180 | <180≥180 | <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≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <180≥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 spacing 17 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 <180≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <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.

| Source | Subyearling Chinook <180≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <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≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <180≥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≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <180≥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.

| Source | Subyearling Chinook | Yearling Chinook | Steelhead | | Coho | | Sockeye |
|--|------------------------|---------------------|-----------|----------|----------|----------|----------|
| | <180≥180 | <180≥180 | <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.

| Source | Subyearling Chinook | Yearling Chinook | Steelhead | | Coho | | Sockeye |
|---|------------------------|---------------------|-----------|----------|----------|----------|----------|
| | <180≥180 | <180≥180 | <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 <180≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <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.

| Source | Subyearling Chinook | Yearling Chinook | Steelhead | | Coho | Sockeye | |
|---|------------------------|---------------------|-----------|----------|----------|----------|----|
| | <180≥180 | <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.

| Source | Subyearling Chinook | Yearling Chinook | Steelhead | | Coho | | Sockeye | |
|--|------------------------|---------------------|-----------|----------|----------|----------|----------|-----|
| | <180≥180 | <180≥180 | <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 duration | | | | | | | | |
| 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 | <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 |
| 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.

| Source | Subyearling Chinook <180≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <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.

| Source | Subyearling Chinook <180≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <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.

| Source | Subyearling Chinook <180≥180 | Yearling Chinook <180≥180 | Steelhead <180≥180 | Coho <180≥180 | Sockeye <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 | <i>Alosa sapidissima</i> | 28 |
| mountain whitefish | <i>Prosopium williamsoni</i> | 26 |
| lamprey | <i>Entosphenus tridentata</i> | 10 |
| yellow perch | <i>Perca flavescens</i> | 9 |
| sucker | <i>Catostomus</i> spp. | 7 |
| peamouth | <i>Mylocheilus caurinus</i> | 4 |
| channel catfish | <i>Ictalurus punctatus</i> | 1 |
| chiselmouth | <i>Acrochelius alutaceus</i> | 1 |
| crappie | <i>Proxomus</i> 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 ($\alpha = 0.05$) among treatment factors.

| Group | Treatment conditions | Calculated statistic | | | |
|---|-------------------------|----------------------|----|-------|---|
| | | 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 ($\alpha = 0.05$) 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 ($\alpha = 0.05$) 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.

| Group | Treatment conditions | Calculated statistic | | | |
|-----------------------------------|----------------------|----------------------|----|-------|---|
| | | 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 |