U.S. Army Corps of Engineers
Portland District

Hydroacoustic Evaluation of Downstream Fish Passage at The Dalles Dam in 2000

FINAL REPORT

December 2001

Prepared by
Battelle's Pacific Northwest Division
P.O. Box 999
Richland, Washington 99352

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Executive Summary

We collected fixed-location hydroacoustic data on juvenile salmonid passage at The Dalles Dam in 2000. Our objectives were to estimate the proportion of smolts passing through the spillway, powerhouse, and sluiceway. Passage estimates were also calculated per proportion of discharge (effectiveness). The results were described in terms of day/night and spring/summer for the May 13 to July 6 study period.

The acoustic screen model formed the basis for fish passage estimation. Single-beam transducers were deployed across the project, and an additional split-beam transducer sampled at each type of deployment (turbine, spillway, and sluice). The split-beam data were used for both detectability modeling and for confirmation of fish entrainment through the sampled locations.

Though the deployment and methods were similar to those used in the 1999 study, the sluice was neither as efficient nor as effective at passing fish in 2000. Although the sluice passed fewer fish, fish passage efficiency (FPE) was still high compared with previous years. This is because more fish passed via the spillway this year, as compared to previous years.

The ice and trash sluiceway continues to be a very effective passage route for smolts, i.e., the sluiceway passes more fish per unit of water than any other route. However, the total number of fish, as represented by the proportion of the run (overall only 7% of the fish that approached the project passed via this route), is insufficient as a stand alone smolt protection measure. The deployment of the J-occlusions, anticipated for testing in 2001, will attempt to increase that number.

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1.0 Introduction

1.1 Background

The U.S. Army Corps of Engineers (Corps) is committed to increasing survival rates for fish passing its projects on the Columbia River. At The Dalles Dam, strategy has entailed the use of spill, the design and prototype testing of a turbine intake extended length submerged bar screen (ESBS) juvenile bypass system, and intake occlusions related to surface collection at the sluiceway. The decision to construct the JBS has been delayed until the potential of surface collection and other options have been evaluated. In the interim, spill is the primary means of salmonid smolt protection at The Dalles Dam.

Historically, to achieve the fish passage efficiency (FPE) goal of 80%, it was assumed necessary to pass 64 percent of total river discharge through the spillway. Although this high level of flow through the spillway efficiently passes migrant juvenile salmonids, it also causes severe turbulence below the spillway and increases the flow over the bedrock shelf on the Oregon side of the tailrace. Juvenile salmon passing through this area are potentially subject to high levels of mortality through predation (Dawley et al. 1998).

Past spillway operations have also included two different spill patterns, the daytime adult pattern, used to provide attraction flows to the fish ladders for upstream migrating adult salmon, and the nighttime juvenile pattern, used to pass migrant juvenile salmonids through the north end of the spillway. The juvenile pattern is intended to increase smolt survival by passing them away from the bedrock shelf, thereby minimizing predation. For the testing in 2000, the Corps in conjunction with regional fisheries managers, discontinued both the 64% spill level and the adult spill pattern. Only one spill level (40%) and the juvenile spill pattern were used.

Attempts have also been made to increase the proportion of juvenile salmon passing through the sluiceway using intake occlusion plates. Preliminary surface collection and bypass studies began at The Dalles Dam in 1995, with the ice and trash sluiceway as an integral component of the system (Nagy and Shutters 1995). In an attempt to deepen the 'zone of influence' of the sluiceway, the upper 22 ft (to elevation 120 ft mean sea level) of the intakes at Main Units 1 and 2 were occluded.

In 1996, more permanent occlusion plates were installed. The number of turbine units that were occluded was increased to include Main Units 1 through 6, and the two Fish Units. The turbine intakes were also occluded to a deeper depth (100.4 ft above mean sea level) in an attempt to further increase fish passage through the sluiceway. Field tests of the existing occlusion plates using fixed-location hydroacoustics were conducted in 1996 (BioSonics 1997). However, the results of the 1996 study were compromised by an unanticipated flow regime created behind the occluded trashracks, resulting in a bias in monitoring during the test condition. The bias caused overestimation of turbine fish passage when the occlusion plates were deployed.

The occlusion plates are being greatly modified in an attempt to increase their hydraulic effectiveness, and Battelle will test the new design in 2001. The modified occlusion plates will require new sluiceway deployment techniques because the extension piece (called the “J”) being added will preclude the methods used in 1995 and 1996 to monitor fish passage at this location.

1.2 Goal and Objectives

The goal of this study was to collect critical information for the Corps' surface bypass and spill passage programs. Estimates of fish passage through sluice, spill, and turbine routes provide a means to optimize fish passage and survival at this facility. The specific objectives of this study were to:

- estimate the proportion of juvenile salmon passing the dam through each passage route, and in relation to discharge

- estimate run timing between routes during spring and summer

- confirm the assumptions of the acoustic screen model through the incorporation of split-beam data

- test transducer deployments for J-occlusion testing anticipated in 2001.

1.3 Study Site Description

The Dalles Dam, located at Columbia River mile 192, includes a navigation lock, a spillway perpendicular to the main river channel, and a powerhouse parallel to the main river channel with non-overflow dams on each side (Figure 1). The spillway spans 1380 ft and has 23 bays, numbered from the Washington shore. The powerhouse spans 2089 ft and has 22 main units (MU), numbered from the west (downstream) end. Each unit is divided into three intakes, numbered again from west to east. Reference to a specific turbine intake is expressed as the turbine unit and intake number, e.g., 2-3 for the east intake of MU 2 and 1-2 for the center intake of MU 1. Two fish units are located just west of MU 1 and have only two intakes each. An ice and trash sluiceway extends the entire length of the powerhouse. The skimmer gates were opened above each turbine intake of MU 1 and discharged into the sluiceway. Maximum discharge of the ice and trash sluiceway through all three gates of one turbine unit is approximately 4750 cfs with the forebay at elevation 160 ft.

The historical river channel, or thalweg, passed through the non-overflow section at the east end of the powerhouse. In addition, there is relatively deep water in front of the powerhouse and through the center of the spillway (Figure 2). The majority of flow in the reservoir above the dam is through the thalweg. This bulk flow following the bathymetric contours below may have implications for fish passage patterns with the bulk of migrants following the thalweg (Johnson and Dauble 1995). The forebay environment is one factor that makes fish passage patterns unique at each hydroelectric facility.

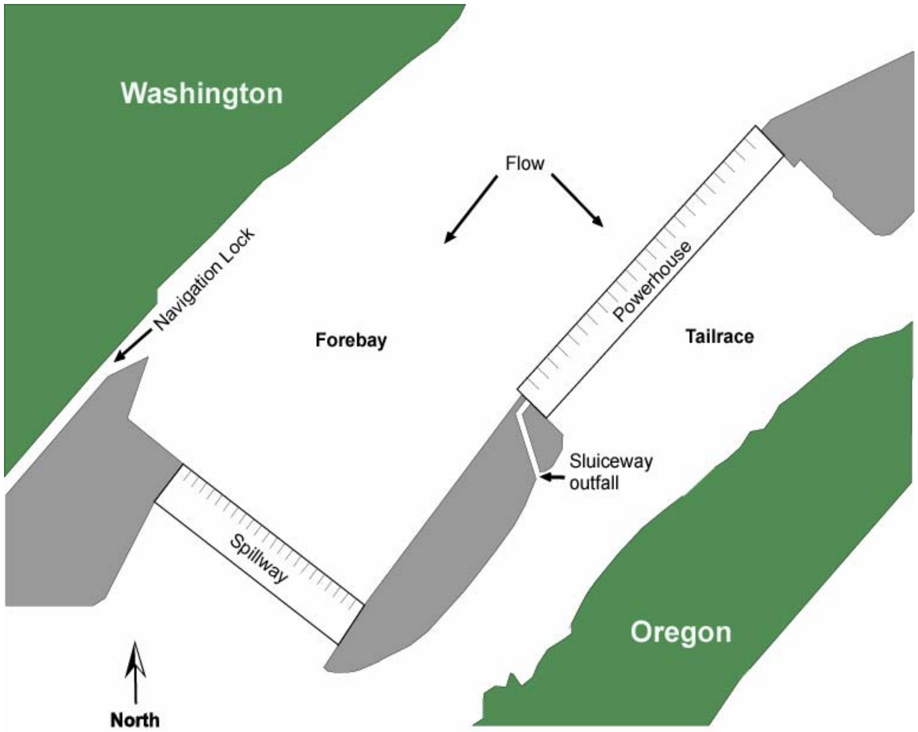


Figure 1. Plan view of The Dalles Dam and shoreline.

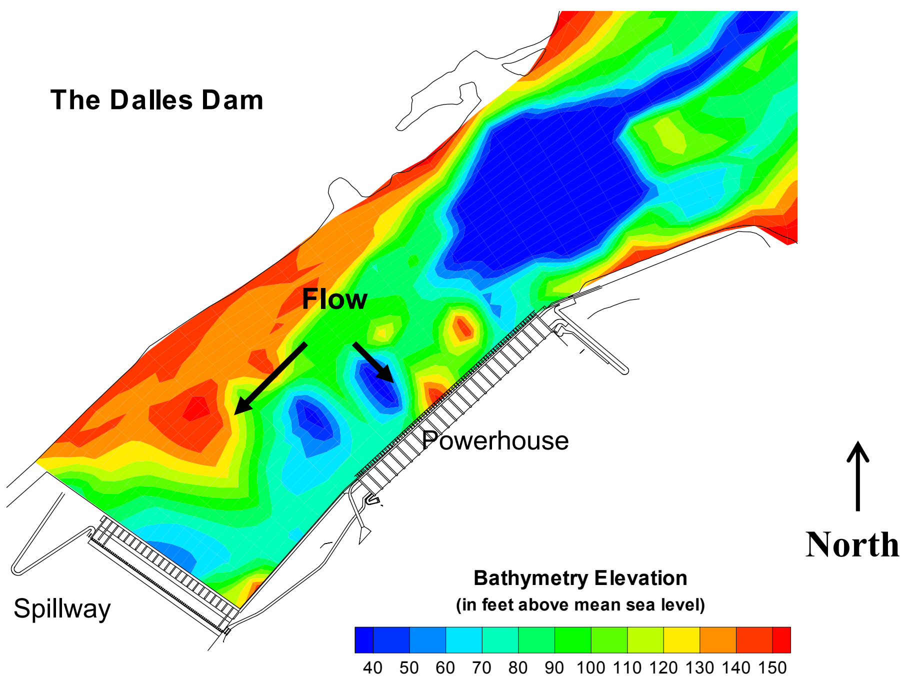


Figure 2. Forebay bathymetry of The Dalles Dam

2.0 Methods

2.1 Study Design and Study Periods

Spill was not manipulated for the purposes of this study, and only the juvenile, or nighttime, spill pattern[1] was used. Fixed-location hydroacoustic techniques were used to sample passage at the spillway, sluiceway, and turbine intakes. Passage estimates for each route, for each hour, were made by expansion of sampling time and volume. Fish passage was monitored 24 hours/day, 7 days/week. Passage through unmonitored routes was estimated by interpolation. Spring data collection occurred from 13 May through 6 June, 2000. Summer data collection occurred from 6 June through 6 July. Nighttime extended from 1900 through 0559 hours.

2.2 Hydroacoustic Systems and Transducer Deployments

A combination of single- and split-beam transducers were deployed to estimate fish passage rates and distributions. This approach uses the acoustic screen model to determine passage rates. Split-beam transducers provided data to determine weighting factors, assess assumptions of the model, and determine the magnitude of any biases. Single and split-beam transducers were deployed to sample fish passage at the spillway, ice and trash sluiceway, and turbines. Transducer sampling volumes were strategically aimed to minimize ambiguity in ultimate fish passage routes and the potential for multiple detections.

The single-beam data collection used five BioSonics ES2000™ multiplexed systems. The split-beam data were collected with three BioSonics DT6000™ split-beam systems. All these systems were calibrated scientific echosounders operating at 420 kHz. All the transducers used in this study had circular transducing elements. Single-beam transducers were multiplexed; split-beam transducers were not.

2.2.1 Turbine

Turbine transducers sampled for 2.5 minutes 4 times per hour, or a total of 10 min for every hr. One randomly selected intake within each of the 22 main turbine units (intake 1, 2, or 3) and the two fish turbine units (intakes 1 or 2) were monitored, except units 4 and 14, which were not scheduled to run during the study period. In addition, transducers were deployed in either an upstream (u), middle (m), or downstream (d) position within the intake. The main unit sampling locations were (unit-intake-position): 1-3u, 2-2m, 3-3m, 5-1m, 6-2m, 7-1u, 8-2m, 9-2m, 10-1d, 11-2u, 12-3m, 13-2d, 15-3u, 16-3m, 17-2m, 18-1u, 19-3m, 20-1u, 21-2m, and 22-1u. The fish unit sampling locations (unit-intake-offset) were: 1-2m and 2-1m. In addition, a split-beam transducer was located at MU 5-1m. A plan view of all the powerhouse transducers and their spatial relationship is shown in Figure 3.

[1] The juvenile spill pattern iniates spill at the north side of the spillway, typically bays 1-14.

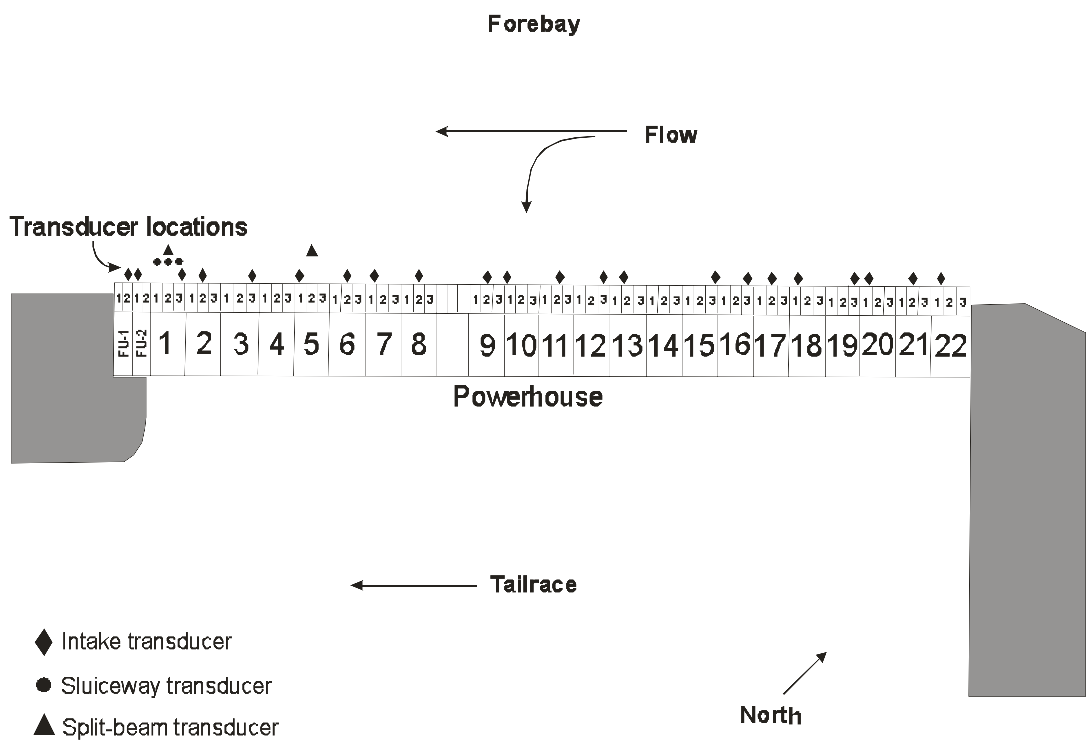


Figure 3. Powerhouse transducer locations at The Dalles Dam in 2000.

We used six-degree single-beam transducers for sampling the powerhouse, and one 6° split-beam was used at one of the powerhouse locations. A trash rack transducer mount was deployed at elevation 75 ft with the transducer aimed upward and about 23° downstream. At this angle, the beam intersects the intake ceiling at a perpendicular angle. Both fish units were monitored with six-degree single-beam transducers from Elevation 75 ft aimed 40° downstream. The pulse repetition rate for all turbine transducers was 15 pings per second (pps) (Figure 4).

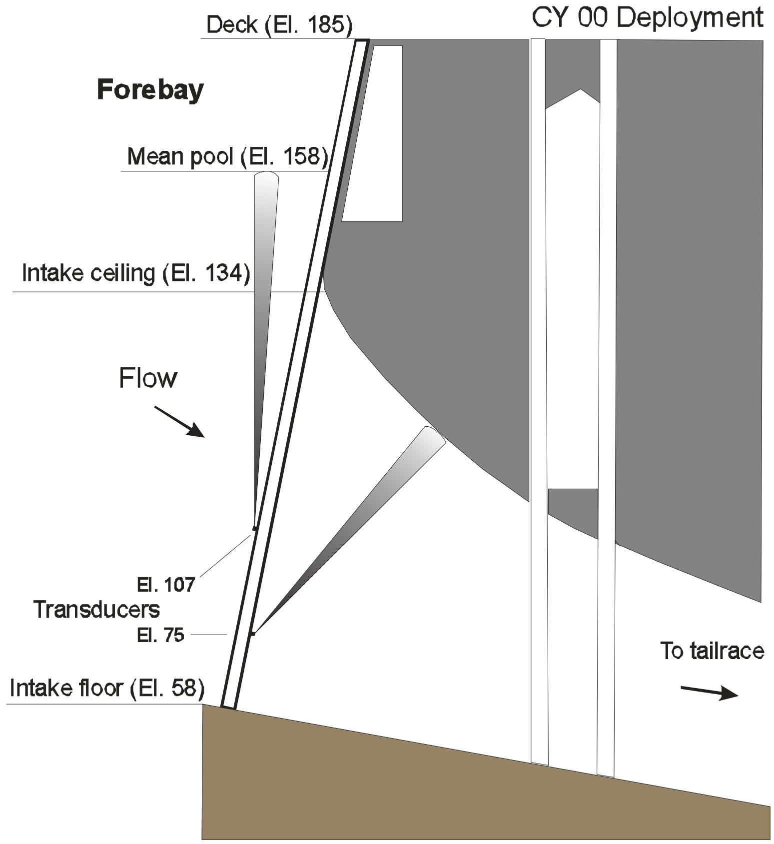


Figure 4. Typical turbine intake and sluiceway transducer deployment at The Dalles Dam, 2000.

2.2.2 Sluiceway

To monitor sluiceway passage, we deployed three 6° single-beam transducers, one below each of the sluice gates of Main Unit 1 at elevation 107 ft. They were aimed upward about 6° downstream (as close to the face of the dam as possible), and were mounted from the trash rack. The pulse repetition rate at the sluiceway was 15 pps (Figure 4). The sluice gate sampling locations (unit-intake) were: 1-1, 1-2, and 1-3. All three transducers were located in the middle of each intake. A 6° split-beam transducer was also located below Gate 1-2, adjacent to the single-beam at that location and with an identical aiming angle. Sluiceway transducers sampled for 2.5 minutes 4 times per hour, or a total of 10 min for every hr.

2.2.3 Spillway

We deployed transducers in 13 of 23 spill bays. We used the spillway pole mounts designed and fabricated in 1999. In addition, each was positioned randomly in either a north (n), middle (m), or south (s) location in an attempt to mitigate for non-uniform horizontal distribution through the spill bays. Spillway sampling locations (bay-position) were: 1n, 3m, 5s, 6m, 7n, 9s, 10m, 12s, 14n, 16m, 17s, 19m, 21n, and 23n. (Transducers were deployed across the spillway before the decision to operate with the juvenile pattern only could be communicated to us.)

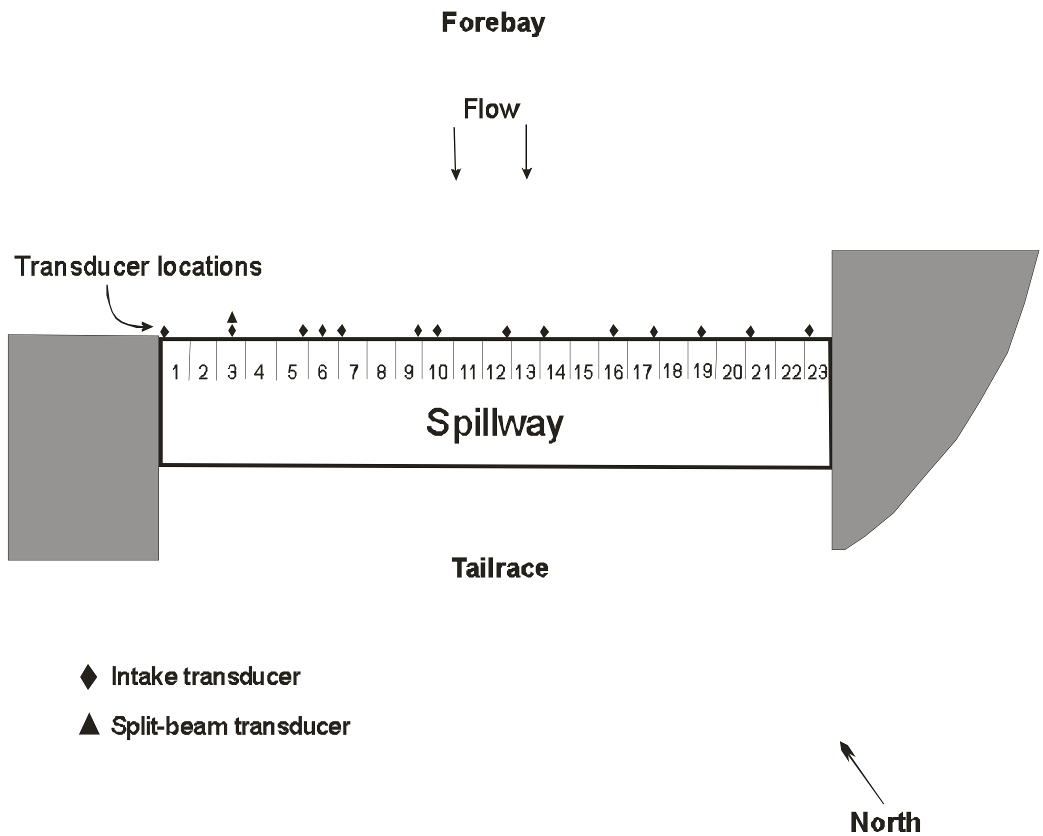


Figure 5. Spillway transducer locations at The Dalles Dam, 2000.

Spillway transducers sampled for 2.5 minutes 3 times per hour, or a total of 7.5 min for every hr. All 14 of the selected spill bays were monitored using 12° nominal single-beam transducers deployed on a pole mount located under the spillway road deck plates (Figure 6). One randomly selected spill bay (Bay 3) was also monitored using a 10° split-beam system. All transducers were mounted on the bottom of a pole (elevation 155 ft) and aimed downward toward the ogee of the spill bay, about 6° downstream. The pulse repetition rate for each transducer at the spillway was 24 pps.

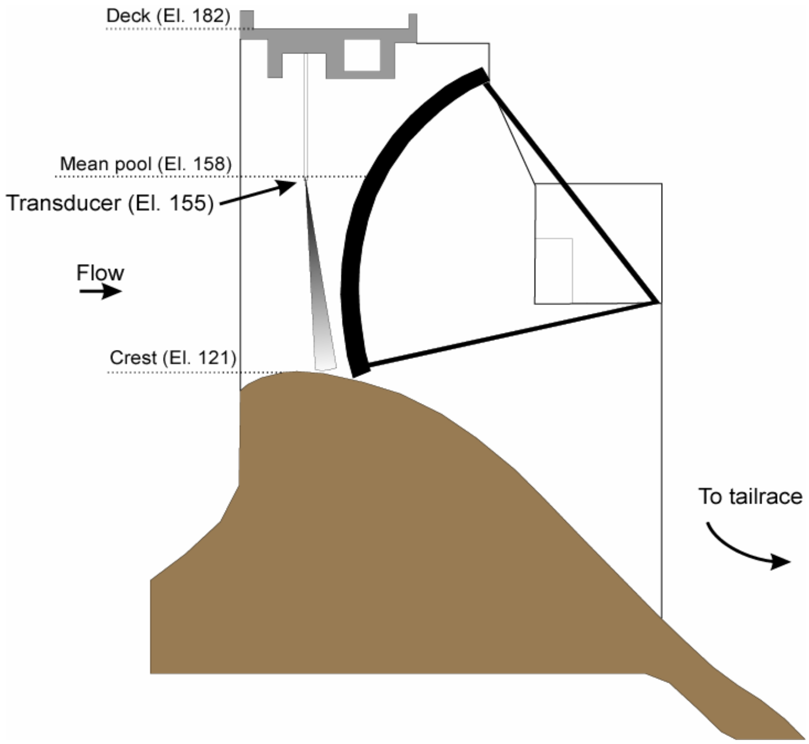


Figure 6. Typical spill bay transducer deployment at The Dalles Dam, 2000.

2.3 Detectability

Passage rate estimates from fish trace data files were produced using the acoustic screen model, an echo counting procedure by which passage rates are estimated from a fixed transducer sample location. The technique relies on detection of echoes from fish that form an identifiable trace, or track, of echoes through space and time. Because track formation is related to the trajectory and speed of fish moving through a transducer's sampling volume, deployment characteristics can greatly alter detectability. The acoustic screen model is limited by noise sources that obscure fish traces, such as electrical, wind-generated turbulence, and reverberation from structures. Johnson (2000) provides a description of the acoustic screen model and an assessment of its assumptions. Some of the critical parameters in the acoustic screen model are the effective beam angle in the echo counting process and the "number of echoes" criterion in the trace formation process.

2.3.1 Fish Velocities and Target Strengths

Range and spill gate opening were the most significant terms in an ANOVA of mean fish velocities at the spillway, so detectability was computed for each meter range and spill gate opening separately. Tracks identified over a range of spill gate opening levels allowed us to characterize differences in detectability among spill gate openings using the split-beam data (Figure 7). A multiple regression was fit to the data by spill opening and range. Detectability computations used the estimated fish velocity for each range and spill gate opening. At the powerhouse, operations were relatively constant, and fewer tracks were identified. The number of fish tracks identified in split-beam data at the sampled turbine were not sufficient to differentiate velocities among diel periods, seasons, or by turbine operations. Therefore, detectability at the intakes was treated as being constant through time for each meter range. Sluice operations were also relatively constant, but there were sufficient fish tracks identified in the split-beam data to compute detectability separately for spring/summer and day/night and each meter range. For turbine and sluice detectability modeling, average velocities were used within each period.

At the spillway, velocity was computed as:

$$V = 0.385077 - 0.09434 * G + 0.019728 * G^2 - 0.10589 * R + 0.030948 * R^2$$

where V = velocity in meters per second
G = spill gate opening in stops
R = range in meters.

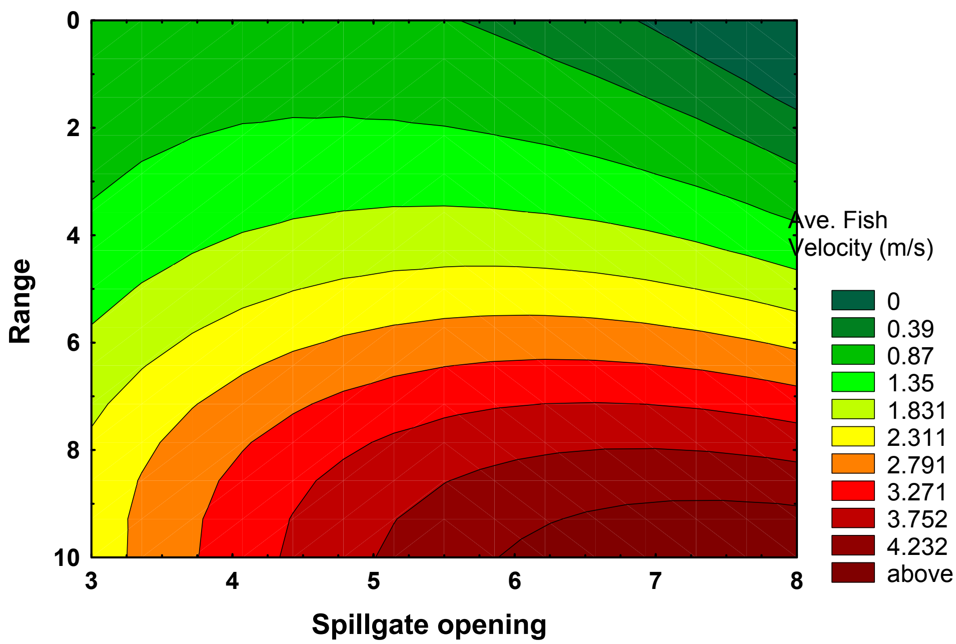


Figure 7. Effect of spill gate opening on fish velocity by range. These contours are based on the average regressed fish velocity as measured by the split-beam transducer at spill bay 2 in m/s. The curvature at short ranges is due to low sample sizes within those range bins.

Mean target strengths were determined for each deployment type, by range, for fish tracks identified in the split-beam data (Table 1). Mean target strength was a direct output of the split-beam data, as described in Appendix A. At the spillway, target strength was computed as a function of spillgate opening and range to be consistent with the estimation of velocity. Sluice data were subdivided into day/night and spring/summer periods and by range to be consistent with analyses of mean velocity. Turbine data were not subdivided due to insufficient samples at any given range. When sample sizes were zero, detectability was not computed. The effect is to set detectability to zero for a range where no fish were sampled by the split beams.

At the spillway, velocity was computed as:

$$TS = -35.6308 - 0.04949 * G + 0.01804 * G^2 - 2.33506 * R + 0.224493 * R^2$$

where TS = target strength in decibels
G = spill gate opening in stops
R = range in meters.

Table 1. Mean target strength (dB) and velocity (m/s) by range for each deployment type and day/night or spring/summer period.

	Range (m)	Turbine TS	Turbine Velocity	Spring Sluice TS	Spring Sluice Velocity	Summer Sluice TS	Summer Sluice Velocity
Day	1	-39.9	0.35	-35.73	0.10	-37.93	0.12
	2	-34.5	0.17	-36.90	0.16	-39.11	0.15
	3	-40.4	0.25	-37.58	0.19	-39.78	0.15
	4	-47.20	0.36	-38.35	0.18	-40.44	0.15
	5	-45.93	0.25	-37.81	0.19	-40.17	0.17
	6	-42.12	0.42	-37.41	0.20	-39.91	0.17
	7	-39.79	1.11	-37.97	0.20	-39.82	0.19
	8	-39.36	0.41	-37.43	0.22	-39.55	0.19
	9	-37.02	0.60	-37.30	0.26	-39.77	0.24
	10	-36.49	0.94	-37.15	0.27	-38.64	0.29
	11	-35.96	0.53	-37.08	0.33	-38.94	0.34
	12	-39.98	0.85	-37.26	0.42	-38.62	0.41
	13	-41.45	0.79	-36.04	0.56	-37.19	0.54
	14	-42.54	1.07	-35.04	0.65	-35.92	0.64
Night	1			-34.74	0.14	-28.96	0.17
	2			-34.60	0.28	-35.44	0.32
	3			-35.35	0.35	-38.15	0.31
	4			-35.65	0.31	-39.43	0.25
	5			-36.13	0.26	-38.99	0.23
	6			-34.42	0.23	-37.11	0.22
	7			-32.56	0.23	-36.72	0.23
	8			-31.90	0.22	-36.53	0.20
	9			-32.32	0.26	-37.64	0.25
	10			-34.40	0.30	-37.83	0.28
	11			-36.61	0.39	-38.71	0.36
	12			-37.20	0.51	-38.52	0.42
	13			-36.28	0.65	-37.76	0.57
	14			-35.13	0.74	-36.99	0.66

TS = target strength

2.3.2 Effective Beam Width

Mean or estimated velocity and target strength by range were combined with other deployment parameters such as ping rate, minimum number of echoes, beam width (measured at calibration), aiming angle, trajectory by range, and target strength threshold in the detectability model. Figure 8 illustrates the estimated effective beam widths for the turbine intake deployments. For most ranges, detectability was equal to, or greater than, the nominal beam width of 6°. Figure 9 illustrates the estimated effective beam widths for the spill deployments. The high ping rate at the spill deployments (24 pps) helped maintain high estimated detectability.

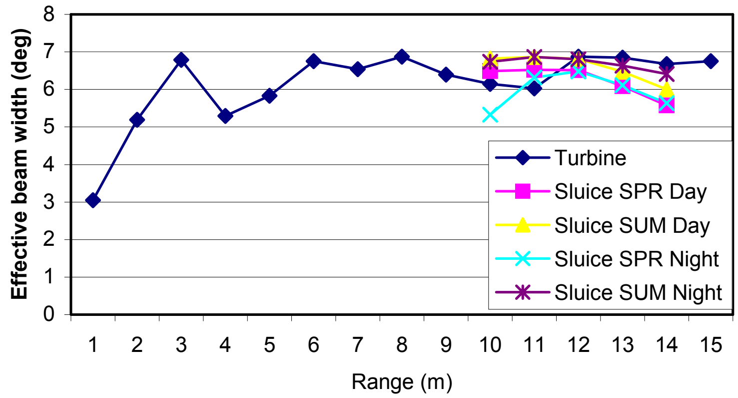


Figure 8. Estimated effective beam widths for the sluice and turbine units. Sluiceway beam widths are subdivided into day/night and spring/summer.

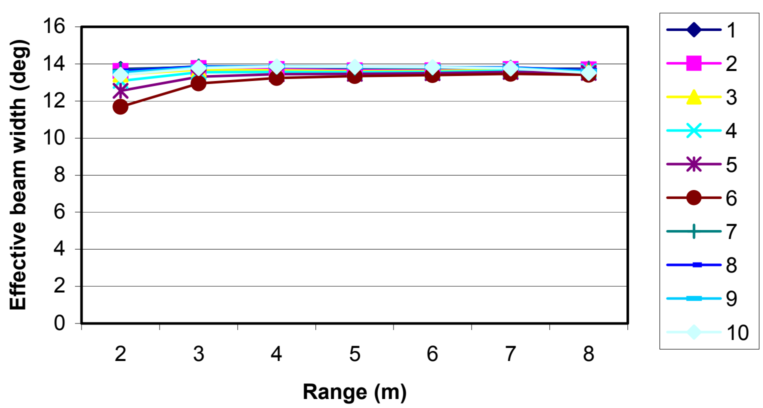


Figure 9. Estimated effective beam widths for the spillway by range for gate opening (measured in stops).

Single-beam detectability was computed using velocity and target strength information obtained from the split-beam transducers. Fish velocities in three-dimensional space were then converted to velocities perpendicular to the beam for each 1-m range bin from the transducer. The mean velocity and target strength were used to compute the effective beam width for each 1-m range.

To determine effective beam widths, we used the combined detectability/Raleigh method. The detectability approach uses the effective beam angle output from a detectability model (D_ANGLE). The Raleigh approach uses a statistical model for backscattering cross-section to determine effective beam angle relative to the half power angle as a function of the backscattering and the system threshold. Backscattering is expected to be Raleigh distributed, as the ratio of fish length to wavelength would be about 35 for fish lengths of 125 mm and a 420 kHz acoustic system. Ehrenberg (circa 1985) showed the relationship between the 1) ratio of the effective beam angle to half-power angle (RATIO), and 2) difference in dB of mean back-scattering cross-section and system threshold. Finally, the Detectability/Raleigh Combined approach incorporates detectability with the Raleigh characteristics of the target strength distribution. Effective beam angle was the product of D_ANGLE and RATIO defined above. More details of this method are described in Johnson (2000).

2.4 Data Processing

2.4.1 Data Entry

All the single-beam data were manually tracked. In this process, technicians manually inspect echograms for fish traces. In-season estimates of both inter- and intra-tracker precision were made as part of the track identification quality assurance effort (see Appendix B for details). All split-beam data were processed with Vtrack™, an automated tracker, at BioSonics in Seattle, Washington. Because of the redundant single and split deployments for this study, the split-beam data were not used directly for fish passage estimation, but only for detectability modeling for single beams. This allowed us to relax the periods for tracking fish to those times when noise levels were relatively low. This procedure was important because split-beam data are more susceptible to acoustic noise than are single-beam data. The result is that the autotracker produced more reliable data. The data analysis process for split-beam data is described in greater detail in Appendix A.

In addition, special care was taken to deal with acoustic noise in the split-beam analysis at the track identification stage, by selecting only fish unaffected by noise. The inclusion of bubbles in a fish track, for instance, would have added false phase angle data. False phase angle data would reduce the precision of estimates of fish location. Given the relatively few samples per fish (a four-ping minimum), this low precision could lead to inaccurate representation of fish velocities and trajectories. These kinematics-based measures form the basis of the fish track analysis, which in turn serves as input for the detectability model. The split-beam trajectory data were also used to verify the movement of fish through a particular route. This ensured that fish counted by the single-beams were indeed committed to passing the dam, i.e., they were not counted multiple times.

2.4.2 Track Filtering

Track selection criteria were applied (Table 2), eliminating some selected tracks. Table 2 details the track selection criteria for all analyses. Some criteria were applied analytically after track identification because they are difficult to evaluate visually.

Table 2. Track selection criteria.

Track selection criteria	Used in manual track ID	Main Units and Fish Units	Sluice	Spill
Minimum number of echoes	Y	4	4	4
Maximum number of echoes	Y	30	60	60
Slope	N	-	Upward (from crest of sluice to 3m below crest)	Downward (away from transducer)
Direction of movement	N	-	Within 90º of downstream toward opening	Within 90º of downstream toward spill gate
Range	N	≥1m	≥10m	≥2.3
Linearity	Y	>.5	>.5	>.5
Avg. Narrow Pulse width	N	<0.47	<0.47	<0.47

Y = yes; N = no

At the spill bays and turbine intakes, the greatest number of fish tracks eliminated were due to a failure to meet the direction of movement criteria (Table 3). The eliminated tracks did not indicate the fish was moving toward the tainter gate opening or the intake and, therefore, committed to passing. These criteria could not be implemented on a trackwise bases for single-beam data, so a correction factor was applied to the expanded fish counts. At the sluiceway, the greatest numbers of fish were eliminated due to range limits. The eliminated fish were greater than 3 m away from the entrance of the sluiceway when they passed through the beam. In other words, the sample volume of those beams included areas beyond where it is likely that fish would pass via the sluice.

Table 3. Percentage of fish tracks eliminated by track selection criteria.

Track selection criteria	Percentage eliminated (Spill)	Percentage eliminated (Sluice)	Percentage eliminated (Intake)
Minimum number of echoes	<1	<1	<1
Maximum number of echoes	4	9	17
Slope	18	10	0
Direction of movement	33	-	29
Range	5	40	0
Linearity	2	1	3
Avg. Narrow Pulse width	0	0	10

2.5 Data Analysis

2.5.1 Passage Metrics

Fish passage efficiency describes the proportion of fish that passed through non-turbine routes. Fish passage effectiveness (FPS) describes FPE in terms of the proportion of water that passed through those non-turbine routes. Spill efficiency (SPY) describes the proportion of fish that passed through the spillway. Spill effectiveness (SPS) describes SPY in terms of the proportion of water that passed through the spillway. Sluice efficiency (SLY) and effectiveness (SLS) are similar metrics for passage through the ice and trash sluiceway. The definitions below are consistent with those reported in Ploskey et al. (2000) and other studies in the region. Spatial and temporal expansions for each metric follow the methods developed by Skalski (2000).

$$FPE \equiv \frac{X_{spill} + X_{sluice}}{X_{spill} + X_{sluice} + X_{turbine}} \tag{1}$$

$$FPS \equiv \frac{FPE}{\left(Q_{spill} + Q_{sluice}\right) / \left(Q_{spill} + Q_{sluice} + Q_{turbine}\right)} \tag{2}$$

$$SPY \equiv \frac{X_{spill}}{X_{spill} + X_{sluice} + X_{turbine}} \tag{3}$$

$$SPS \equiv \frac{SPY}{Q_{spill} / \left(Q_{spill} + Q_{sluice} + Q_{turbine}\right)} \tag{4}$$

$$SLY_{project} \equiv \frac{X_{sluice}}{X_{spill} + X_{sluice} + X_{turbine}} \tag{5}$$

$$SLS_{project} \equiv \frac{SLY_{project}}{Q_{sluice} / \left(Q_{spill} + Q_{sluice} + Q_{turbine}\right)} \tag{6}$$

2.5.2 Statistical Methods

Metrics were compared by a two-tailed t-test ($\propto$=0.05), assuming independent samples. Each hourly mean was considered an independent observation. Metrics were compared among deployment types (turbine, spill, or sluice) for day versus night or spring versus summer. 95% confidence intervals are plotted on figures.

3.0 Results

3.1 River Discharge and Dam Operations

Dam operations were obtained from the powerhouse operator every hour on the half-hour by telephone, 24 hours/day, 7 days/week. Daily forebay elevation and temperature data were obtained from the Data Access Real Time web site (http://www.cqs.washington.edu/dart). Total project discharge ranged from 135 kcfs to 303 kcfs during the study period. Mean total project discharge was 234 kcfs and 192 kcfs during the spring and summer periods, respectively. Spill occurred 24 hours/day throughout the study, ranging from 28 kcfs to 109 kcfs. Only the juvenile, or nighttime, spill pattern was used. Sluiceway operations did not change, and flow remained constant at approximately 4500 cfs (minor fluctuations with forebay elevation). River water temperature steadily increased from 12.5 to approximately 18.5 °C (Figure 10).

An hourly view of dam operations (Figure 11) showed transient fluctuations over the season; however, the average hourly percent spill showed no bias in the time of day for changes in operations (Figure 12). About two-thirds of the discharge was through the turbine units and one-third through the spillway, with the sluiceway contributing only about 2% of the total project discharge. The sluice contributed a slightly higher proportion of the total discharge in summer (Figure 13).

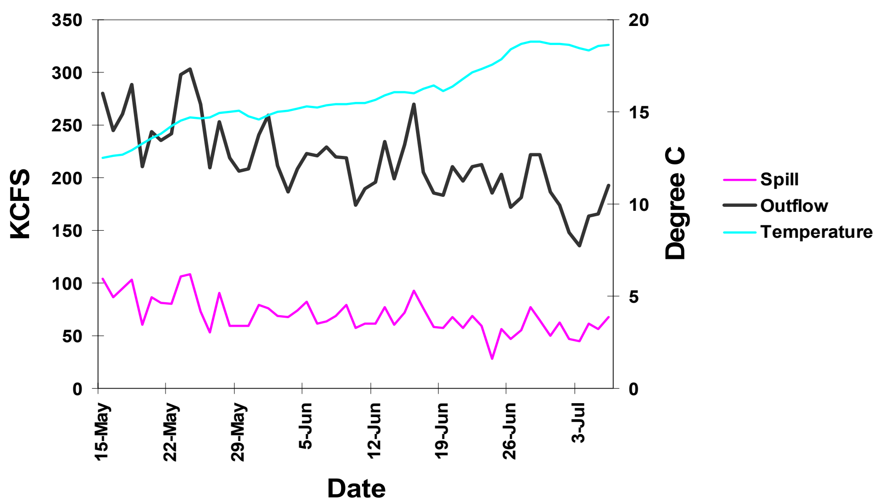


Figure 10. Daily average project discharge, spill, and temperature at The Dalles Dam, 2000.

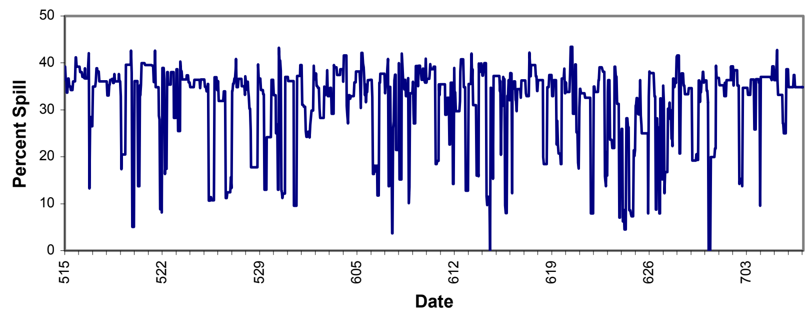


Figure 11. Percent spill by hour for the entire study period at The Dalles Dam, 2000.

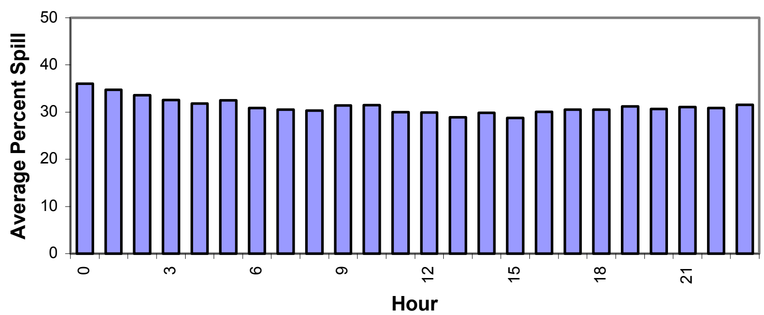


Figure 12. Average percent spill by hour, combined for spring and summer study periods, at The Dalles Dam, 2000.

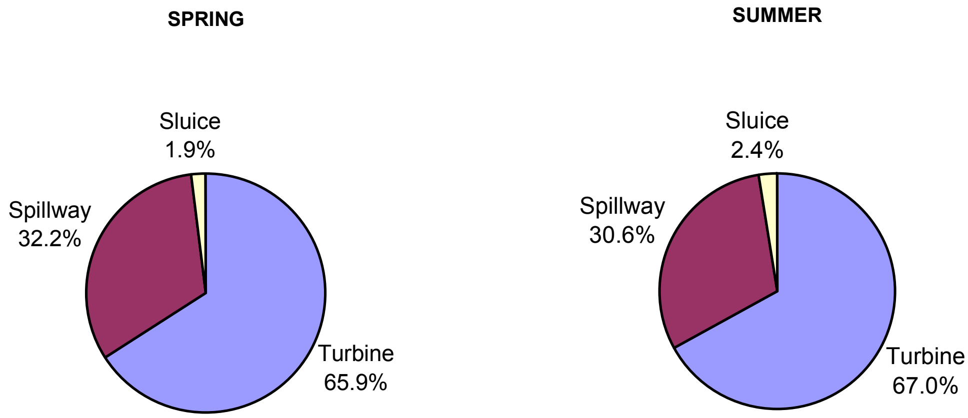


Figure 13. Average percent of flow discharged from the turbines, sluice, and spillway at The Dalles Dam in spring and summer, 2000.

3.2 Species Composition and Run Timing

Species composition data were obtained from the John Day Dam smolt monitoring site via the Data Access Real Time web site (http://www.cqs.washington.edu/dart). John Day Dam is the closest dam upstream from The Dalles Dam with a Smolt Monitoring Program (SMP) facility. During the spring, salmonid species composition from the SMP at John Day Dam was 46% yearling chinook (*Oncorhynchus tshawytscha*), 22% steelhead (*O. mykiss*), 14% coho (*O. kisutch*), 13% subyearling chinook, and 5% sockeye (*O. nerka*) (Figure 14). During the summer, 92% of the downstream migrants were subyearling chinook (Figure 15).

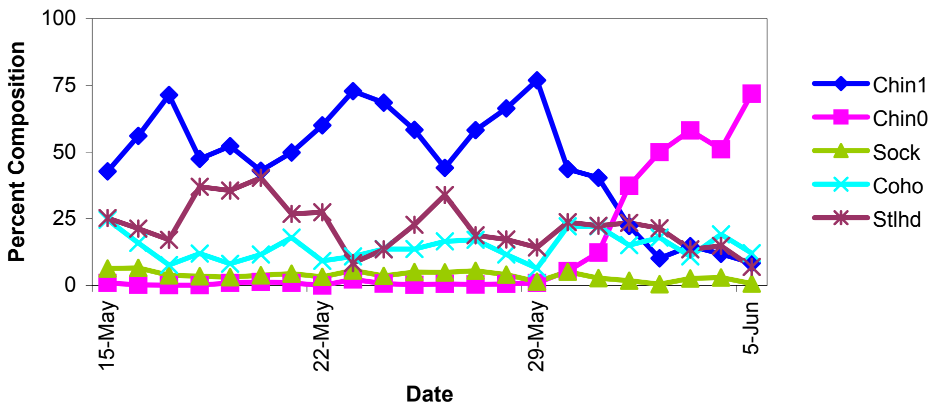


Figure 14. Daily salmonid species composition from the Smolt Monitoring Program during spring 2000 at John Day Dam.

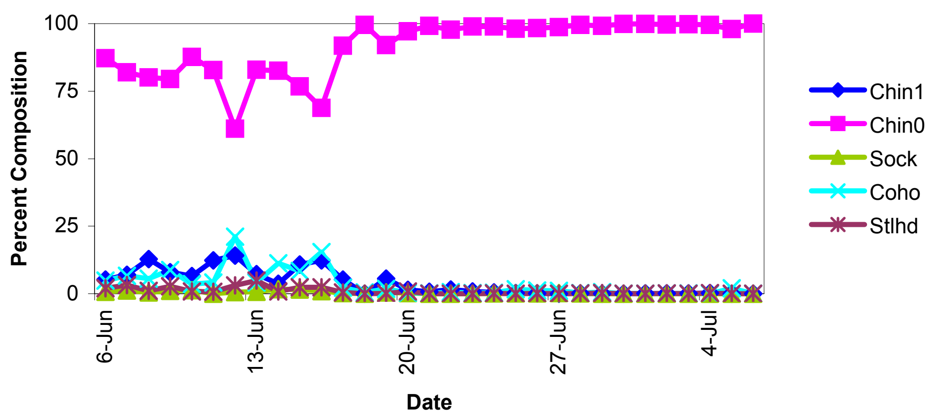


Figure 15. Daily salmonid species composition from the Smolt Monitoring Program during summer 2000 at John Day Dam.

Run timing curves from both hydroacoustic estimates of fish passage and the Smolt Monitoring Program are projected in Figure 16. Passage rates of fish detected by hydroacoustic methods were similar with the magnitude and trends through time estimated in the John Day Dam SMP.

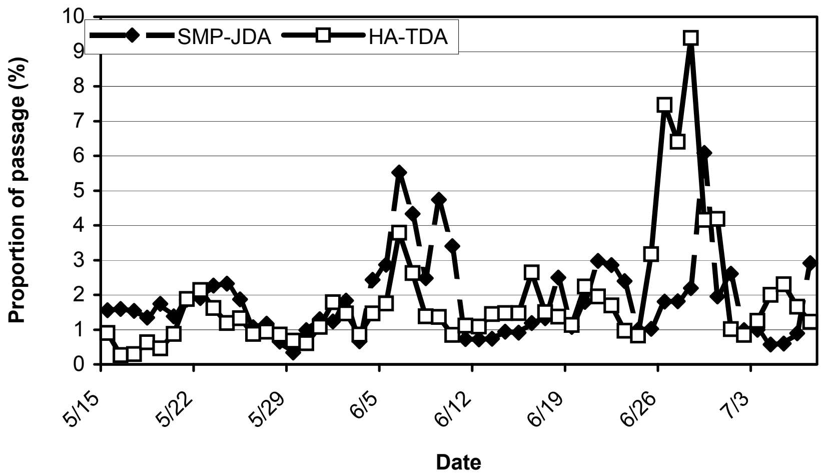


Figure 16. Run timing at The Dalles Dam, 2000. HA is the fixed-location hydroacoustic estimate, and SMP is the Smolt Monitoring Program estimate from John Day Dam for the same period.

3.3 Efficiency and Effectiveness

Fish passage efficiency and effectiveness metrics are used to assess the significance and performance of smolt protection measures at the Corps' mainstem dams. Efficiency metrics are formed from the proportions of the total passage that used various routes. Effectiveness metrics evaluate normalized route passage performance with specific dam operations by accounting for the amount of flow through each route, as well as the proportion of fish passage via that route. Additionally, when these metrics are used consistently within the region, they may be used to compare results between diverse research methodologies and study-years.

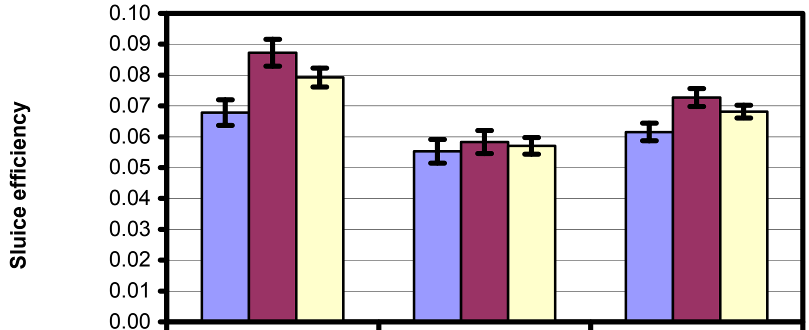
Our analysis showed that overall sluice efficiency and effectiveness were 7% and 3.25, respectively (Figure 17 and Figure 18). Both values are lower than those values reported in 1999 by Ploskey et al. (2000). Table 4 summarizes the metrics for both 1999 and 2000 studies. Both sluice efficiency and effectiveness were significantly higher (t-test, $p < 0.001$) during the day. The sluice passage performance metrics can be used to compare the performance of other surface bypass options in the region.

Table 4. Comparison table of 2000 results with selected previous studies. Transducer deployments and dam operations were very similar between 1999 and 2000.

Year-Season	2000 spring	2000 summer	1999 spring	1999 summer	1998 spring	1998 summer	1996 spring	1996 summer
Period	5/13-6/5	6/6-7/6	4/22-5/27	6/3-7/9	4/20-5/27	6/7-7/6	5/6-6/11	6/17-7/26
#days	21	30	36	35	38	30	22	20
Spill %Q	32%	31%	47%	46%	47%	47%	51%	47%
Sluice %Q	1.9%	2.4%	1.6%	1.4%	1.6%	1.6%	1.0%	1.4%
FPE	92%	81%	79%	69%	94%	91%	59%	81%
FPS	2.20	1.92	n/d	n/d	n/d	n/d	n/d	n/d
Spill Efficiency	86%	74%	66%	59%	61%	61%	48%	70%
Spill Effectiveness	2.16	1.86	1.41	1.27	1.4	1.5	0.8	1.4
Sluice Efficiency*	6%	7%	13%	10%	33%	31%	31%	16%
Sluice Effectiveness*	3.22	3.27	8.57	6.88	20.8	16.2	31.9	11.5

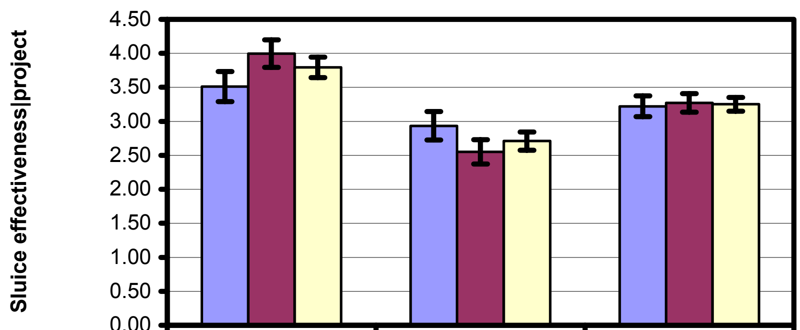
* relative to the entire project
FPE = fish passage efficiency
FPS = fish passage effectiveness

Because sluice performance is not independent of spillway operations, sluice efficiency in relation to the powerhouse is not considered. The intent is to avoid making the assumption that the sluice operating alone (i.e., with no spill) would perform at that level. This is not likely to be the case.



	Day	Night	Total
Spring	0.07	0.06	0.06
Summer	0.09	0.06	0.07
Total	0.08	0.06	0.07

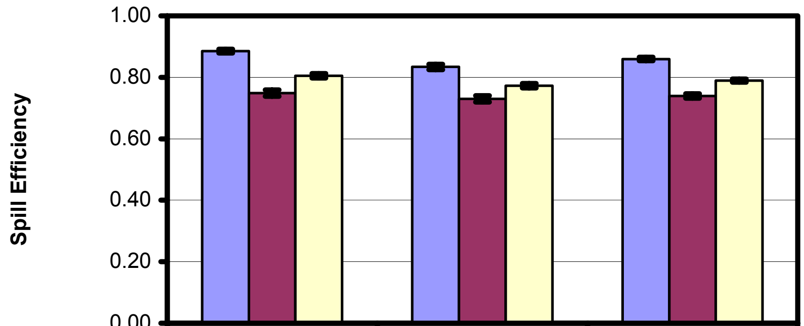
Figure 17. Sluice efficiency relative to the entire project by day/night and spring/summer.



	Day	Night	Total
Spring	3.51	2.93	3.22
Summer	4.00	2.55	3.27
Total	3.79	2.71	3.25

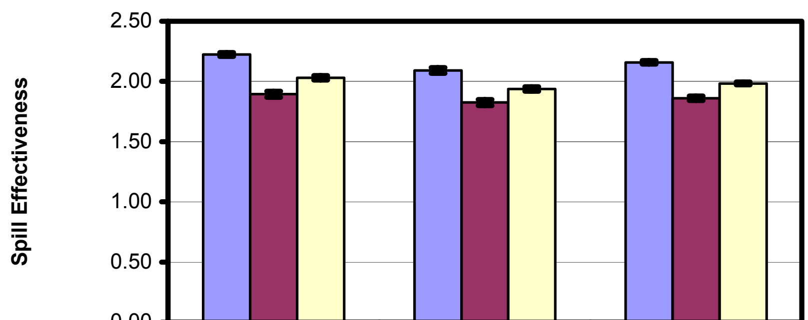
Figure 18. Sluice effectiveness relative to the entire project by day/night and spring/summer.

Spill passage metrics are used to evaluate the utility of spill passage as a smolt protection measure. Spill efficiency offers insight into the biological effectiveness of the spill program. Spill effectiveness alone does not. Spill effectiveness does measure performance of a passage route in terms of number of fish per unit of water. Together, they provide important performance measures specifically for the voluntary spill program. Overall spill efficiency and effectiveness was 79% and 1.98, respectively (Figure 19 and Figure 20). Both metrics were significantly higher (t-test, $p < 0.001$) in the spring than the summer. Overall, FPE was 86%, and it was significantly higher (t-test, $p < 0.001$) in spring at 92% than in summer at 81% (Figure 21 and Figure 22).



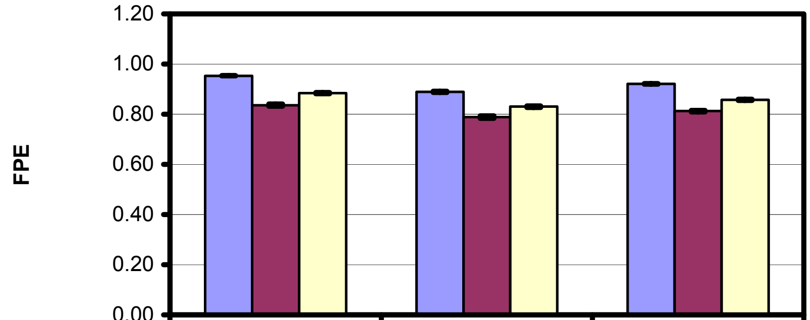
	Day	Night	Total
Spring	0.89	0.83	0.86
Summer	0.75	0.73	0.74
Total	0.81	0.77	0.79

Figure 19. Spill efficiency by day/night and spring/summer.



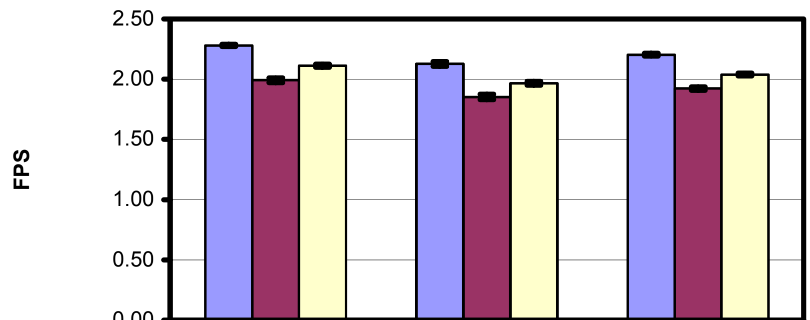
	Day	Night	Total
Spring	2.22	2.09	2.16
Summer	1.89	1.83	1.86
Total	2.03	1.94	1.98

Figure 20. Spill effectiveness by day/night and spring/summer.



	Day	Night	Total
Spring	0.95	0.89	0.92
Summer	0.84	0.79	0.81
Total	0.88	0.83	0.86

Figure 21. Fish passage efficiency by day/night and spring/summer.



	Day	Night	Total
Spring	2.28	2.13	2.20
Summer	1.99	1.85	1.92
Total	2.11	1.97	2.04

Figure 22. Fish passage effectiveness by day/night and spring/summer.

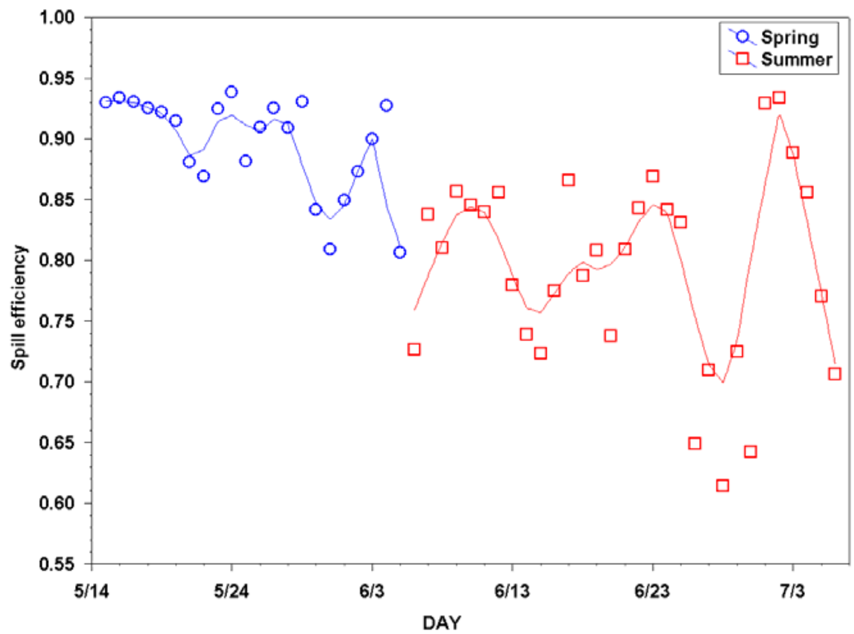


Figure 23. Spill efficiency through time in Spring and Summer. Line is LOWESS fit.

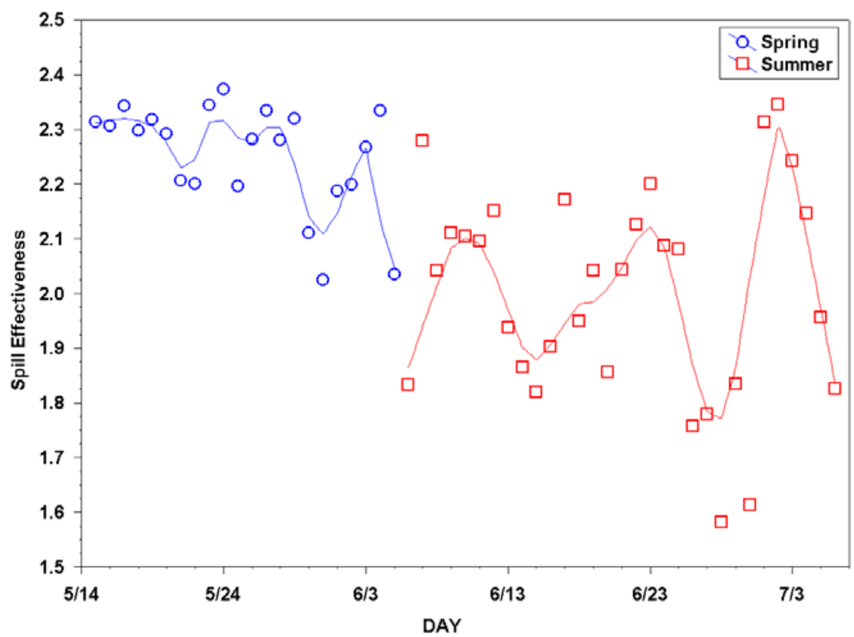


Figure 24. Spill effectiveness through time in Spring and Summer. Line is LOWESS fit.

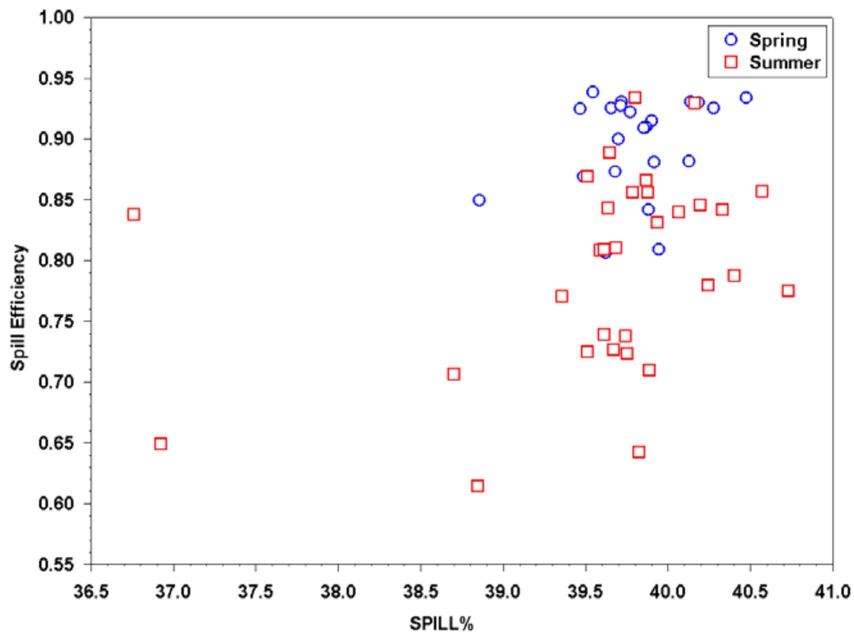


Figure 25. Spill efficiency versus spill percent in Spring and Summer.

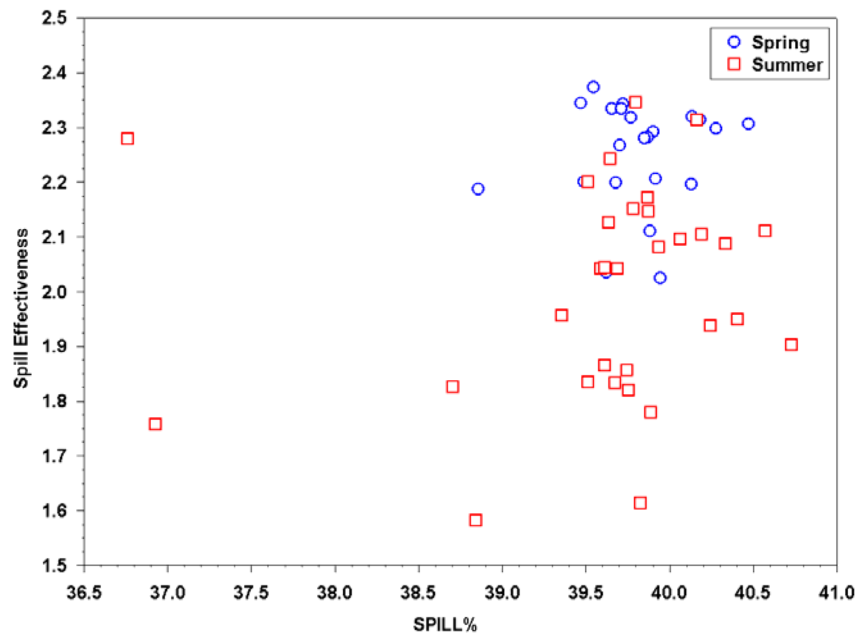


Figure 26. Spill effectiveness versus spill percent in Spring and Summer.

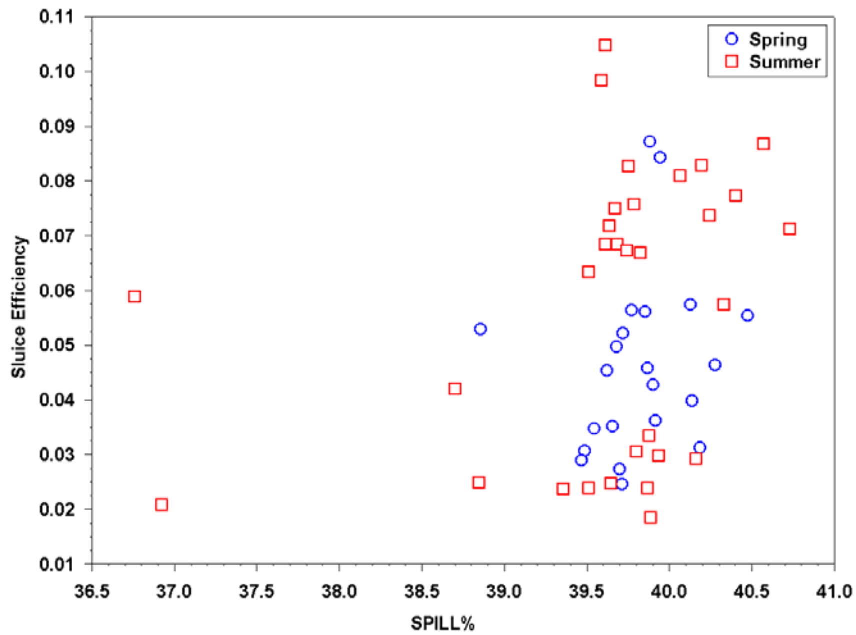


Figure 27. Sluice efficiency versus spill percent in Spring and Summer.

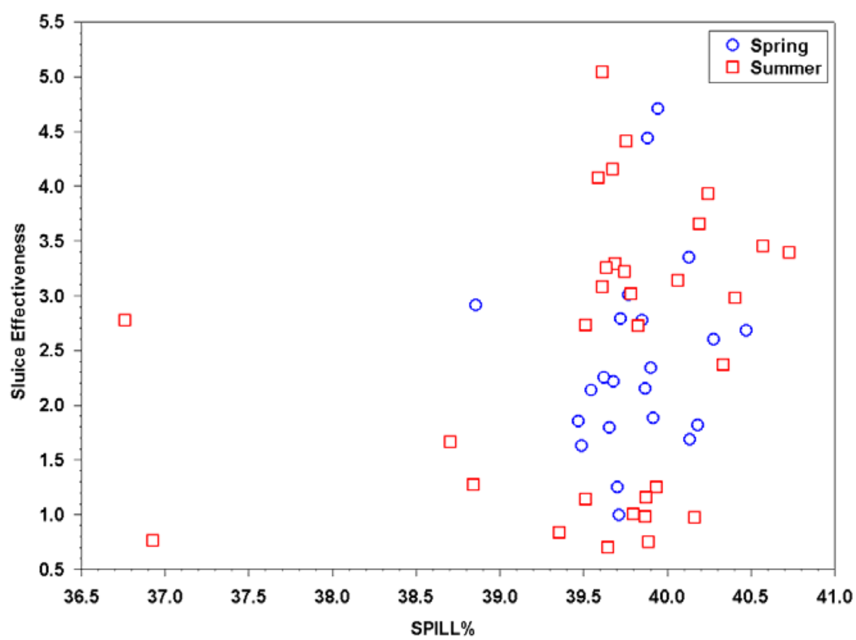


Figure 28. Sluice effectiveness versus spill percent in Spring and Summer.

Sluice and spill efficiencies are calculated as the proportion of the run that use each of these passage routes. The run as a whole then can be compared by passage for both spring and summer. During the summer, more fish went through the turbine units while sluiceway efficiencies remained approximately equal (Figure 29). Figure 29 graphically shows this significance of spill passage as a passage route; it also shows the significance of the ice and trash sluiceway as a non-turbine passage route (when compared solely with the turbines as a passage route). When effectiveness metrics are compared, the sluice remained an effective passage route throughout the study. Spill effectiveness decreased in the summer with more fish passing through the turbines. This also shows that FPS was dominated by the amount of water passing through the spillway (Figure 30).

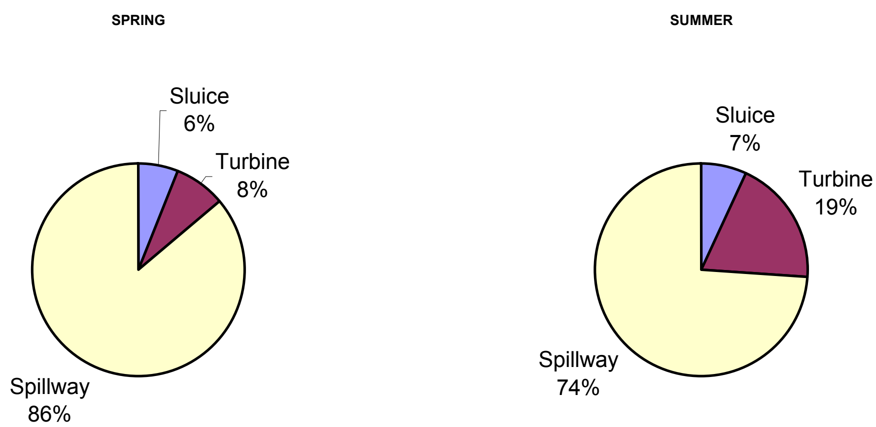


Figure 29. Comparison of the percentage of fish passing through each route at The Dalles Dam for spring and summer, 2000.

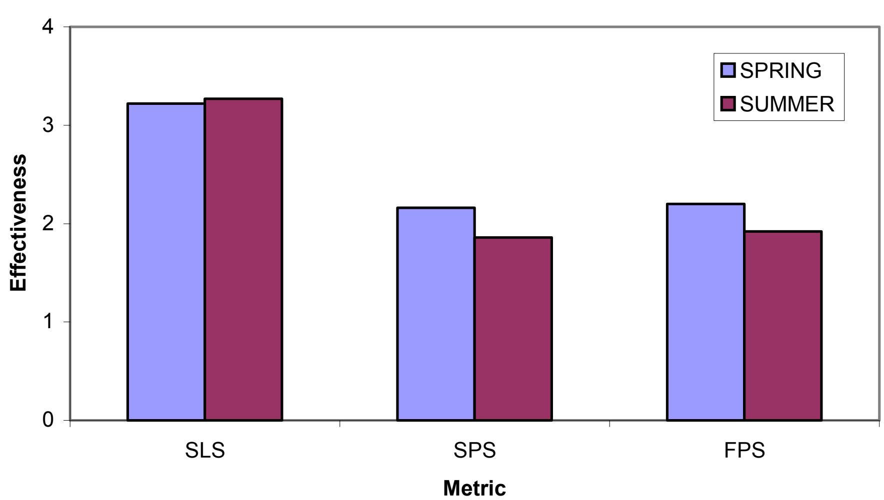


Figure 30. Comparison of passage metrics at The Dalles Dam in spring and summer, 2000. SLS = sluice effectivess; SPS = spillway effectiveness; FPS = project fish passage effectivess

3.4 Vertical Distributions

Vertical distribution at the turbines showed fish passed in the upper portion of the water column near the intake ceiling (Figure 31). Passage both above and below the sill of the sluice opening (elevation 151 ft) showed passage to have a central tendency around elevation 143 ft (Figure 32). The spillway also showed a surface orientation of fish (Figure 33).

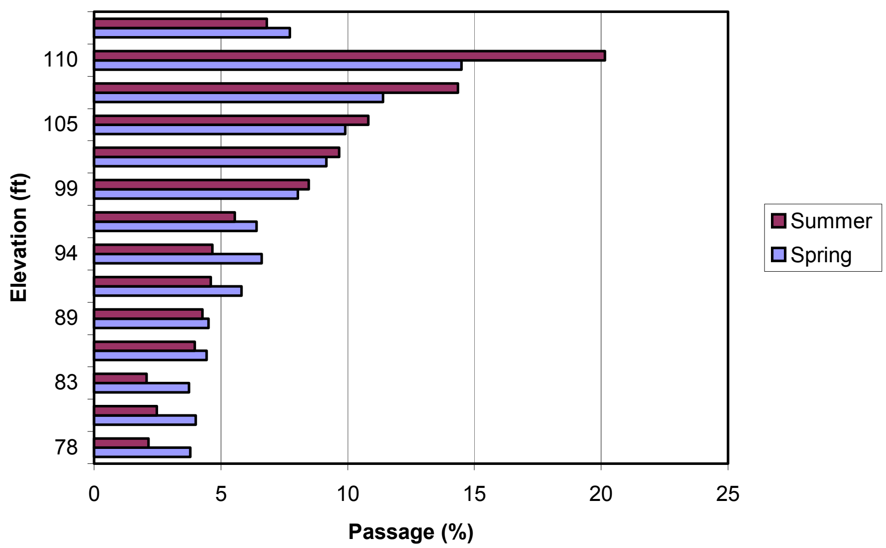


Figure 31. Vertical distribution of fish passage at the turbines at The Dalles Dam in spring and summer, 2000.

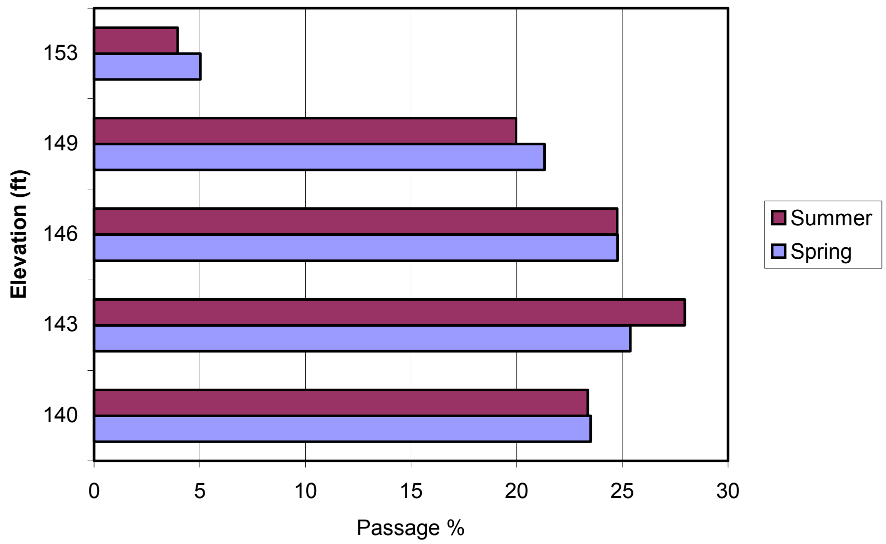


Figure 32. Vertical distribution of fish passage at the sluiceway at The Dalles Dam in spring and summer, 2000. Forebay elevation fluctuations meant that the top range bin (153 ft) sampled only a portion of the time.

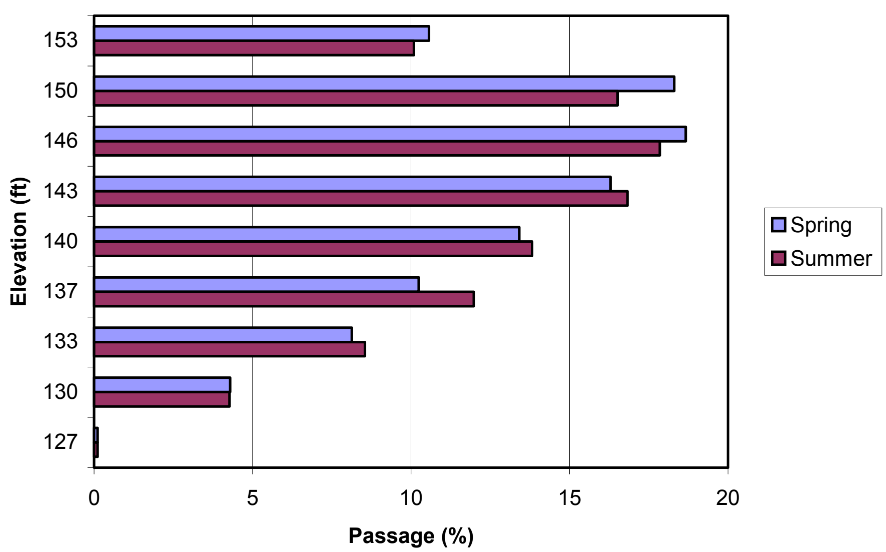


Figure 33. Vertical distribution of fish passage at the spillway at The Dalles Dam by spring and summer, 2000.

Vertical distributions changed according to the time of day at all locations. Fish were slightly higher in the water column as they entered the intakes of the powerhouse during the day (Figure 34). The opposite trend is evident at the sluice and spillway (Figure 35 and Figure 36). Fish we detected were clearly higher in the water column during the night at both the sluice and spillway.

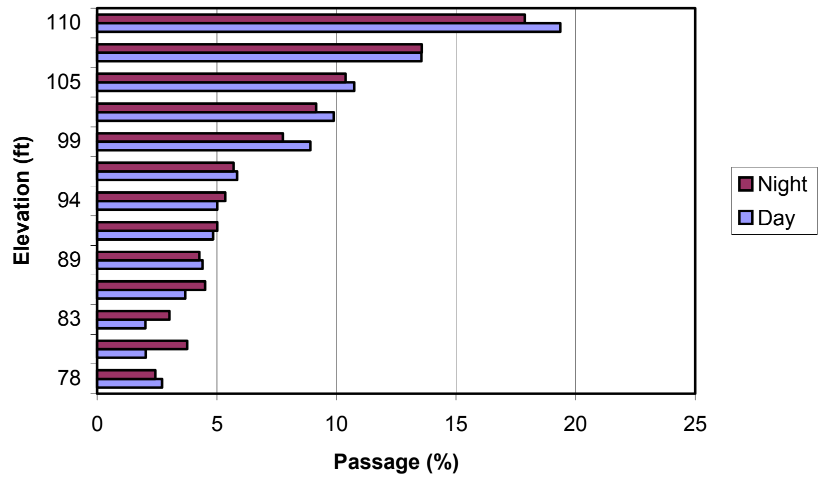


Figure 34. Vertical distribution of passage at the intakes at The Dalles Dam by day and night.

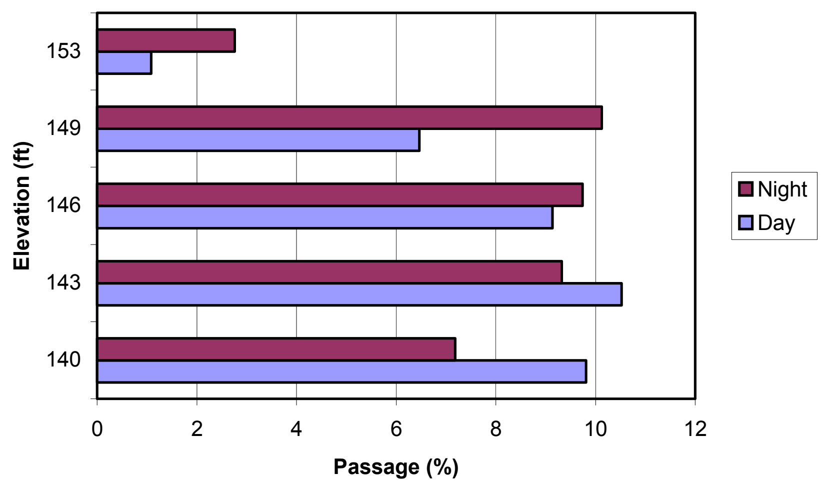


Figure 35. Vertical distribution of passage at the sluice at The Dalles Dam by day and night.

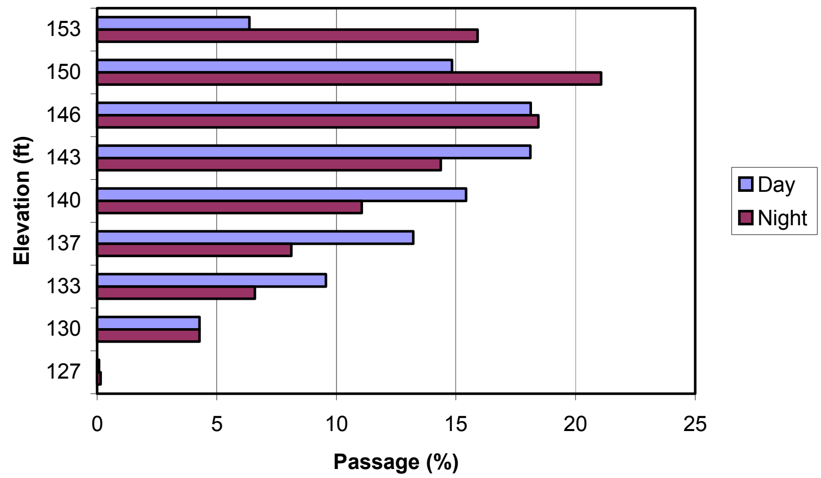


Figure 36. Vertical distribution of passage at the spillway at The Dalles Dam by day and night.

3.5 Horizontal Distributions

Horizontal distribution of fish passage through the sluiceway was more uniform at night than during the day. Passage rates were significantly higher (t-test, $p < 0.001$) during the day than at night at the sluiceway (Figure 38). Passage rates at the sluiceway were not significantly higher (t-test, $p > 0.05$) during spring than summer (Figure 37).

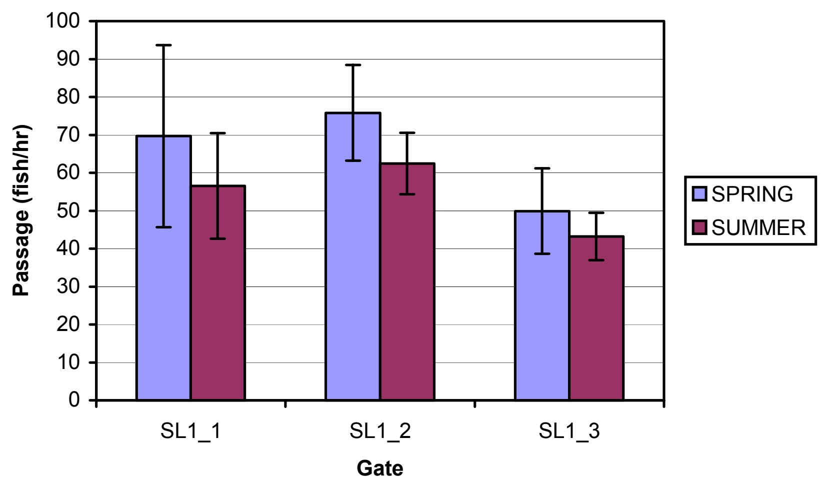


Figure 37. Horizontal distribution of passage at the sluiceway by spring/summer.

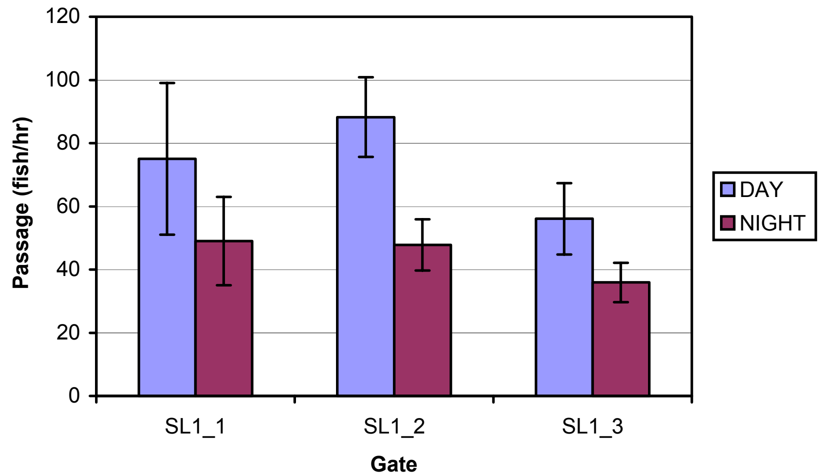


Figure 38. Horizontal distribution of passage at the sluiceway by day/night.

Spillway passage was skewed generally higher toward the middle of those bays which were open. Passage was highest in through Bays 5 and 7 for both the spring and summer periods (Figure 39). This trend was not a function of flow (Figure 40). The flow data used to calculate spill effectiveness by bay showed that the performance of each bay as a passage route is comparable between spring and summer (Figure 41). Passage at the spillway was higher during day than at night, but was more uniform during night than day (Figure 42). This trend was also not a function of flow (Figure 43). Again, spill effectiveness by bays indicates that the performance of each bay as a passage route is comparable between day and night (Figure 44).

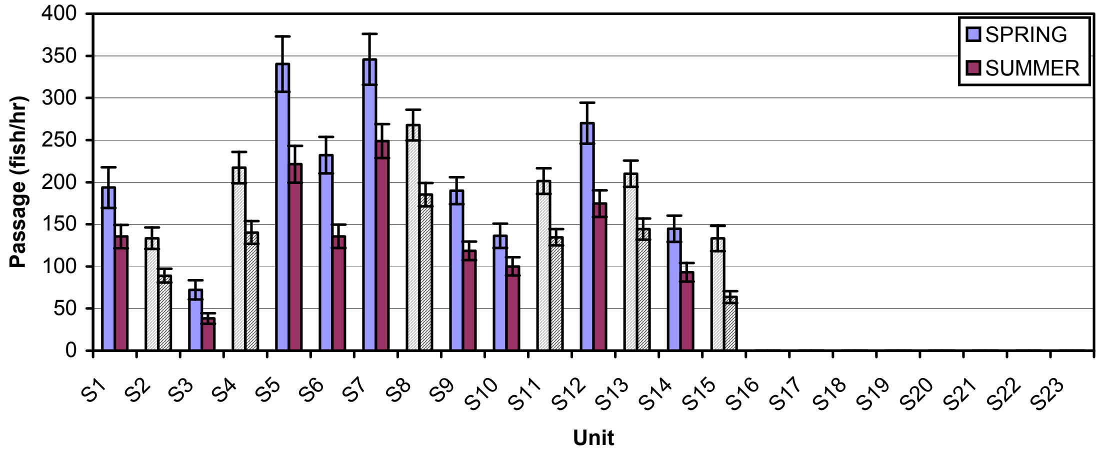


Figure 39. Horizontal distribution of passage at the spillway by spring/summer. Interpolated bays are shown with stripes.

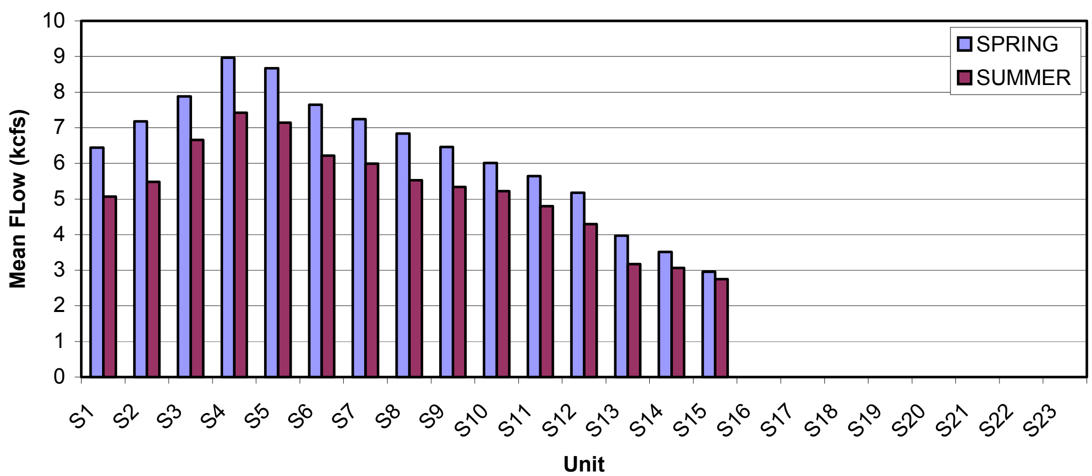


Figure 40. Horizontal distribution of flow at the spillway by spring/summer.

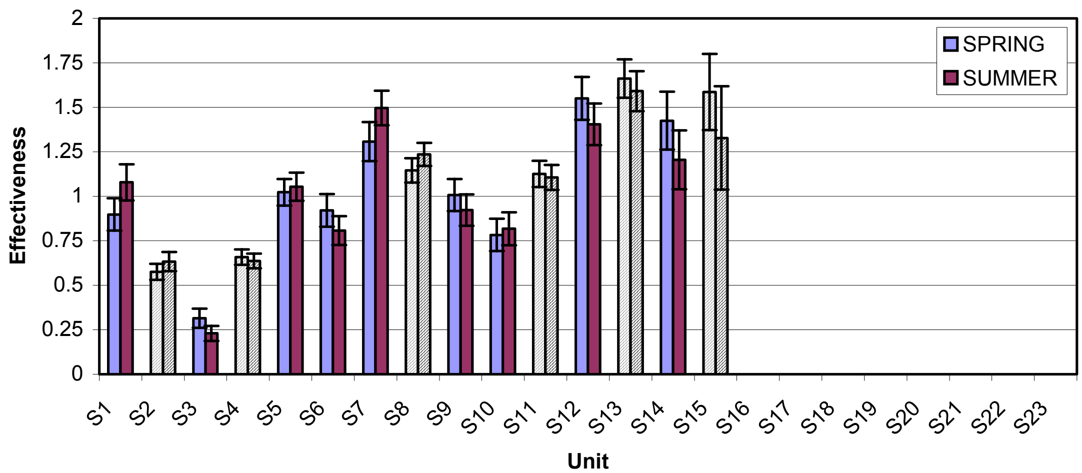


Figure 41. Horizontal comparison of effectiveness of spill bays relative to the entire spillway by spring/summer. Interpolated bays are shown with stripes.

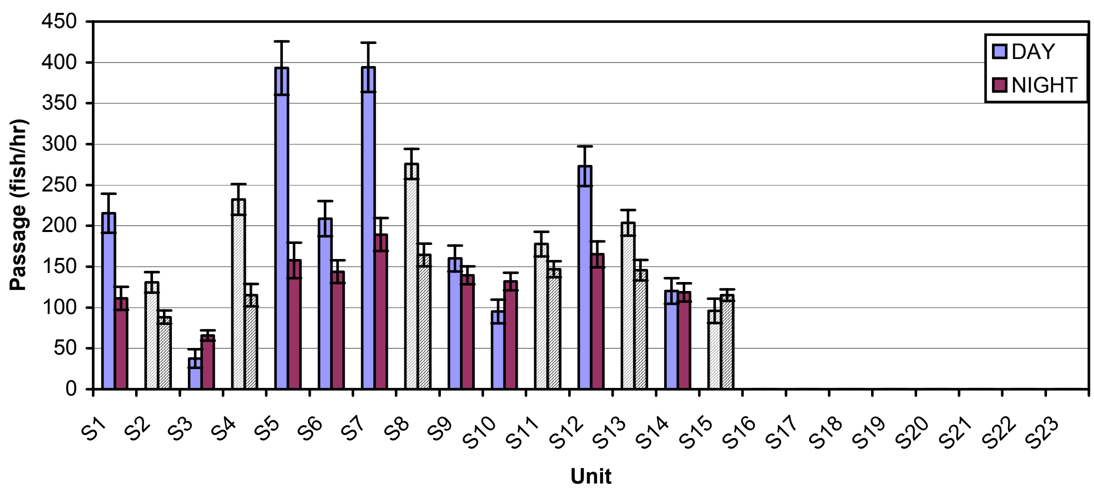


Figure 42. Horizontal distribution of passage at the spillway by day/night. Interpolated bays are shown with stripes.

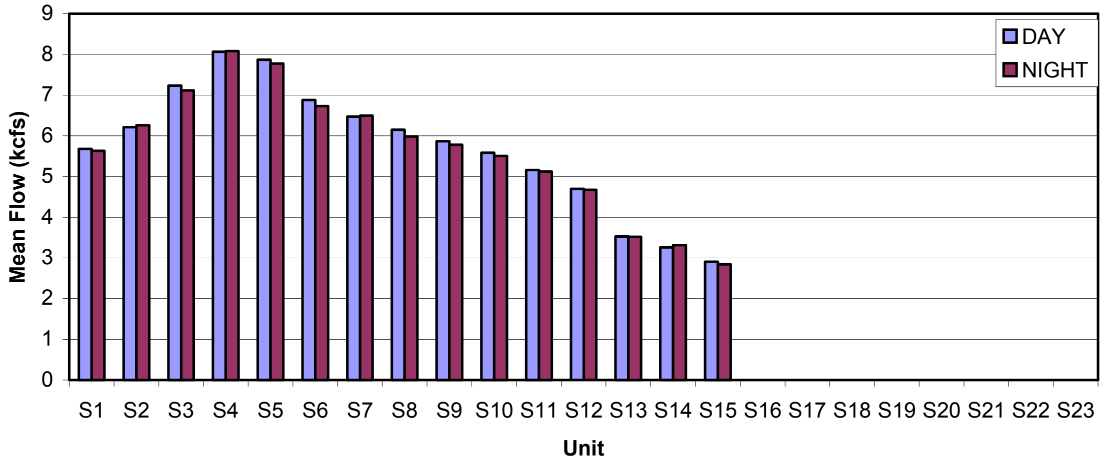


Figure 43. Horizontal distribution of flow at the spillway by day/night.

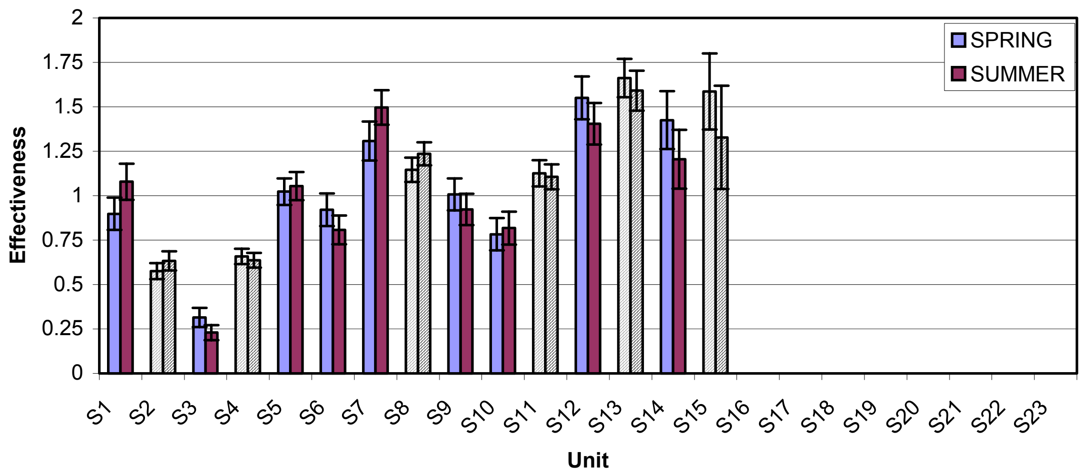


Figure 44. Horizontal comparison of effectiveness of spill bays relative to the entire spillway by day/night. Interpolated bays are shown with stripes.

Horizontal distributions of turbine passage at the powerhouse were relatively uniform during the spring. This was not the case in summer when passage was highly skewed toward the upstream end of the powerhouse (Figure 45). Sluiceway passage, which occurred above Main Unit 1 is not shown. The fish unit intakes are narrower and deeper than the Main Unit intakes, with less discharge, and historically pass fewer fish than the main units. Turbine passage was not significantly different (t-test, p =0.55) between day and night (Figure 47).

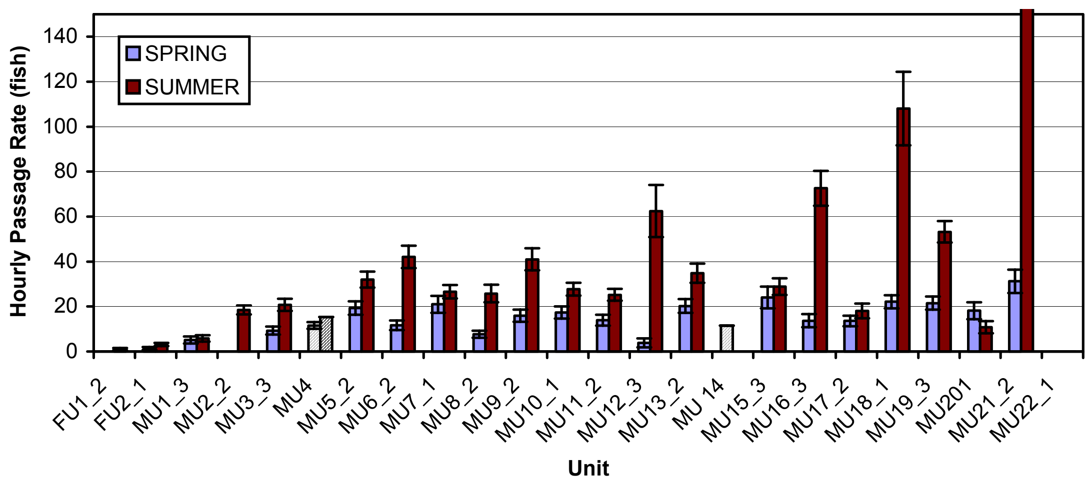


Figure 45. Horizontal distribution of turbine passage at the powerhouse by spring/summer. Passage through the sluice, located above MU1, is not shown.

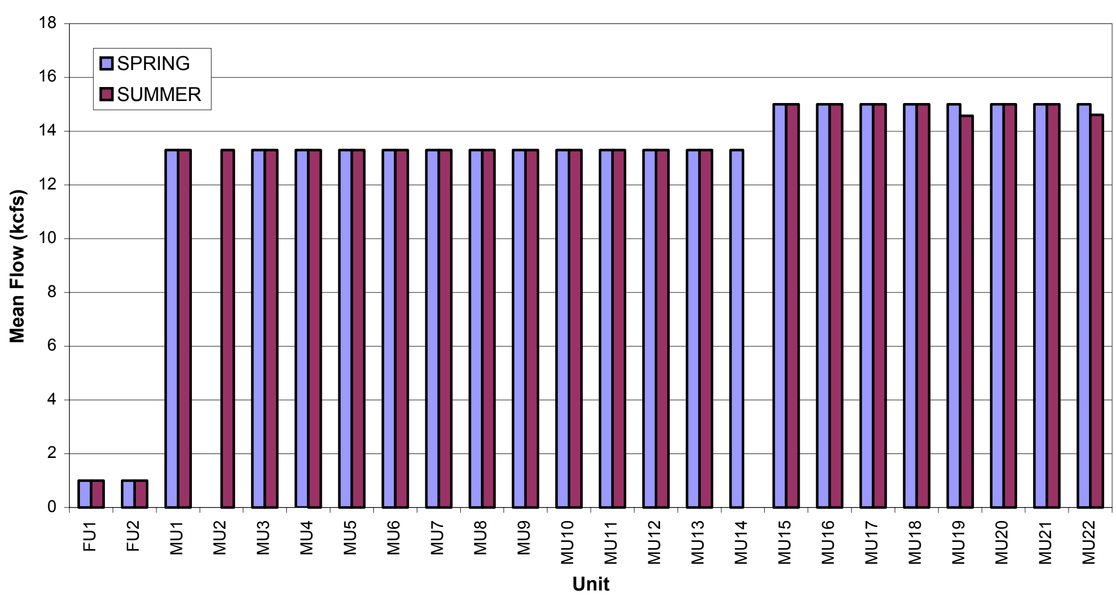


Figure 46. Horizontal distribution of flow at the powerhouse by season.

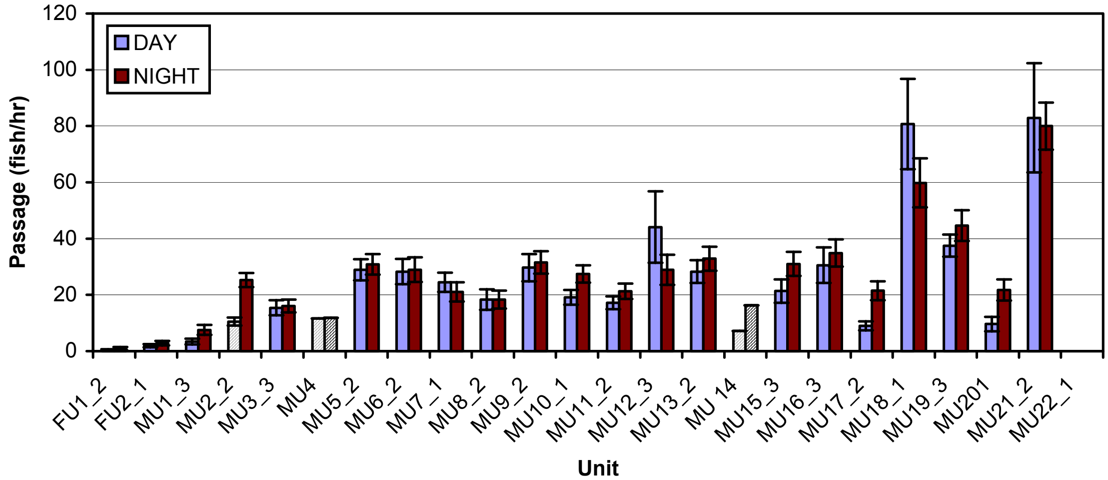


Figure 47. Horizontal distribution of turbine passage at the powerhouse by day/night. Passage through the sluice, located above MU1, is not shown.

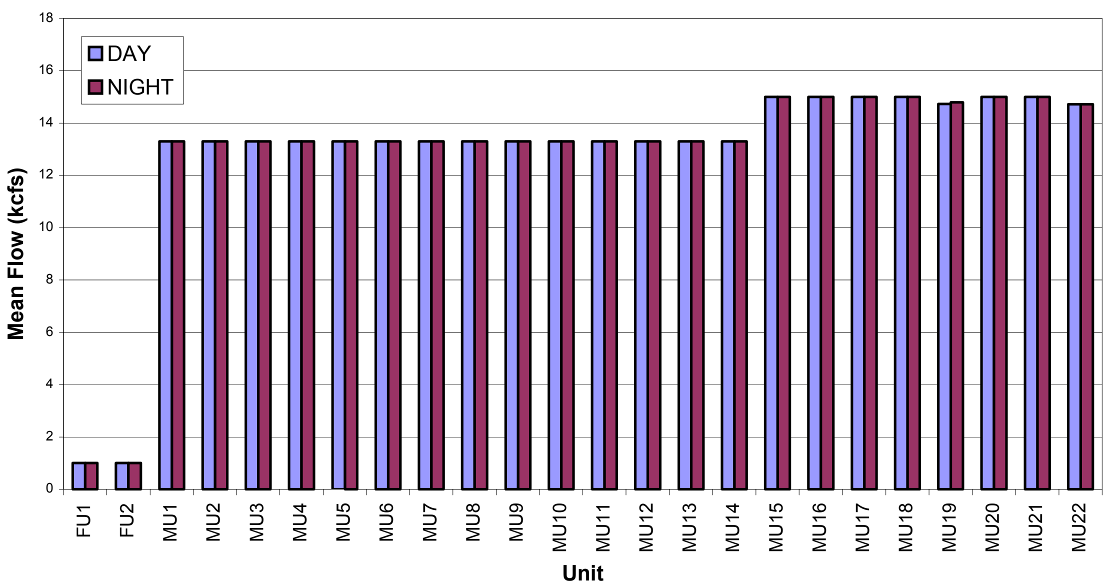


Figure 48. Horizontal distribution of flow at the powerhouse by day/night.

The relative performance of each passage route is shown in Figure 49 with the performance of the sluiceway highlighted in red. The sluiceway is an efficient non-turbine passage route, passing as many fish as a typical spill bay.

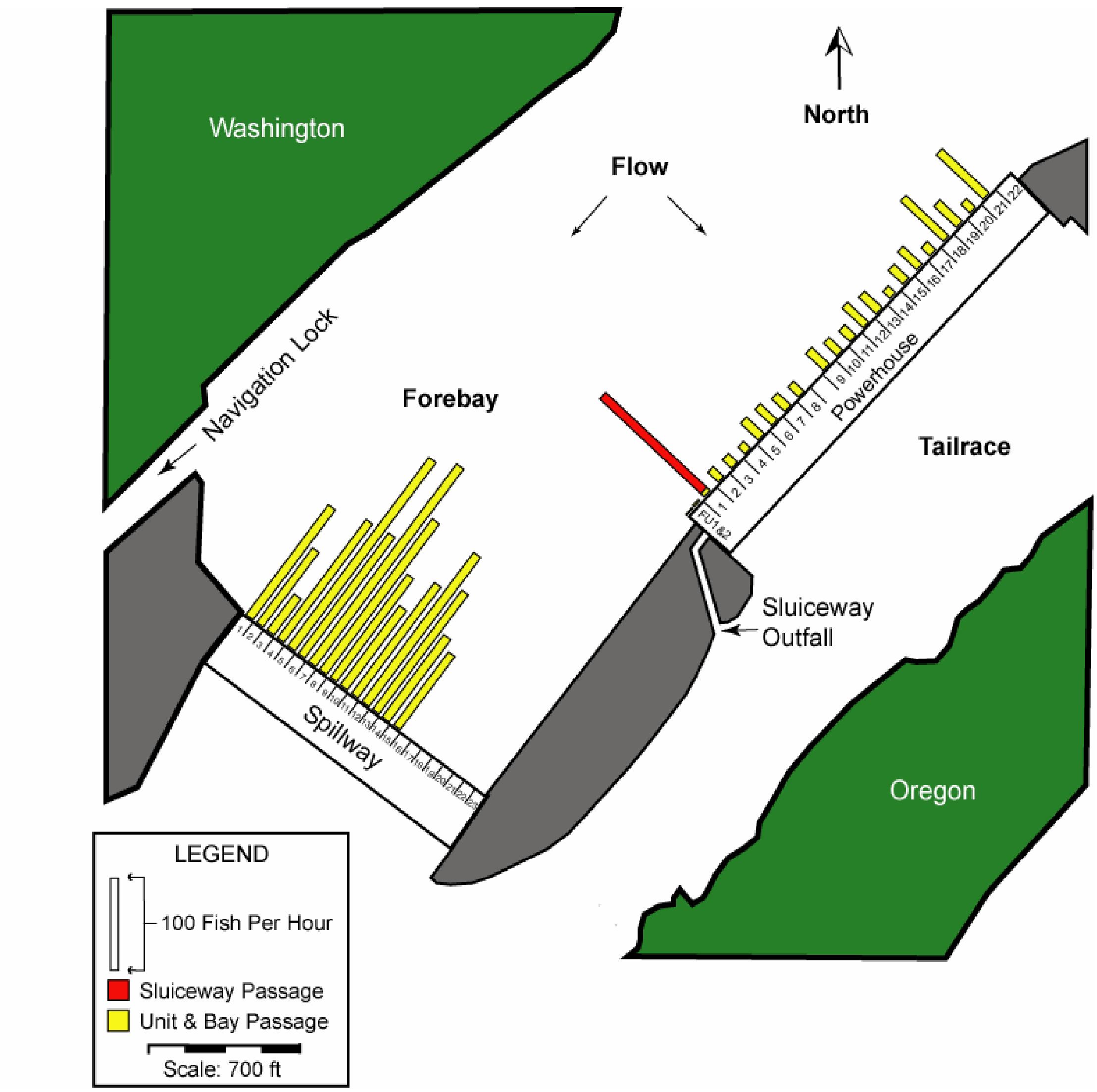


Figure 49. An all-project view of the horizontal distribution of fish passage (spring and summer study periods combined).

3.6 Diel Distribution

Relative passage rates between the major routes of turbine, sluice, and spillway were used to examine temporal differences in passage. Turbine passage peaked at night in the spring, but that peak shifted to afternoon by summer (Figure 50 and Figure 51). Spillway passage showed a peak in the morning hours, and this trend remained through the summer. There was a pronounced trend for fish to preferentially pass through the sluice during the day rather than at night. This trend was clear in both spring and summer, it was observed in 1999 as well.

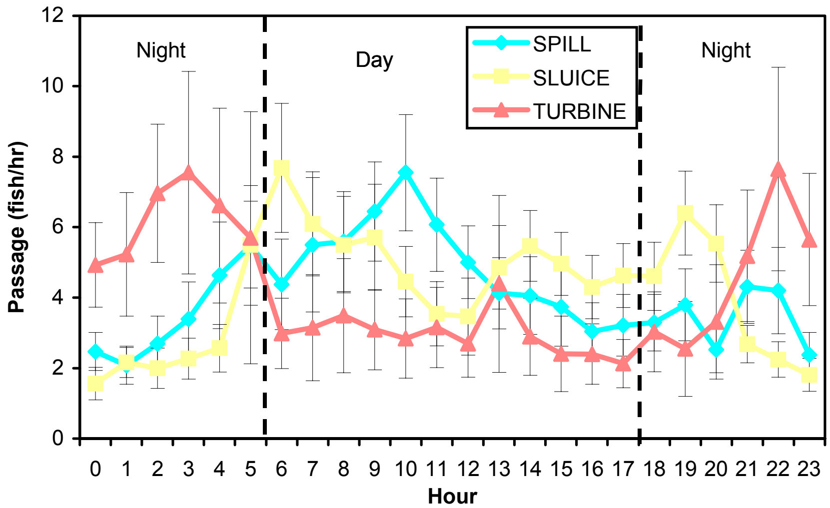


Figure 50. Diel distribution of fish passage in the spring.

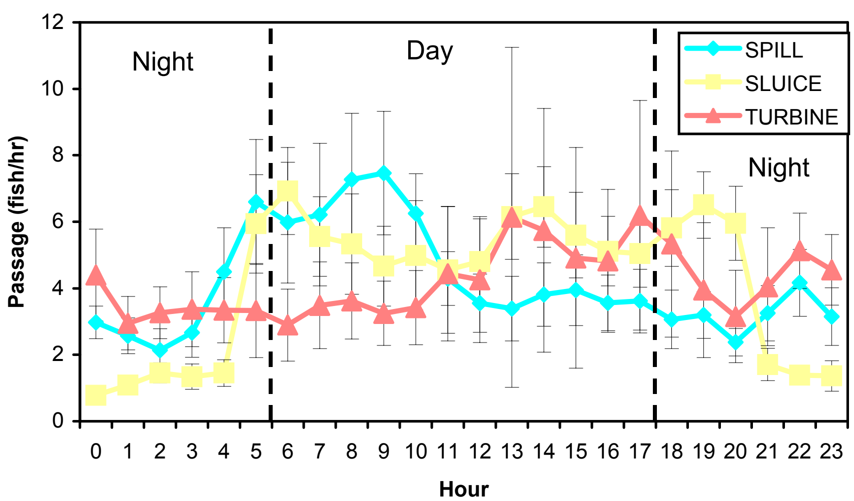


Figure 51. Diel distribution of fish passage in the summer.

4.0 Discussion

4.1 Fish Passage

Preliminary surface collection and bypass studies began at The Dalles Dam in 1995, with the ice and trash sluiceway as an integral component of the system (Nagy and Shutters 1995). They found that when the intakes were occluded, an increase in the proportion of fish entering the sluiceway relative to the number entering the turbines was observed. In an attempt to deepen the 'zone of influence' of the sluiceway, the upper 22 ft (to elevation 120 ft mean sea level) of the intakes at Main Units 1 and 2 were occluded.

In 2000, overall project fish passage efficiency (FPE) was 86%. Spill efficiency and effectiveness were 79% and 1.98, respectively. Sluice passage efficiency and effectiveness, relative to the project as a whole, was 7% and 3.25, respectively. Similar spatial and diel patterns were observed between this study and the one in 1999 conducted by Ploskey et al. Notable are the pronounced daytime passage rates at the sluice and relatively high passage rates through the upstream end of the powerhouse in summer, compared to passage rates across the powerhouse. Trends at the sluice tended to follow the same trends at the spillway, and both the sluice and spillway tended to have trends opposite those of the turbines. At both the sluice and spillway, fish were higher in the water column at night. Also, the proportion of fish that passed through those routes at night decreased, as shown in the diel distribution.

Fish passage efficiency metrics measure the performance of the facility as a whole in passing fish via non-turbine routes. Fish passage efficiency information may be combined with survival by passage route information to aid in regional fish passage decision-making. Fish passage effectiveness could be used to compare fish passage performance among facilities within the Columbia River Basin in a cost-benefit type of analysis. FPS may also find use in annual comparisons at one facility in which dam operations vary.

Results from recent hydroacoustics studies in which the ice and trash sluiceway was operated for fish passage are shown for comparison in Table 4. The 1999 Ploskey et al. (2000), 1998 BioSonics, Inc. (1999), and 1996 BioSonics, Inc. (1997) studies reported higher sluice efficiency and effectiveness metrics with essentially the same sluiceway flows. A concurrent study will synthesize juvenile salmonid passage data for both The Dalles and John Day dams. Therefore, that effort is not duplicated here.

4.2 Hydroacoustic Data Quality and Sources of Error

The methods used in this study closely approximated those used in 1999 by Ploskey et al. (2000). Wherever possible we've used empirically measured data from split-beams as the basis for our detectability modeling. This method alone is not sufficient in the long run, and can be highlighted with two examples. First, we must know when fish are not detected. That is, fish traveling through the beam that fall below the ping minimum threshold. The second drawback is sample size. When a season of data is subdivided into day/night, spring/summer, spill gate opening, and range, the sample sizes may be too low for statistical analysis. The data subset may not have enough fish samples to adequately describe a mean or a distribution at a range. Detectability modeling, supported by comprehensive flow information, is still needed to both fill in the data gaps and to ensure we are not underestimating non-detected fish.

This last assumption of horizontal uniformity across the passage route was tested by Ploskey et al. (2000) and supported with data from fyke net studies. The conclusion was that this assumption was generally not met. The magnitude and extent to which this assumption is not true has not been tested fully at The Dalles Dam. For example, whether randomization of transducer placement horizontally alone is sufficient mitigation at all locations has not been demonstrated.

5.0 Conclusions and Recommendations

Based on the results of our 2000 study, we conclude that the sluice was neither as efficient nor as effective at passing fish in 2000 as it was in 1999, although the deployment and methods were similar to the 1999 study. Even though the sluice passed fewer fish, FPE was still high compared with previous years. This is attributed to greater numbers of fish passed via the spillway in 2000, and the spill pattern concentrated near the Washington shore, compared to previous years.

The ice and trash sluiceway continued to be a very effective passage route for smolts, i.e., the sluiceway passes more fish per unit of water than any other route. However, the total number of fish, as represented by the proportion of the run (overall only 7% of the fish passed via this route), is insufficient as a stand alone smolt-protection measure. The deployment of the J-occlusions, anticipated for testing in 2001, will attempt to decrease turbine passage.

The sluiceway at the upstream end of the powerhouse may provide an opportunity to increase sluice passage as a smolt protection measure. Turbine passage was shown to be an important fraction of the total in the summer period from this study and also in 1999. The Corps should consider opening the sluiceway at the upstream end of the powerhouse during the summer as a future option. Current operation of the sluiceway is limited by hydraulic capacity.

The current investigation has indicated several ways to improve the ability to quantify fish passage at The Dalles Dam in the future:

- The strategic placement of split-beams is critical to assure sample sizes are sufficient to model detectability for single-beams. At the powerhouse, the unit should be scheduled to be used for the study period. At the spillway, the split-beam should be placed at a bay that will most likely collect the greatest range of spill gate openings. Deployment of two split-beam transducers at the spillway is recommended to provide more data for detectability modeling.

- Sample all spill bays; avoid interpolation where possible

- Test for non-uniform horizontal distribution of fish passage within a spillbay.

- Hydraulic data are required to determine what proportion of fish can be detected, and to fill in any possible data gaps. Advanced knowledge of forebay hydraulics can be used for planning deployments and predicting detectability as well. When possible, hydraulic data gathering or model construction should precede fisheries research. Computational fluid dynamic (CFD) model data were not available at the time of this report.

6.0 References

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