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by Gene R. Ploskey, Larry R. Lawrence

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

William T. Nagy

U.S. Army Engineer District, Portland
P.O. Box 2946
Portland, OR 97208-2946

Michael E. Hanks, Carl R. Schilt, Peter N. Johnson

AScI Corporation
1365 Beverly Road
McLean, VA 22101

Gary E. Johnson

BioAnalysts, Inc.
11807 Northeast 99th Street, Suite 1160
Vancouver, WA 98683

Deborah S. Patterson

DynTel, Inc.
3530 Manor Drive, Suite 4
Vicksburg, MS 39180

John R. Skalski

University of Washington
Columbia Basin Branch. School of Fisheries
1325 Fourth Avenue, Suite 1820
Seattle, WA 98101-2509

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Portland, OR 97208-2946

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Preface

This report was prepared by the Fisheries Engineering Team, Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), with support by AScI Corporation, McLean, VA; BioAnalysts, Inc., Vancouver, WA; DynTel Corporation, Vicksburg, MS; the Fisheries Field Unit, U.S. Army Engineer District, Portland; and the University of Washington, School of Fisheries, Seattle (UW). This work was funded by the U.S. Army Engineer District, Portland (CENWP).

The report was prepared by Messrs. Gene R. Ploskey, WQCMB, Michael E. Hanks, AScI, Gary E. Johnson, BioAnalysts, William T. Nagy, CENWP, Carl R. Schilt, AScI, Dr. Larry R. Lawrence, WQCMB, Ms. Deborah S. Patterson, DynTel, Mr. Peter N. Johnson, AScI, and Dr. John Skalski, University of Washington. The research was conducted under the general supervision of Dr. Mark Dortch, Chief, WQCMB; Dr. Richard Price, Chief, EPED; and Dr. Dave Tazik, Acting Deputy Director, EL. Mr. Marvin Shutters, CENWP, provided technical oversight. Drs. Skalski, UW, and Cliff Pereira, Oregon State University, Corvallis, as well as investigators and sponsors, attended statistical oversight meetings. Ms. Toni Schneider, WQCMB, managed project funds. Much of the manual tracking of hydroacoustic data was performed by Messrs. Alexander Bourdeau and Chad Tennison (contracted through Ms. Jessie Seager), and by Ms. Jina Kim, contract student, WQCMB. Brege Consulting, Rufus, OR, was contracted to monitor hydroacoustic systems at night. Mr. Mark Weiland, AScI, measured vertical distributions of water velocities at a spillway gate. Messrs. Dean Brege and Mike Gessel, National Marine Fisheries Service, and Mr. Rick Klinge, Douglas County Public Utility District, provided fyke net data. Mr. Duane Harrell, Duke Power Company, Charlotte, NC, supplied a report on a fish entrainment study in the Southeastern United States. Mr. John Ehrenberg, Boeing, Inc., Seattle, WA, reviewed a draft of Appendix B. Schlosser Machine, Hood River, OR, fabricated steel transducer mounts. Honald Crane, Inc., The Dalles, Oregon, provided support for installation of transducers at the spillway. Advanced American Divers, Inc., Oregon City, OR, installed all mounts on trashracks at the powerhouse. The Dalles Project provided crane support to position three equipment trailers at the powerhouse and a crane and manbasket to help route cables under the powerhouse deck.

Single-beam hydroacoustic equipment deployed at the spillway was calibrated before sampling and maintained during the sampling season by BioSonics, Inc., Seattle, WA. Mr. Alan Wirtz, Precision Acoustic Systems (PAS), Inc., Seattle, WA, provided all preseason calibrations for PAS single- and split-beam hydroacoustic equipment (six systems) and was responsible for valuable quality-control checks on software configurations.

At the time of publication of this report, Director of ERDC was Dr. James R. Houston. Acting Commander was Mr. A. J. Roberto, Jr.

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Summary

Objectives and Methods

The objectives of this fixed-location hydroacoustic study were to (a) estimate fish-passage rates through three major routes (spill bays, turbines, and the sluice openings), (b) calculate a variety of fish-passage metrics for comparing 30- and 64-percent spill treatments, (c) describe horizontal, vertical, and diel distributions of passage, and (d) evaluate assumptions in the acoustic screen model by exploring detectability modeling and adjustment of counts among locations. The study design included six blocks with two treatments each (30- and 64-percent spills along with concomitant powerhouse operations) for spring and summer. Each block was 6 days long with each treatment in place for three consecutive days. We sampled 22 turbine intake slots (1 randomly selected slot of 3 per unit), 2 fish-unit slots (1 randomly selected slot of 2 per unit), 13 spill bays (with 17 transducers), and 4 sluiceway openings. The location of transducers in every intake and spill bay was randomly selected from three possible locations except in two spill bays, each of which was sampled by three transducers to evaluate the lateral distribution of passage within bays. All acquired data from turbines and spill bays were processed, i.e., no subsampling was employed, and 40 percent of all data acquired from sluiceway sampling were subsampled and processed. Turbine and spillway data were processed by automated tracking software. Three people then reprocessed about 10 percent of these data for quality control and assurance.

The assumption of equal detectability among sampled passage routes is a cornerstone of hydroacoustic estimation of fish passage metrics, and detectability must be carefully modeled to develop accurate spatial expansion factors and to assure the validity of the equal detectability assumption. We explored methods of improving calculations of detectability to increase the accuracy of the expansion factors used in the data processing. Split-beam transducers were used in tandem with single-beam transducers to determine effective beam angles for all of the transducers. Our approach to modeling detectability incorporated both range and target-strength effects in spatial expansions. In this study, effective beam angles were from 0.5 deg (single beam in turbine) to 2.5 deg (single-beam spillway)[1] less than would be predicted from modeling effects of range alone or from a –3 dB nominal beam angle. Flow data for TDA spillway revealed that modeling hydroacoustic detectability was much more complicated than was previously

[1] A table for converting non-SI units of measurement to SI units is presented on page xviii.

thought. These results indicate how important accurate target strength and flow data are for modeling detectability.

In our effort to provide the most unbiased and defensible estimates of fish passage possible, we have identified inter-tracker variation as an important potential source of error. If not properly controlled, individual differences could provide a source of systematic bias that could compromise the reliability of analyses based upon hydroacoustic data. We can find no established method for the quantitative evaluation of differences between and among trackers, either human or computer, and we find no established standards for evaluation and control. We tested a number of measures to test inter-tracker precision. All of the measures indicate that precision was highest for the relatively acoustically clean turbine data and decreased for the noisier sluiceway and spillway data.

We found that when tracking data with potential for significant amounts of tracker bias, like data from the spillways or the sluiceway at TDA, consideration must be given to distributing data files among trackers. Potential for bias increased with the duration of tracking because bias was additive.

Our efforts to continue development of a reliable autotracker met with some success. An autotracker is not affected by factors that may result in intra-tracker variations with human trackers (e.g., fatigue). On average, the autotracker tracked only 6 percent more fish than did manual trackers at the spillway. On relatively cleaner in-turbine echograms, the autotracker found 15 percent more fish than did manual trackers. We were unable to develop an autotracker that was reliable on sluiceway data. An autotracker requires careful, routine calibration against trained manual trackers to assure that it is performing properly. Because the noise conditions that affect tracker performance vary temporally and spatially, the calibration for one time or location cannot assure adequate performance for other times and locations. Therefore, our calibration regressions of manual tracker counts on autotracker counts were based upon many transducer locations within the powerhouse and spillway and > 100 hr from a variety of days in spring and summer. We used regression lines to convert autotracker counts into human tracker counts. This provided a quality control check on the autotracker and a way of standardizing counts by the autotracker (spillway and turbines) with counts by people for the sluiceway.

Results

All p-values in this section are from Wilcoxon Signed Ranks Tests performed on metrics computed for six blocks ($n = 6$ with 5 degrees of freedom, $\propto = 0.5$) for each season. "Passage" refers to estimates of absolute numbers passed. "Efficiency" refers to the proportion of fish that pass into a nonturbine route to the sum of the fish that pass by both turbine and nonturbine routes. "Effectiveness" refers to the proportion of fish bypassed to a nonturbine route at a structure relative to the amount of water bypassed by that same route. In the spring, project fish passage efficiency (FPE) was estimated at 0.84 during a 64-percent spill and 0.76 during a 30-percent spill. At night, FPE was significantly higher ($p = 0.028$) during a 64-percent spill (0.81) than during a 30-percent spill (0.70). Overall, spillway efficiency was estimated at 0.72 during a 64-percent spill and 0.61 during a 3-percent spill, but differences between spill treatments were only significant at night (p = 0.028). However, numbers of fish spilled at night (spillway passage) did not differ significantly between the two spill treatments, day or night, and most of the difference in spill efficiency can be explained by significantly higher fish passage through turbines during a 30-percent spill than during a 64-percent spill at night. Overall total (day and night) sluiceway efficiency relative to the entire project was estimated at 0.12 during a 64-percent spill and 0.15 during a 30-percent spill. It was significantly higher during a 30-percent spill (0.13) than during the 64-percent spill (0.08) at night (p = 0.028), but there was no significant difference during the day. Significantly more fish passed the sluiceways with the 30-percent spill regime (p = 0.046 for days, p = 0.028 for nights).

Estimated FPE from summer sampling was 0.76 during a 64-percemt spill and 0.64 during a 30-percent spill. Project FPE was significantly higher (16 percent, p = 0.028) during a 64-percent spill than during a 30-percent spill at night, but no difference was detected during the day. Spillway efficiency was estimated at 0.66 during a 64-percent spill and 0.54 during a 30-percent spill. As in spring, spill efficiency was significantly higher (16 percent, p = 0.028) during the 64-percent treatment than during a 30-percent treatment at night, but differences were not significant during the day. We observed significantly higher (p = 0.046) numbers of fish spilled during the 64-percent treatment (mean number / hour = 3010.3) than during the 30-percent treatment (mean number / hour = 2479.5) at night, but we detected no significant differences during the day. Although sluiceway efficiency relative to the entire project (0.09-0.10) did not differ among spill treatments during night or day, significantly more fish were detected passing through turbine intakes during a 30-percent spill than during a 64-percent spill at night (p = 0.046). Turbine passage did not differ significantly by treatment during the day, although the p-value (0.075) was relatively small with the 30-percent treatment passing more, if not significantly more, fish.

We found high hourly rates of fish entrainment in the turbines at the upstream end of the powerhouse during both spring and summer; especially during the 30-percent spill treatment when most turbines were operating. Out-migrating smolts approaching TDA along the south shoreline may encounter attracting flow nets from many turbine units before they become available to a relatively safe surface passage route at the sluiceway or spillway. Low passage rates during the spring at Main Unit 1 suggest that the sluiceway openings above Unit 1 may effectively reduce entrainment into the intakes below the sluice openings. These data suggest that an additional surface collection opening located at the upstream end of the powerhouse may prove beneficial at reducing turbine entrainment.

The juvenile spill pattern was effective in redistributing total juvenile passage toward the middle and Washington side of the spillway. While the density of fish passage (i.e., fish per unit discharge) at the spillway was relatively uniform or even slightly skewed toward the Oregon side, total passage usually predominated at middle spill bays (3 or 4 through 13). The distribution of total passage was clearly affected by the extent and duration of gate openings, whereas the distribution of fish-passage density was independent of operations.

Vertical distribution data from turbines in spring indicated that fish were slightly deeper during a 30-percent spill than during a 64-percent spill. In summer, spill treatment differences were less obvious than day and night differences, when fish were deeper at night than during the day.

Diel distribution data indicate that more fish passed the turbines at night than during the day, whereas that pattern was reversed at the sluiceway. At the spillway, fish exhibited typical crepuscular peaks in passage soon after dark and in early morning.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees	0.01745329	radians
feet	0.3048	meters
cubic feet/sec	0.0283	cubic meters/sec
statute mile (U.S.)	1,609.3470	meters

1 Introduction

Background

The U.S. Army Corps of Engineers (USACE) is committed to increasing survival rates for fish passing its projects on the Columbia River and several approaches for increasing survival are being evaluated at The Dalles Dam (TDA). The USACE has evaluated effects of spill level on juvenile salmon (*Oncorhynchus* spp.) survival and proportions of fish passing through the spillway, sluiceway, and turbines. Extended submersible bar screens (ESBS) have been designed and tested. However, the decision to construct a full-scale juvenile bypass system (JBS) has been delayed until the potential for developing a satisfactory combination of spill and surface collection has been thoroughly explored. Plans are being developed to use the sluiceway as the basis for surface collection at TDA.

As part of a 1996 study, the USACE conducted an evaluation of 30- and 64-percent spill levels (BioSonics, Inc. 1996). However, high flows prevented the Reservoir Control Center (RCC) from adhering to the spill schedule and many of the days designated for a 30-percent spill were lost. Because of these problems and the inherent variability in this type of data, the study was repeated in 1998 (BioSonics, Inc. 1998).

Although the RCC met each day's percent-spill target in 1998, fish passage estimates at the spillway were suspect because they were consistently much higher during the day than at night, particularly during the 30-percent spill treatments. Many fish were observed milling through the upper portion of the down-looking hydroacoustic beams during days with the 30-percent spill. Fish passage estimates also were higher during the day than at night during the 64-percent spill treatments. Radio telemetry data indicate that residence times of juvenile salmon are higher during the day than at night. Hydroacoustic sampling bias may have resulted from decreased detectability when spill was concentrated on the Washington side of the spillway at night or from multiple counts of uncommitted fish during the day, particularly at a 30-percent spill. We suspect that fish more readily pass the spillway at night because of higher water velocity resulting from the juvenile spill pattern and because darkness reduces the availability of visual orientation and control cues. Spill gates on the Washington side of the spillway are opened much more at night than during the day to keep juvenile salmon away from the rocky shelf below spill gates on the Oregon side of the tailrace. In contrast, the horizontal distribution of spill is much more evenly spread across the spillway during the day, when more spill bays can be opened less and still accommodate the same total spill volume as at night.

Hydroacoustic detectability among transducers at the spillway may not have been equal, thereby invalidating day/night passage comparisons and confounding spill-pattern evaluations. The Portland District did not use 30-percent-spill estimates to calculate project fish-passage efficiency (FPE) or effectiveness because of uncertainties about multiple counting and detectability. Project fish-passage efficiency is the proportion of all fish that passed the project by nonturbine routes (i.e., the sluiceway and spillway). Project-passage effectiveness is the ratio of FPE to the proportion of total discharge that passed by nonturbine routes.

A major component of the 1999 research was to evaluate assumptions of the acoustic screen model for estimating fish passage with fixed-aspect hydroacoustics. High priority was placed upon validation of assumptions in the acoustic screen model, detectability modeling, and adjustment of counts to account for differences in detectability among locations. Flow trajectories and velocities that were not available to earlier investigators were incorporated into detectability models and adjustments to hydroacoustic counts. Three split-beam transducers were deployed in one spillbay, one turbine, and one sluiceway to evaluate fish directions, target-strength distributions, and swimming speeds to facilitate detectability modeling. These data also were used to estimate effective beam angles (i.e., sample volume). Spillway mounts were redesigned to reduce the probability of multiple counting of fish.

Objectives

The objectives of this study are as follows:

a. *Task 1*: Make project- and route-specific estimates of fish passage, fish-passage efficiency, and fish-passage effectiveness by spill treatment.

Spill pattern is presumed to have a large effect on the survival of fish in the tail waters of hydroelectric projects, especially at TDA, and may have an effect on fish passage and spill efficiency. This research evaluates fish passage at two distinct spill levels to determine the effect of spill level on fish passage and spill efficiency. The following list of specific objectives was developed for the times of interest (i.e., day, night, spring, and summer):

(1) Estimate fish passage, efficiency, and effectiveness and associated 95-percent confidence intervals for the sluiceway by spill treatment.

(2) Estimate the fish passage, efficiency, and effectiveness and associated 95-percent confidence intervals for the spillway by spill treatment.

(3) Estimate fish passage and associated 95-percent confidence intervals for turbines by spill treatment.

(4) Test for differences in sluiceway fish passage, efficiency, and effectiveness between 30- and 64-percent spill treatments.

(5) Test for differences in spillway fish passage, efficiency, and effectiveness between 30- and 64-percent spill treatments.

(6) Test for significant differences in turbine passage between the two spill treatments.

(7) Test for significant differences in project fish-passage efficiency between the two spill treatments.

(8) Present the horizontal distribution of fish passage, at the spillway and powerhouse, by spill treatment.

(9) Present the vertical distribution of fish passage, for the sluiceway, spillway, and powerhouse, by spill treatment.

(10) Present diel distributions of fish passage for the sluiceway, spillway, and powerhouse by spill treatment.

(11) Compare run timing and abundance estimates with the John Day Smolt Index.

b. *Task 2*: Evaluate assumptions for fixed-aspect acoustic monitoring.

We used split-beam hydroacoustics to assess whether single-beam-monitoring techniques meet the assumptions of the acoustic screen model. A split-beam transducer was installed in one spillbay, one sluiceway opening, and one turbine intake in the same positions and with the same aiming angles as all single-beam transducers. We produced the following list of specific objectives to facilitate the testing of assumptions for fixed-aspect acoustic monitoring.

(1) Describe the acoustic screen model and its underlying assumptions.

(2) Assess the assumptions and identify critical uncertainties requiring monitoring and research.

(3) Apply data from this study and other studies to test uncertain assumptions.

(4) Recommend specific ways to improve the acoustic screen model and its application.

(5) Use flow velocity data to model hydroacoustic detectability at every major passage route. Modeling was to be by 1-m strata if warranted by the distribution of flow measurements along the acoustic axis of the hydroacoustic beams.

(6) Use data from split-beam transducers to corroborate flow data obtained from modeling and field measurements.

(7) Use the distribution of acoustic backscattering cross sections of fish as determined from split-beam sampling to estimate the effective beam angle of transducers.

(8) Determine the distribution of travel directions of tracked fish at the sluiceway and consider the implications of applying corrections to single-beam estimates.

Study Site

TDA, located at Columbia River mile 192, has a powerhouse that is parallel to the main river channel, a spillway that is perpendicular to the river channel, and a navigation lock on the Washington shore (Figure 1).

The spillway has 23 bays, numbered from the Washington shore. The powerhouse has 22 main units (MU), numbered from downstream end. Each unit is divided into three intakes, also numbered from the downstream end. Reference to a specific 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 (FU) are located just downstream of MU 1, and each unit has only two intakes each. An ice and trash sluiceway extends the entire length of the powerhouse but was only opened at MU 1 on the downstream end throughout most of spring and summer. It was opened at MU 1 and 2 in late summer. There are skimmer gates above each turbine intake of MU 1 that discharge up to 1,500 cfs into the sluiceway. Maximum discharge of the ice and trash sluiceway when all gates are fully open is 4,500 cfs.

Study Design

The study design included six blocks with two treatments (30- and 64-percent spill) in spring, and six blocks of the same two treatments were sampled in summer. The two test treatments (about 30-percent spill and inherent powerhouse operations versus about 64-percent spill and inherent powerhouse operations) were interspersed, beginning with a 64-percent spill for both seasons. Table 1 shows the study design and treatment schedule.

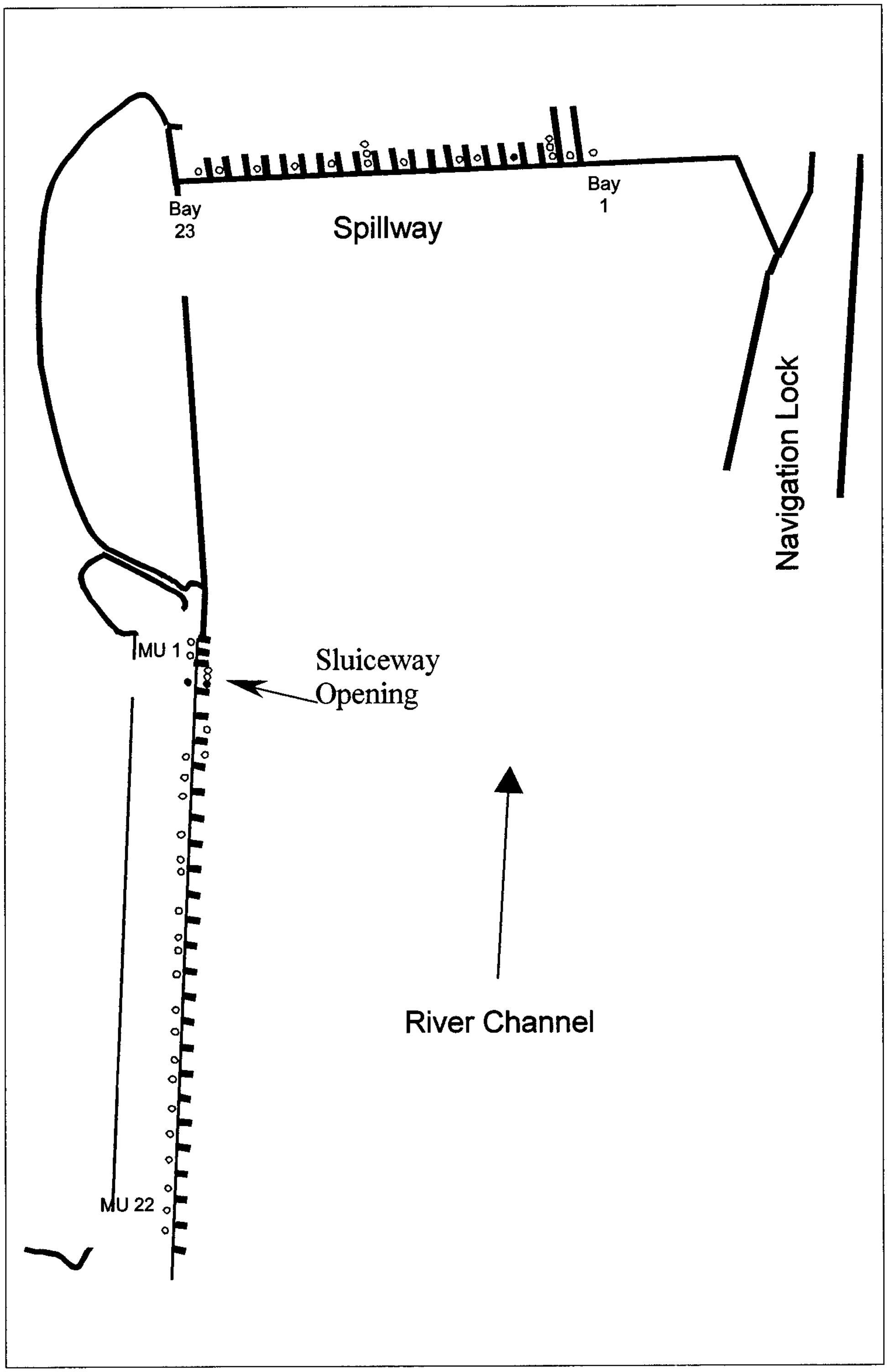


Figure 1. Diagrammatic representation of TDA Project in plan view. Transducer locations are indicated by small circles (filled = split beam; unfilled = single beam). Multiple transducers in Spill Bays 3 and 13 were located adjacent to each other in a line parallel to the spillway axis

Table 1
Study Design and Schedule for the Spill Levels (% of total discharge) during the Hydroacoustic Evaluation at TDA in 1999. A data day was defined from 0600 – 0559 hr

Spring				Summer			
Date	Julian Date	Block	Spill level	Date	Julian Date	Block	Spill Level
22-Apr	112	1	64	3-Jun	154	1	64
23-Apr	113		64	4-Jun	155		64
24-Apr	114		64	5-Jun	156		64
25-Apr	115		30	6-Jun	157		64
26-Apr	116		30	7-Jun	158		30
27-Apr	117		30	8-Jun	159		30
28-Apr	118	2	64	9-Jun	160	2	64
29-Apr	119		64	10-Jun	161		64
30-Apr	120		64	11-Jun	162		64
1-May	121		30	12-Jun	163		30
2-May	122		30	13-Jun	164		30
3-May	123		30	14-Jun	165		30
4-May	124	3	64	15-Jun	166	3	64
5-May	125		64	16-Jun	167		64
6-May	126		64	17-Jun	168		64
7-May	127		30	18-Jun	169		30
8-May	128		30	19-Jun	170		30
9-May	129		30	20-Jun	171		30
10-May	130	4	64	21-Jun	172	4	64
11-May	131		64	22-Jun	173		64
12-May	132		64	23-Jun	174		64
13-May	133		30	24-Jun	175		30
14-May	134		30	25-Jun	176		30
15-May	135		30	26-Jun	177		30
16-May	136	5	64	27-Jun	178	5	64
17-May	137		64	28-Jun	179		64
18-May	138		64	29-Jun	180		30
19-May	139		30	30-Jun	181		30
20-May	140		30	1-Jul	182		30
21-May	141		30	2-Jul	183		30
22-May	142	6	64	3-Jul	184	6	64
23-May	143		64	4-Jul	185		64
24-May	144		64	5-Jul	186		64
25-May	145		30	6-Jul	187		30
26-May	146		30	7-Jul	188		30
27-May	147		30	8-Jul	189		30

2 Materials and Methods

General

Eight hydroacoustic systems were deployed at TDA in 1999. Precision Acoustic Systems (PAS) provided preseason calibrations of four single-beam and two split-beam hydroacoustic systems. The PAS transducers were controlled by PAS 103 transceivers and Hydroacoustic Assessments' HARP software on Pentium-class computers. BioSonics, Inc., calibrated two single-beam hydroacoustic systems deployed at the spillway before sampling. BioSonics 101 transceivers and 151 multiplexers controlled these systems, and data from the Model 101 transceivers were channeled to a computer with an echo-signal processor controlled by BioSonics ESP software.

All transducers transmitted at 420 kHz and had circular beam patterns. All were single-beam transducers except for two 6-deg, split-beam transducers deployed in MU 1 and in Sluiceway 1-3 and another 13-deg split-beam transducer deployed in Spill Bay 5. Locations of transducers (Figure 1) were selected to provide adequate coverage and representative sampling. All systems of transducers were operated at least 23 hr/day, except when equipment failed. Failures were rare but did occur during 3 days in spring at spillway systems, 1 week at MUs 1 through 3, and 1 week at MU 14. From 0.25 to 1 hr per day was required to download data.

Turbine Passage

We randomly selected and sampled one of two intakes in each of the two fish units and one of three intakes in 21 of the 22 MUs (Figure 1). MU 2 was inoperable throughout the study. All intakes were sampled with 7-deg single-beam transducers except Intake 1-3, which had a 6-deg split-beam transducer. Transducers were randomly located in one of three lateral locations (downstream, center, upstream) within every turbine intake. Transducer location and aiming angles were based upon monitoring configurations used in prior years (BioSonics 1996 and 1998). Divers mounted each transducer at the bottom of Trash Rack 5 at a depth of about 26.8 m. Transducers were oriented upward and aimed about 34 deg downstream of vertical (Figure 2). Maximum sampling range was about 13.7 to 15.4 m for fish units and 15.4 to 17.0 m for main units. There were no minimum ranges of detection for in-turbine transducers except for the blanking range of

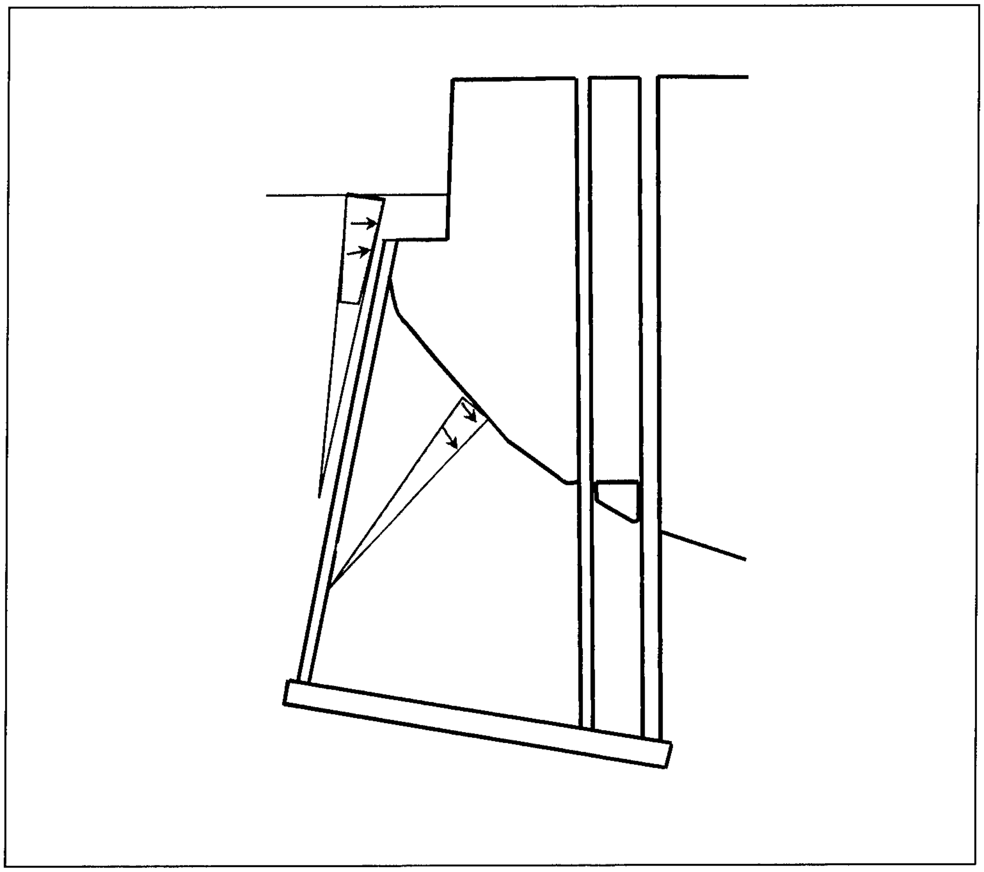


Figure 2. Cross section of a turbine intake at MU 1 showing typical deployment of up-looking hydroacoustic beams for sampling fish passing into the sluiceway (left) and turbine (right)

1 m. However, detectability as a function of range was corrected using methods described under Detectability Modeling below.

The 22 single-beam transducers in turbine intakes were divided among and controlled by three computer-transceiver systems, one of which also controlled the two single-beam transducers in the sluiceways. Each system had eight transducers, which were sampled in pairs for 1 min every 4 min, so that every transducer sampled fifteen 1-min periods every hour. The pulse repetition rate for the transducer pairs was 28 pings/sec (14 pings/sec each). Every fish detected was expanded to the width of the intake based upon Equation 1, and spatially expanded counts and within-hour variances were temporally expanded to the whole hour using methods described in Appendix A. These expansions of sums and variances included extrapolation to intakes that were not sampled.

Sluiceway Passage

We sampled fish passage at sluiceway openings using 7-deg single-beam transducers at Gates 1-1 and 1-2 throughout the study and at Gate 2-2 during the last week of summer. We used a 6-deg split-beam transducer and transceiver to sample fish passing into Sluice Gate 1-3. Transducers were located at the end of 1-m long poles mounted on the upstream side of the fourth trash rack at a depth of about 16.5 m (BioSonics, Inc. 1998). Transducers were aimed upward 5 deg off the plane of the trash racks. The downstream edge of the beam passed within 0.5 m of the upstream edge of the weir (Figure 2). Maximum range of acoustic fish detection was about 16.5 m but varied with forebay elevation.

$$EXP\_FISH = PW / (MID\_R \times TAN(EBA / 2) \times 2) \tag{1}$$

where

EXP_FISH = expanded number of fish

PW = width of the passage route (intake, sluice opening. or spillbay)

MID_R = midpoint range of a trace

TAN = tangent

EBA = effective beam angle in degrees as determined from detectability modeling

Units of PW and MID_R must be consistent (m).

We used the split-beam transducer located in sluice opening 1-3 to characterize the distribution of fish trajectories on an azimuth scale of 0 to 360 deg, where 270 deg was directly downstream into the sluice opening. Fish traces with directions ranging from 205 to 335 deg were counted as passing into the opening if traces were above the weir elevation or within 3 m below the weir but moving up in the water column (positive slope). The fraction of fish meeting the azimuth direction criterion for passage was applied to all single-beam counts at Sluice Gates 1-1, 1-2, and 2-2. This assumes that similar proportions of fish moved toward the opening in the single- and split-beam sample volumes. The upper 0.5 to 1 m of the water column had high densities of entrained air, which likely obscured fish, 90 percent of the time. We estimated passage through the uppermost 1 m of the opening by a four-step process. First, we identified all 1-min samples during each spring and summer spill treatment when the entire range of interest had little or no acoustic noise. Second, for those low noise samples (about 10 percent of all samples), we estimated the vertical distribution of fish from 12 m in range to the water's surface for each season and by spill treatment. Third, for the low noise samples, we calculated the ratio of fish in the upper 1 m to the number passing between 1 and 5 m deep. Fourth, for the 1-min samples in which fish were likely obscured by noise (about 90 percent of all samples), we discarded all fish counts for the uppermost 1 m and replaced them with estimates made from multiplying the ratio calculated in Step 3 by the number of fish tracked in the 1- to 5-m depth range in that sample. For all ranges of those samples in which the upper meter of water was not noisy and for ranges below the top meter of all samples, we used the actual counts from each echogram file.

Transducers sampling sluiceway openings were controlled by several different computer-transceiver systems. The single-beam transducers at Sluice Gates 1-1 and 1-2 were controlled by a computer-transceiver system used to sample turbine units as described in the last paragraph in the previous section on Turbine Passage. The single-beam transducer at Sluice Gate 2-2 and the split-beam transducer at Sluice Gate 1-3 also were controlled by separate computer-transceiver systems, but spatial and temporal sampling and expansions were similar. Each transducer was sampled for 15 randomly selected 1-min periods per hour at a pulse-repetition rate of 14 pings/sec. Every fish detected was expanded to the width of the intake based upon Equation 1, and spatially expanded counts and within-hour variances were expanded to the whole hour using methods described in Appendix A. All open sluice gates were sampled except for the one at Sluice Gate 2-1, which was opened during the last week of summer. We estimated passage through that gate by linear interpolation between passage rates at Sluice Gates 1-3 and 2-2.

Spillway Passage

We sampled 13 spill bays with sixteen 10-deg single-beam transducers and Bay 5 with one 13-deg split-beam transducer (Figure 1). Two bays (3 and 13) were sampled with three single-beam transducers each to evaluate the assumption of a uniform lateral distribution across the 50-ft-wide bays (Results are presented in Appendix B.). Each transducer was mounted on the end of a 30-ft-long, 2.5-in.-outside-diameter pipe that was threaded into a 7.6- × 6-ft base. The base of the mount was designed to span the deck-plate opening in the spillway road surface, support the pipe and transducer extending below (Figure 3), and allow the deck plates to be reinstalled to restore the roadway.

The 1999 deployment located transducers about 4 m downstream of where they were deployed in previous years. Transducers were located at el 154 ft and were aimed 8 deg downstream of vertical (Figure 4).

Flow trajectories and velocities immediately upstream of the spill gates were obtained from simple hydraulic modeling assuming conservation of mass and from field measurements made with an Acoustic Doppler Velocimeter (ADV). We also calculated trajectories and speeds of fish passing through the sampling volume of the split-beam transducer.

Every single-beam transducer was sampled for three 2.5-min periods per hour with a pulse-repetition rate of 24 pings/sec, and the split-beam transducer was sampled for fifteen 2-min periods/hour at 27 pings/sec. Every fish detected was expanded to the width of the intake based upon Equation 1, and spatially expanded counts and within-hour variances were expanded to the whole hour using methods described in Appendix A. Fish passage through spill bays that were not sampled was estimated as described in Appendix A.

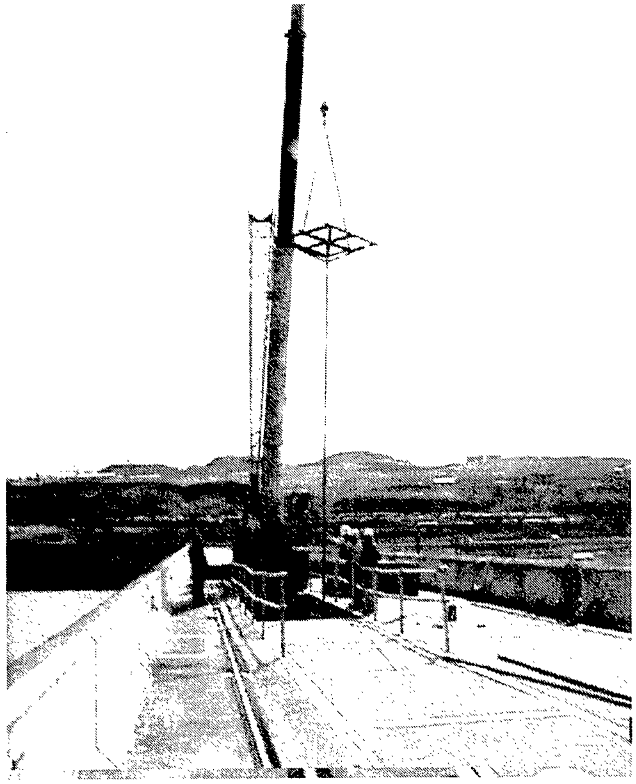


Figure 3. Photograph of a pipe mount being deployed through the deck-plate opening in The Dalles spillway

Fish Trace Selection

Four or more successive echoes in a pattern meeting deployment-specific criteria were tracked as fish. General fish-tracking criteria by deployment are presented in Table 2.

Project Operations

River discharge and its distribution between the powerhouse and spillway were obtained from the Internet (www.cqs.washington.edu/dart). Specific dam operations were obtained by calling the powerhouse operator at about 30 min after the hour, 24 hr each day, and requesting information on down turbines for the current hour. Every day we obtained photocopies of log sheets indicating hourly spill-gate openings from the Control Room at the dam. All data on project operations and total spill and powerhouse discharge were entered into a data set and integrated with fish passage data. Fish passage was set to zero when passage routes were closed, and missing data from failure of monitoring equipment were estimated by linear interpolation or regression.

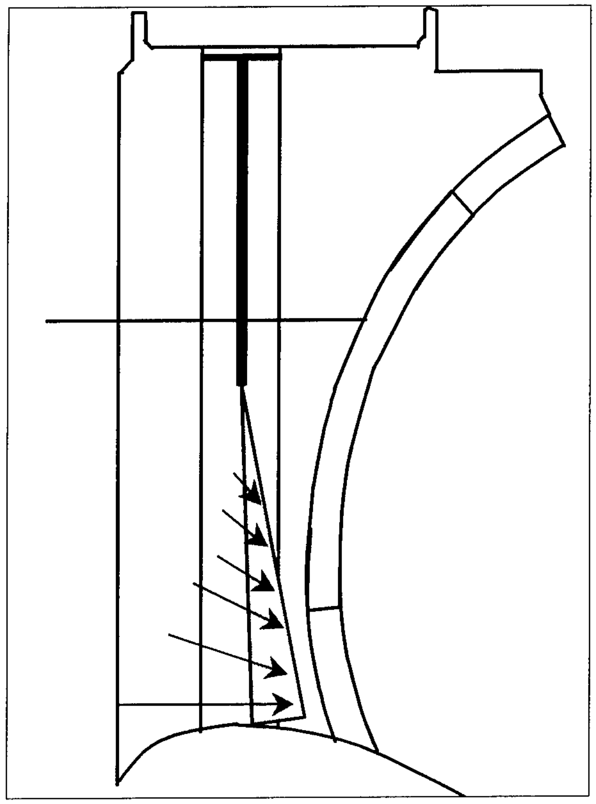


Figure 4. Cross section of a spill bay showing a pipe mount and transducer beam. Approximate flow trajectories are indicated by arrows

Table 2
List of Fish-Tracking Criteria for Deployments at Three Major Passage Routes

Tracking Criteria	Turbines	Spill Bays	Sluiceways
Minimum number of echoes with seed of at least 3 echoes in 5 contiguous pings	4	4	4
Maximum ping gap	4	4	10
Maximum number of echoes	30	60	60
Slope		2.3-20 cm/ping	Range dependent (see range below)
Range	1 m to maximum	2.3 m to maximum	> 15 m; 12-15 m with slope > 0
Direction of movement		Downstream toward spill gate	Azimuth direction = 205-235°; where 270° Is into the opening
Noise around trace	Light	Light	Moderate
Acceptable sampling time as a function of noise due to reverberation	< 30% of range 70% of the time	< 30% of range 70% of the time	All as long as fish traces have at least 4 consecutive echoes

Detectability Modeling

Hydroacoustic detectability is the probability of obtaining adequate numbers of echoes from targets of interest passing through a hydroacoustic beam. Detectability varies with the acoustic size of fish passing through hydroacoustic beams (i.e., fish target-strength distribution) relative to the threshold for data collection and with range from the transducer depending upon characteristics of the hydroacoustic system configuration and environmental conditions. A detailed discussion of the acoustic screen model, which is used to expand counts of fish as a function of detectability, is presented in Appendix B. Only a brief overview is presented here.

The effective beam angles (EBA) for the various hydroacoustic deployments were derived by multiplying an estimated EBA based upon target-strength data (EBA_{TS}) by a normalized EBA (range = 0 to 1 m) based upon range from the sampling transducer ($NEBA_R$). We estimated EBA_{TS} from a model developed by Dr. John Ehrenberg (*circa* 1985). The correlation describes the ratio of EBA to the nominal beam angle as a function of the difference between target strength and the data collection threshold (Figure 5). Target-strength distributions were obtained from split-beam sampling of one turbine, one sluice gate, and one spill bay.

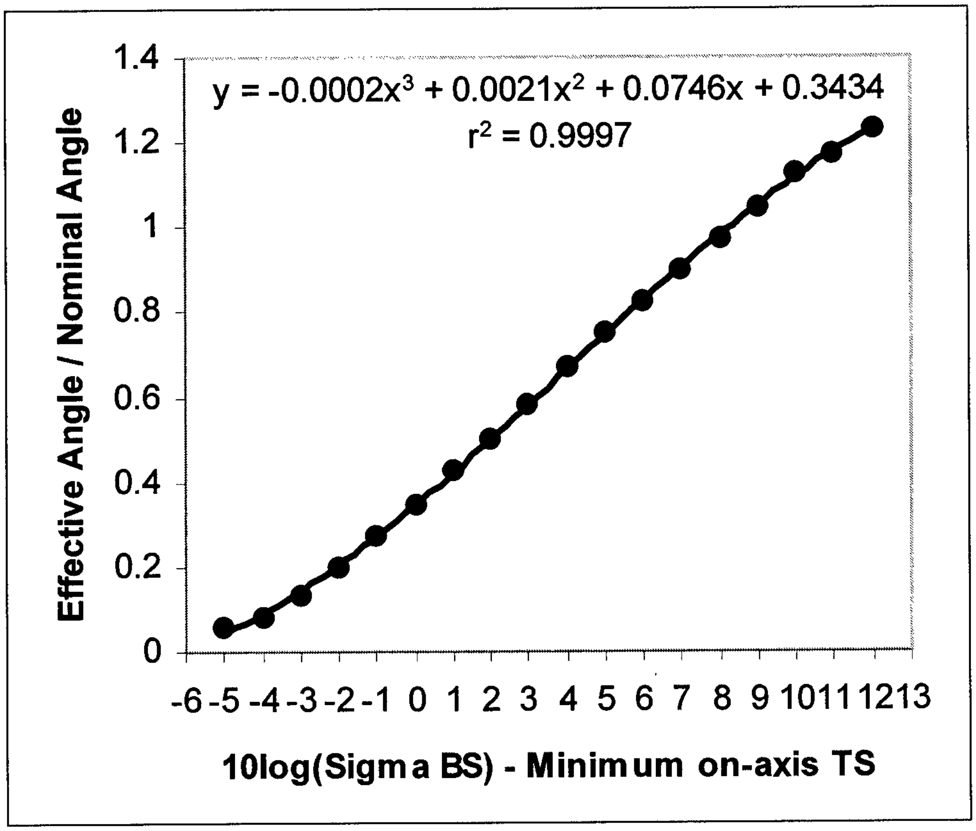


Figure 5. Relation between the effective beam angle to nominal beam angle ratio and the difference between target strength and the minimum on axis threshold. Target strength is calculated from mean back-scattering (Sigma BS) cross section of fish

We estimated $NEBA_R$ by modeling detectability as a function of range from each transducer using a model developed by BioSonics, Inc. The model uses a variety of inputs and estimates effective beam angle as a function of range, which we normalized (Figure 6). The saturation curve in Figure 6 is typical of range-dependent detectability when fish speed and trajectory vary little with range (e.g., in turbines without screens or upstream of sluiceway openings).

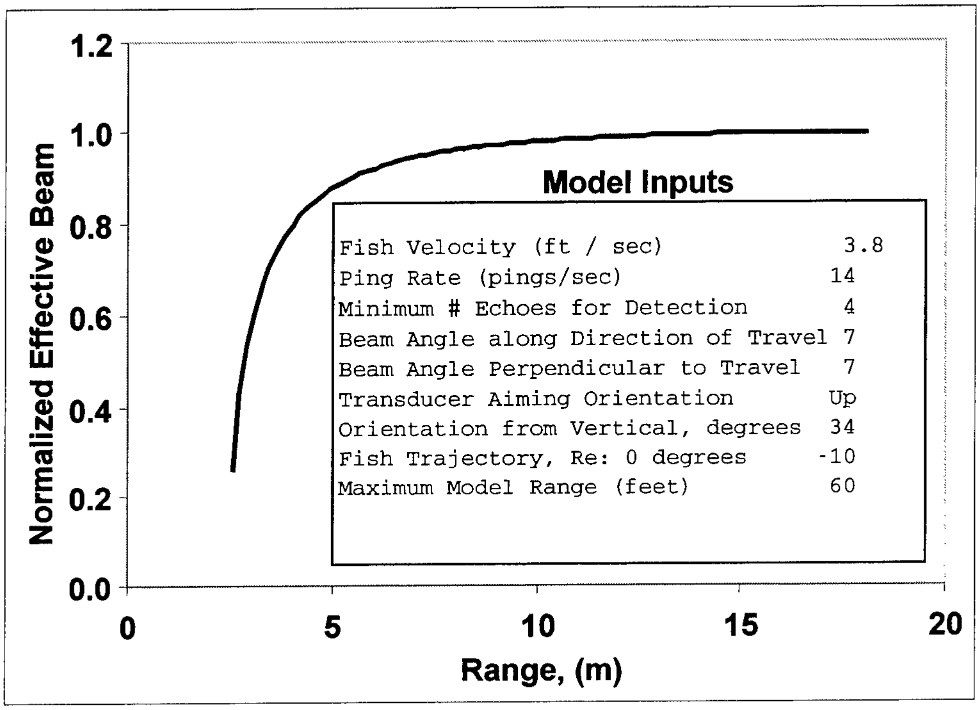


Figure 6. Examples of normalized effective beam angle as a function of range, given detectability model inputs listed in the text box

However, detectability curves can be distinctly different if flow through the hydroacoustic beam varies spatially and temporally, and these characteristics are modeled. For example, we estimated EBA_R for the spillway by running the model once for each of 10 gate openings using eight 1-m-range strata. In every model run, we input different values for fish velocity and trajectory based upon model and field estimates of water velocity and trajectory for a spill gate (Figure 7).

Data Processing and Quality Control

All data collected from the turbine and spillway data were processed with automated tracking software written by Mr. William Nagy, U.S. Army Engineer District, Portland. Some of the turbine and spillway data (about 10 percent) were tracked by people to assure that the autotracker was performing adequately. We regressed human-tracker counts of fish from data collected by turbine and spillway systems on autotracker counts and used the resulting r^2 value as an indicator of the quality of autotracker processing. We also used the regression equations to convert autotracker counts into estimated human-tracker counts before comparing or combining estimates for the spillway and turbines with estimates for the

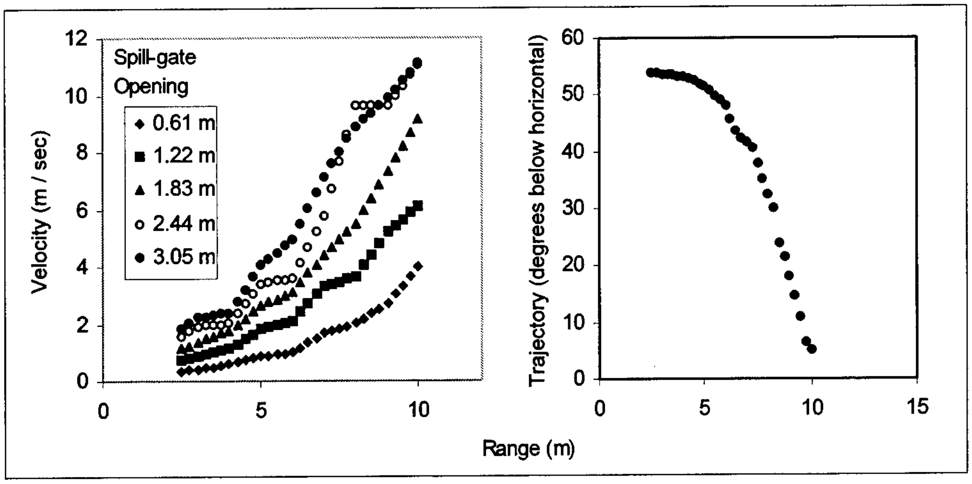


Figure 7. Flow velocity and trajectory as a function of gate opening and range from a down-looking transducer at TDA spillway

sluiceway. This procedure was an effort to reduce systematic bias in data processing within and among the three passage routes. Since the autotracking software could not process the very noisy sluiceway data, we subsampled 40 percent of the sluiceway data for manual tracking by eight people. To minimize intertracker differences in counts among spill treatments, which usually lasted 3 days, the same person tracked all raw data files collected during a 24-hr period for all passage routes. Whether tracking to calibrate the autotracker (on turbine and spillway data) or to provide passage and ratio estimates, each person tracked the entire day's sample. However, the assignment of days to people was not systematic.

Hypothesis tests comparing the various passage metrics under the two spill treatments were done using nonparametric Wilcoxon Signed Rank Tests with $n = 6$ (5 degrees of freedom) and a rejection region with $\alpha = 0.05$. We used a nonparametric test because of the small sample size (there were only six blocks in each season). The Wilcoxon Signed Rank Test compares the treatment periods of each block as a paired sample, as would a paired t-test if the data were deemed approximately normal.

Tracker training

The three students who were our primary trackers were trained together over several days before actual data processing began. After introductory training, they all tracked the same one hundred-eighty 12-min-long files from 1998 Bonneville Dam data that we used for tracker precision evaluation in the previous year (Ploskey et al. in preparation). This data set presents a wide array of tracking challenges, including very noisy data from up-looking transducers inside the Prototype Surface Collector at Bonneville Dam Powerhouse 1. The resulting fish count files were compared fish-by-fish, and traces on which trackers did not agree were discussed and reconciled within the group. The student trackers were responsible for tracking the subset of 1999 TDA turbine and spillway data that were used to calibrate the autotracker program.

The automated tracker could not reliably track the very noisy sluiceway data, and eight trackers, including the three students, manually tracked 40 percent of those data. Although the five added trackers did not train with the students, all were given the same tracking criteria, all had a minimum of 2 years of experience tracking similar data, and possible biases were discussed with them.

Tracker precision

To evaluate the level of precision at which our trackers were operating, we had all of the trackers who worked on data from each passage route redundantly process sample data sets drawn from the 1999 hydroacoustic data files. We evaluated agreement between and among trackers primarily by linear regression and by graphing cumulative fish counts for each tracker and computing percent error (highest minus lowest cumulative count divided by mean cumulative count × 100).

We also computed an "Index of Average Percent Error" presented by Beamish and Fournier (1981) as a means of evaluating precision among technicians analyzing fish otolith data to determine fish age. We computed mean coefficient of variation (the mean of the coefficients of variation across all trackers for each hour), a Pearson Correlation Coefficient, and performed nonparametric hypothesis tests of equality among tracker counts. We used r^2 values from correlations of counts by different trackers as another measure of tracker-induced experimental error.

To evaluate the precision among the three students who did all manual tracking on turbine and spillway data, we paired the students against each other on selected days of data files from the current (1999) year. In both the turbine and spillway cases, the results were compared by linear regression and by plotting cumulative counts for each tracker. For the turbine data, there were three pairings of trackers (all possible combinations), but for the spillway data, one tracker was paired against each of the other two in separate tests. In both cases, each of the three students was paired against the other two.

For us to evaluate the precision with which the eight trackers were operating, they tracked the same forty-eight 12-min files from the sluiceway data, chosen as above. Those files include hydroacoustic data from two up-looking transducers at SL1-1 and SL1-2. Separate counts were recorded for each of the transducers. Since hydroacoustic data are expanded to whole hours, the eight sets of counts from the 48 different 12-min files were arbitrarily summed in groups of five files each. Results from the three remaining files were discarded. The individual tracker counts for each of the resulting two transducers, for each of the 9-hr-long samples, were compared by the methods described for the spillway and sluiceway data sets above.

3 Results

Detectability Modeling

Detectability curves describing effective beam angle as a function of range from the transducers were distinctly different for the spillway deployment compared with the powerhouse deployments (Figure 8). Unlike the typical curves for the powerhouse in which detectability increases with range, at the spillway, detectability decreased with range and spill-gate opening.

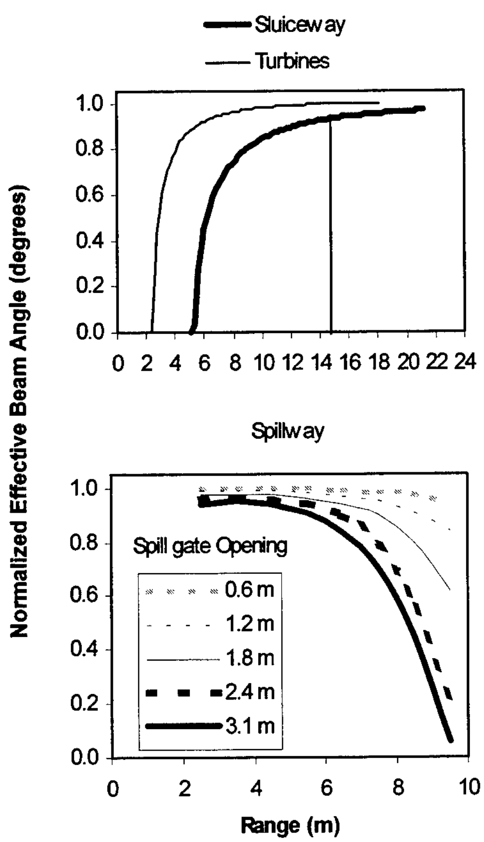


Figure 8. Plots of normalized effective beam angle as a function of range from transducers deployed in sluiceway openings, turbines, and spill gates

The average number of echoes per fish decreased with increasing range from the spillway transducers and also was lower on days of 64-percent spill than on days of 30-percent spill (Figure 9).

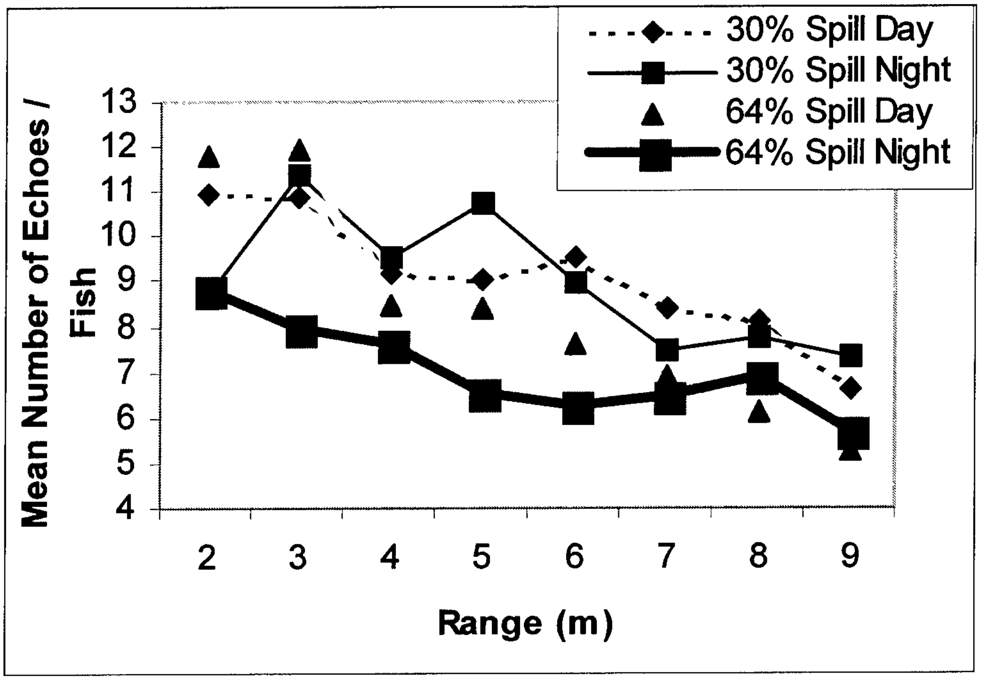


Figure 9. Plot of the mean number of echoes/fish as a function of range from spillway transducers that were transmitting at 24 pings/sec

Intertracker Comparisons

Turbine data

Comparisons among the three student trackers showed very good agreement on the turbine data. For three possible pairings of the three students, the r^2 values were: 0.993 for Students A and B, 0.987 for B and C, and 0.828 for A and C. (Figure 10). The cumulative fish counts for the three trackers also show very good agreement with final cumulative counts differing by less than 2 percent for Students A and B and Students A and C. However, Students B and C differed by nearly 14 percent (Figure 11).

Spillway data

Unfortunately, we never collected data comparing Students B and C, but for the other two pairings, the comparisons among the three student trackers showed less agreement with the spillway data than with the turbine data. The two pairings for which we have data yielded r^2 values of 0.866 for Students A and B and 0.8804 for Students A and C (Figure 12). The cumulative fish counts for the two pairs of trackers for whom we have data differed by almost 8 percent for Students A and B and 40 percent for Students A and C (Figure 13).

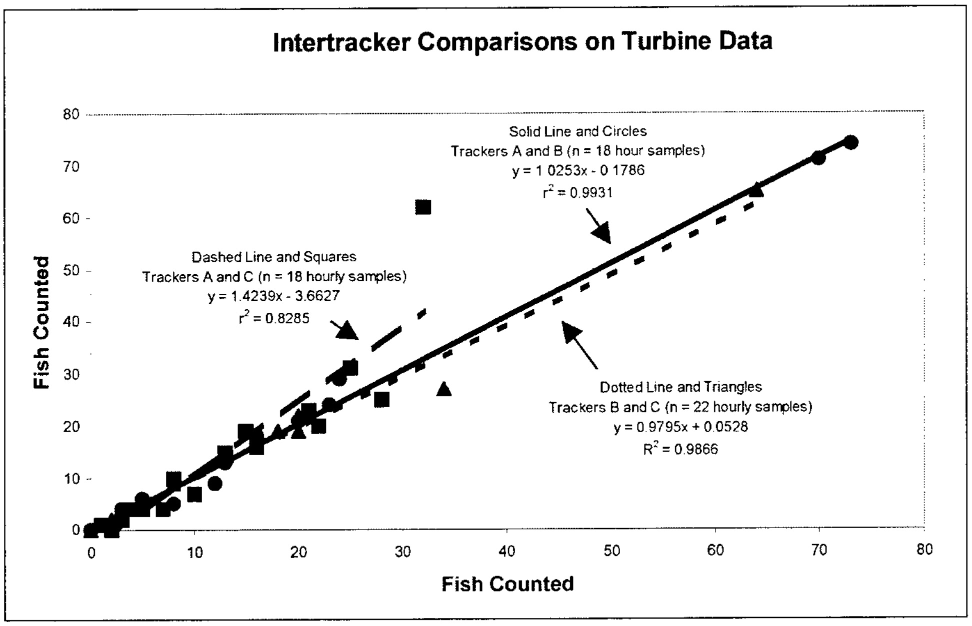


Figure 10. Regressions comparing all possible combinations of two human trackers from the three students who tracked a subset of all of the raw turbine data for calibrating and correcting the autotracker on turbine data

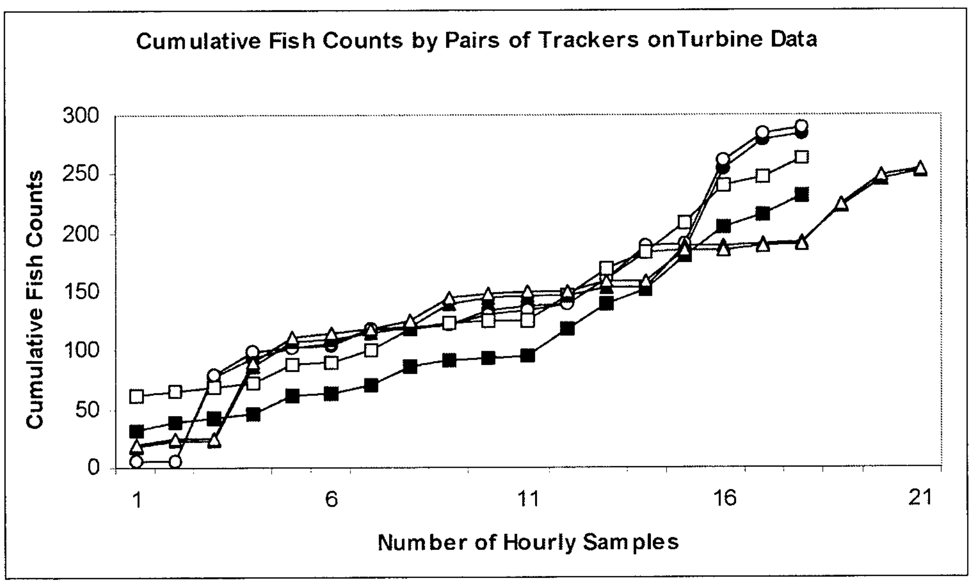


Figure 11. Cumulative fish counts for the three possible combinations of the three students who tracked a subset of all of the raw turbine data for autotracker calibration and correction on turbine data. The solid circles represent cumulative counts of Trackers A (upper solid circles) and B (lower open circles) from the same 18 hourly samples. The solid squares represent cumulative counts of Trackers A (upper solid squares) and C (lower open squares) from the same 18 hourly samples. The solid triangles represent cumulative counts of Trackers B (upper solid triangles) and C (lower open triangles) from the same 22 hourly samples

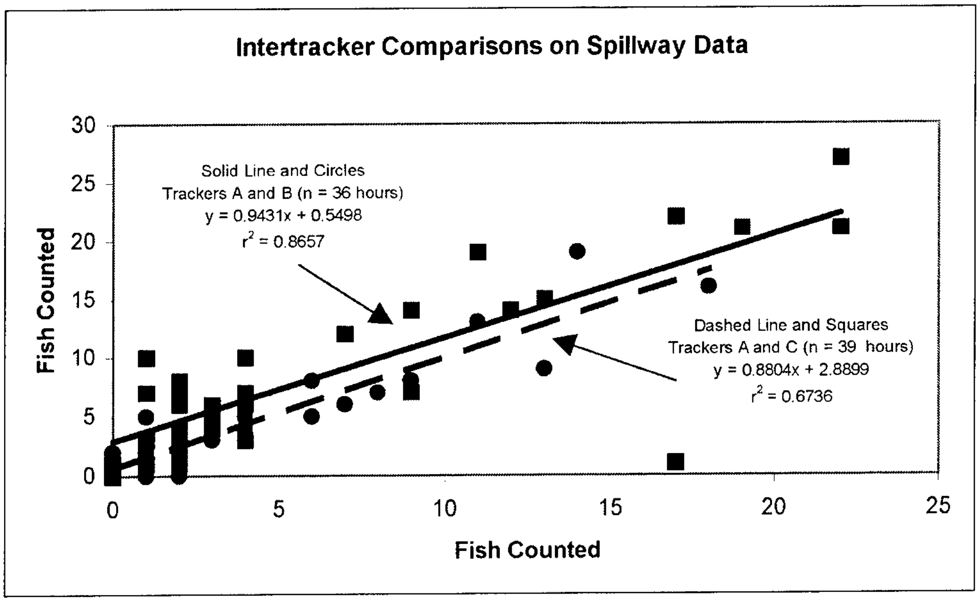


Figure 12. Regressions comparing two of three possible combinations of two human trackers from the three students who tracked a subset of the raw spillway data for calibrating and correcting the autotracker on spillway data. Trackers B and C never tracked the same spillway raw data sets and could not be compared

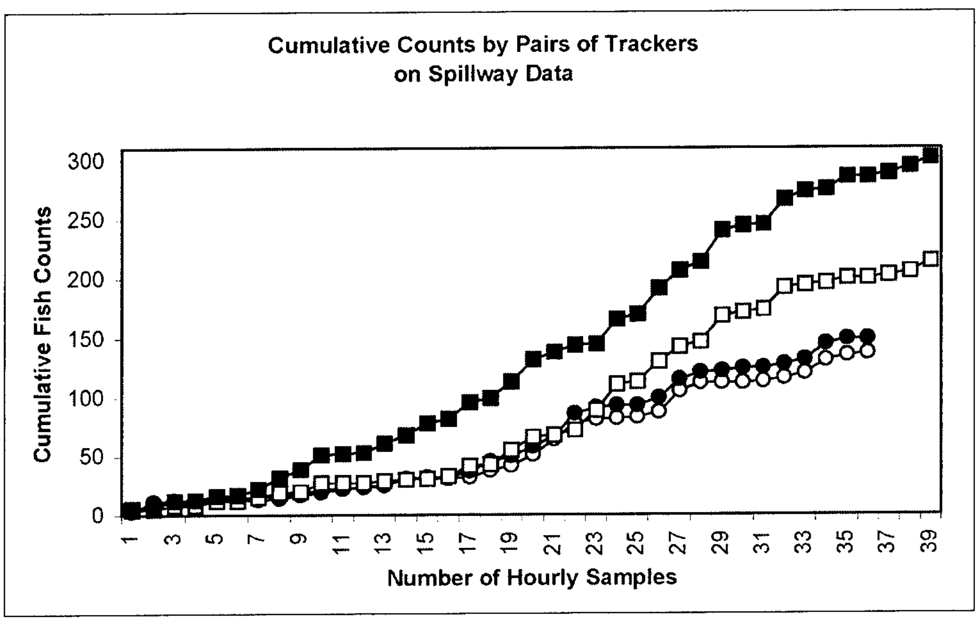


Figure 13. Cumulative fish counts for two of three possible combinations of the three students who tracked a subset of the raw spillway data for autotracker calibration and correction on spillway data. The solid circles represent cumulative counts of Trackers A (upper circles) and B (lower circles) from the same 36 hourly samples. The solid squares represent cumulative counts of Trackers A (upper squares) and C (lower squares) from the same 39 hourly samples. Trackers B and C never tracked the same spillway raw data sets and could not be compared

Sluiceway data

The test on sluiceway data involving eight trackers indicated that precision there was intermediate between that for the turbine and the spillway data sets. We pooled 9 hr of data from two sluice gates to obtain a sample of 18 hr. For these data, the regression was between each of the eight trackers' counts and the mean count of all trackers. These data indicate a fair agreement among the eight trackers ($r^2 = 0.860$, Figure 14). However, the cumulative fish counts indicate considerable divergence over the18 hr, with final cumulative sums ranging from 374 to 535, a difference of 35.4 percent (Figure 15).

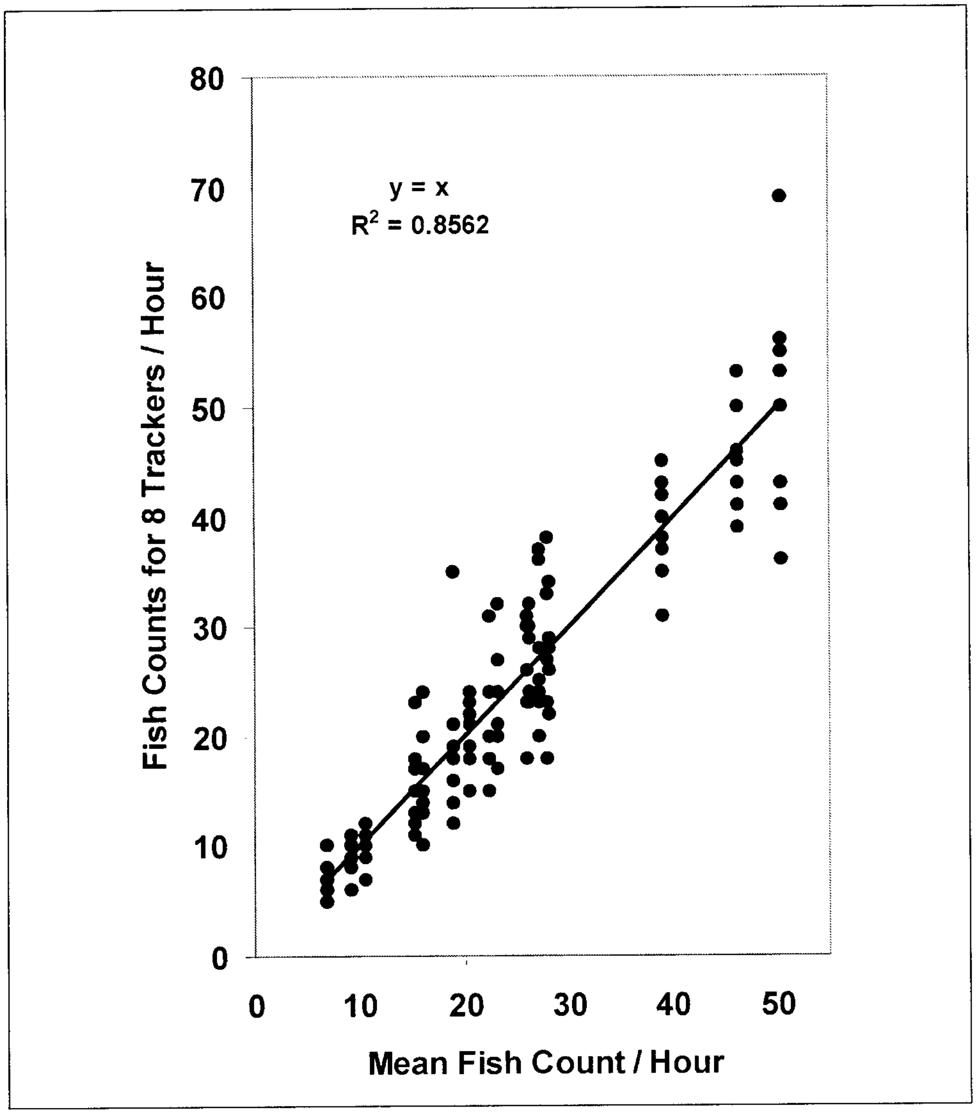


Figure 14. Regression plot comparing fish counts of eight trackers on 18 hr of TDA sluiceway data collected in spring 1999

Other measures of intertracker precision

We considered several other possible measures of tracker precision (Table 3). All measures indicate that intertracker precision was highest for turbine data, next highest for sluiceway data, and lowest for spillway data. The opposite order would result if we ranked the passage routes by the noisiness of echograms.

Table 3
Various Measures of Intertracker Tests of Precision on Hydroacoustic Data from Three Different Passage Routes at TDA in Spring 1999

Data Set	Total # Trackers	Total # Hours	Mean r^2	Cumulative Percent Error	Index of Average Percent Error[1]	Coef. of Variation	Pearson Correlation Coef.	Probability
Turbine	3	57[2]	0.94[2]	4.20%	9.12%	12.89	0.97	0.89[3]
Spillway	3	75[2]	0.77[2]	24.60%	33.08%	46.97	0.85	0.00[3]
Sluiceway	8	18[4]	0.85[5]	35.40%	15.08%	19.98[6]	0.927	0.00[7]
Sluiceway	3	18[4]	0.77[5]	21.00%	13.31%	16.00[8]	0.915	0.00[7]

[1] After Beamish and Fournier (1981).
[2] All pairings (three for turbine, two for spillway) of three trackers combined.
[3] Wilcoxon Signed Ranks Test.
[4] SL1 and SL2 treated separately.
[5] All individual counts plotted against mean count for each hour.
[6] Average of 28 coefficients for eight trackers.
[7] Friedman Test.
[8] Average of three coefficients for three trackers.

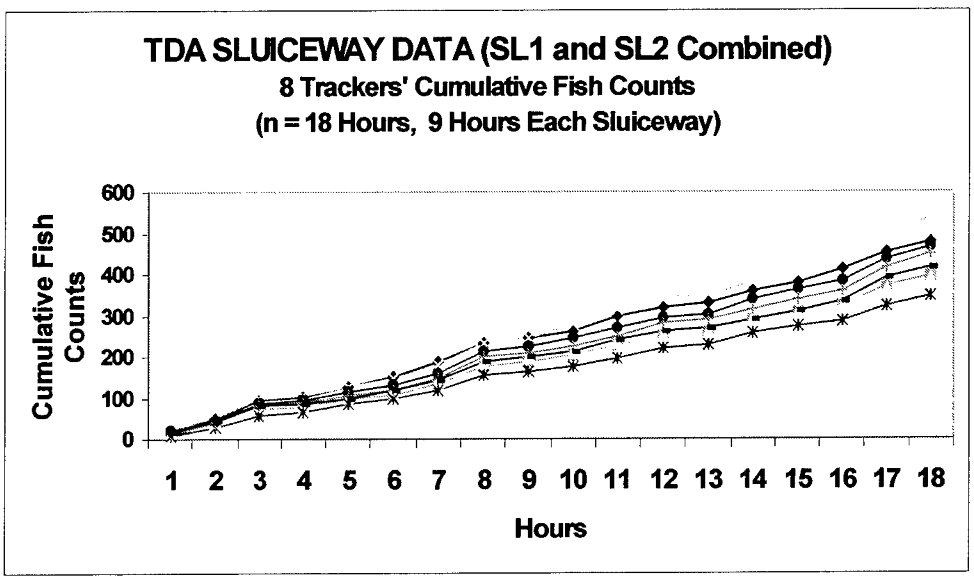


Figure 15. Cumulative fish counts of TDA sluiceway data collected in spring 1999. There were 9 hr of data from two transducers tracked by the eight trackers. Hours 1 through 9 are from SL1, and hours 10 through 18 are from SL2

Autotracking performance

Fits of correlation lines between human tracker counts and autotracker counts were highly significant (Figure 16). Slopes of lines with an intercept set to zero were different for the spillway and turbine deployments. The slope for the spillway regression was closer to unity (0.94) than was the slope for the turbine regression (0.85).

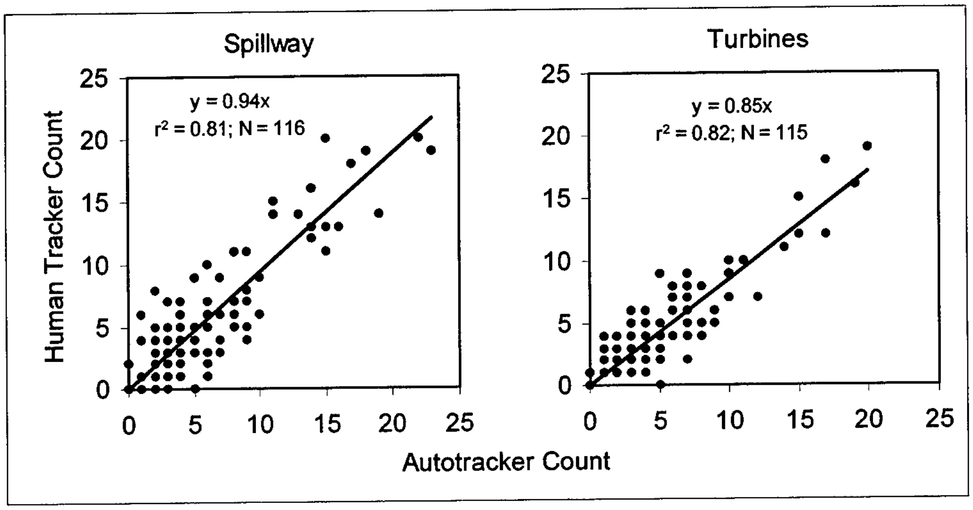


Figure 16. Scatter plots of correlation lines between autotracker counts and counts by people processing the same data set

Treatments

Trends in hourly discharge and percent spill indicate that operators did a good job providing the 30- and 64-percent spill treatments for this study (Figures 17). The average daily percentage of water spilled during the 30-percent spill treatment was 31 percent during both spring and summer. During the 64-percent treatment, spill averaged 62 percent of total discharge during spring and 61 percent during summer.

John Day smolt monitoring and species composition

Although hydroacoustic sampling does not distinguish between species of fish passing the project, species composition data were available from the John Day Dam smolt monitoring facility (Figure 18). These data provide a general indication of run composition and timing during the spring season. However, the John Day smolt index is derived from fish diverted from the turbines and into the juvenile bypass system. It does not account for fish passage through the John Day Dam spillway. During the second half of the spring sampling season, the index varied inversely with the volume spilled (Figure 19).

The summer smolt outmigration consists almost entirely of subyearling chinook (Figure 20). In addition, the seasonal pattern of passage seen in the smolt index data is similar to the total counts of fish detected with hydroacoustics at TDA (Figure 21).

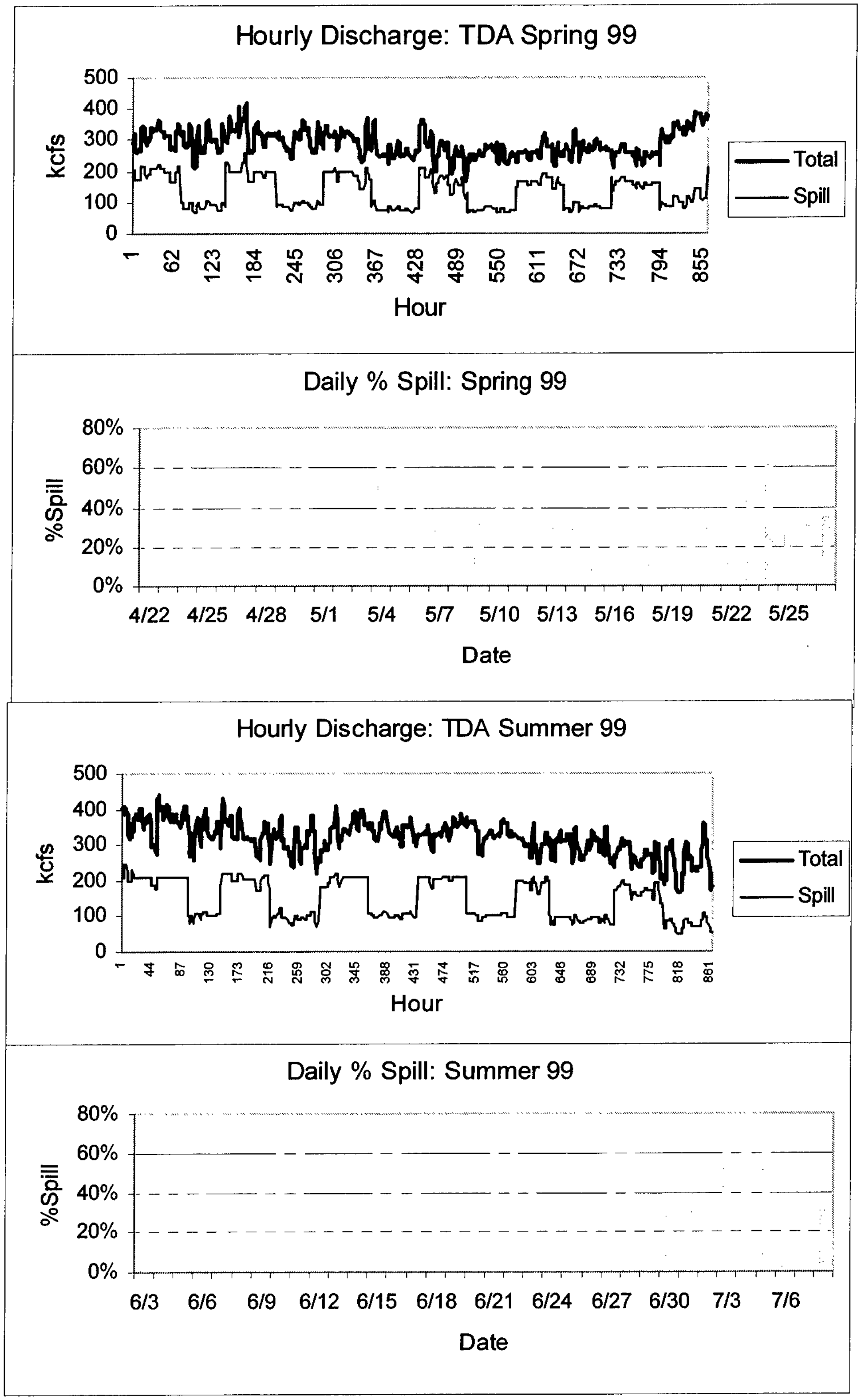


Figure 17. Trends in project discharge and percent spill at TDA in spring and summer 1999

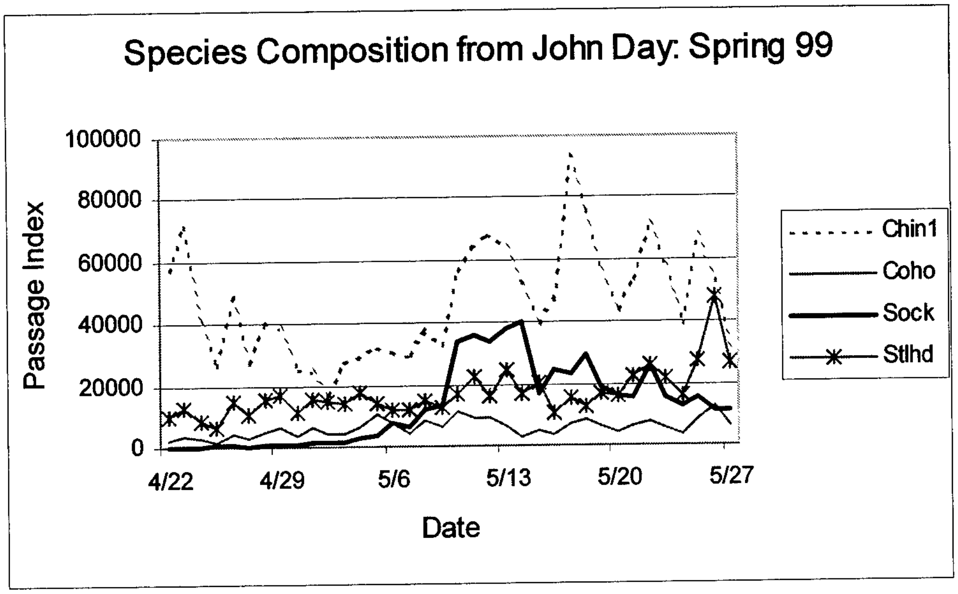


Figure 18. Species composition data from John Day Dam during spring 1999

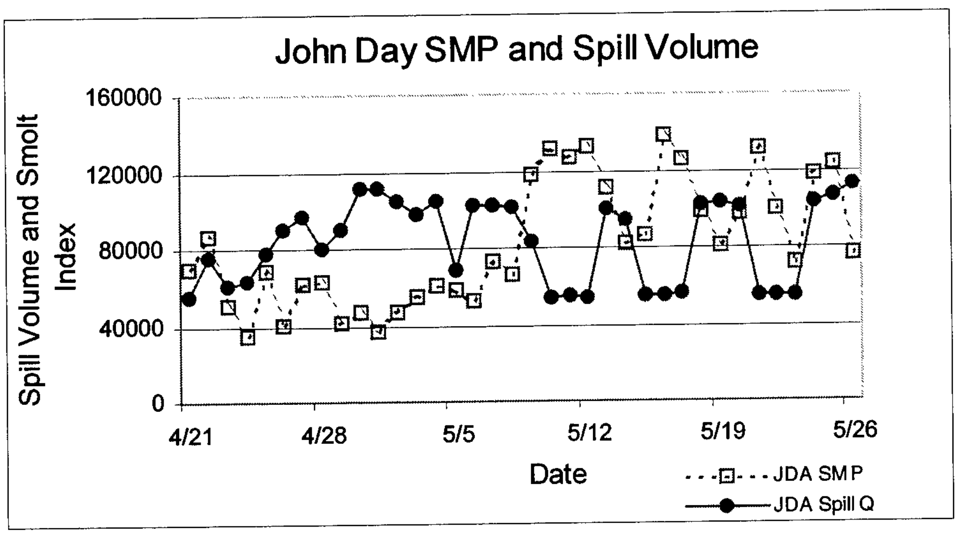


Figure 19. John Day smolt passage index and spill volume from John Day Dam during spring 1999

Interpolation of estimates to unsampled spill bays

In our comparison of linear interpolation vs spill bay discharge (Q), we found many significant correlations of fish passage estimates based on our sampling at Spill Bay 2 with estimates from linear interpolation of our estimates from sampling at Spill Bays 1 and 3. Passage estimates were rarely correlated well with Q. Linear interpolation was somewhat more successful at night, under lower spill regimes, and in summer. Linear interpolation between passage estimates at Spill Bay 2 and the means of those from Spill Bays 1 and 3 were improved somewhat by normalizing the estimates by Q. For a complete discussion of interpolating unsampled spill bays, see Appendix C.

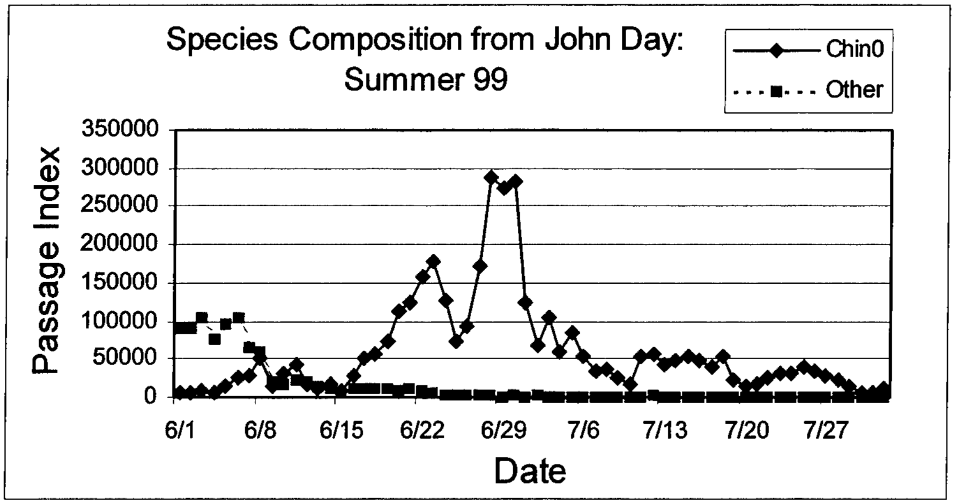


Figure 20. Species composition data from John Day Dam during summer 1999

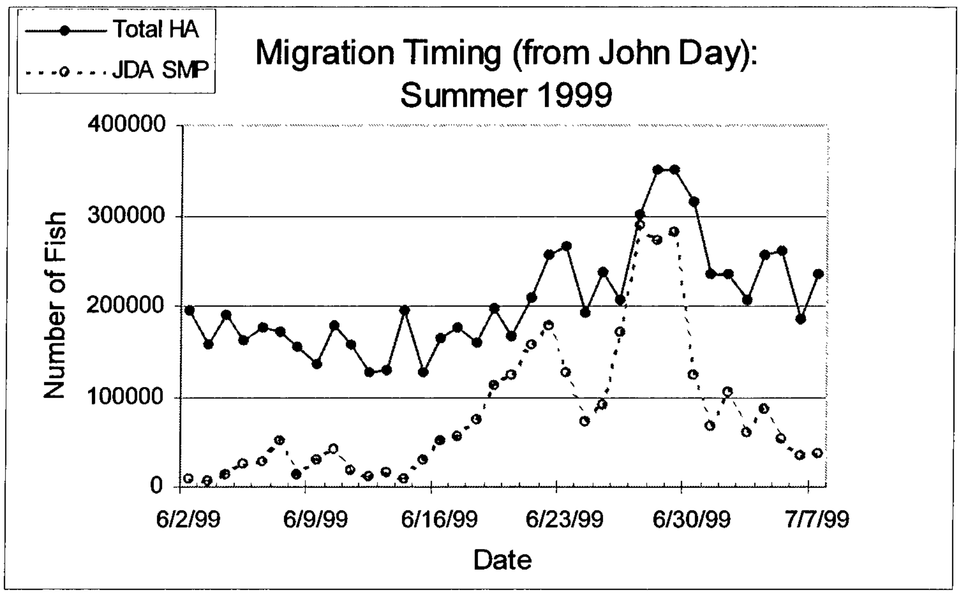
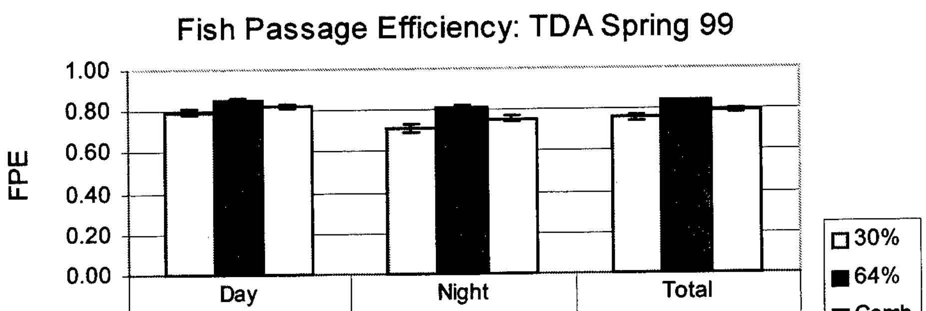


Figure 21. Smolt migration index from John Day Dam (dashed line) and the hydroacoustic measure of passage (solid line) during summer 1999

Passage metrics

a. *Fish passage efficiency.* Project fish passage efficiency (FPE) was estimated at 0.79 during spring 1999. Project FPE was estimated at 0.84 during 64-percent spill and 0.76 during 30-percent spill in spring. We found significantly greater passage at night during 64-percent spill ($p = 0.028$) as compared with the lower spill level but found no differences between spill levels during the day (Figure 22, Table 4).



	Day	Night	Total
30%	0.79	0.72	0.76
64%	0.86	0.81	0.84
Comb	0.82	0.75	0.79

Figure 22. Histogram showing The Dalles project FPE by spill treatment and time of day in spring 1999

Table 4
Results of Wilcoxon Signed Rank Tests of Comparisons of Passage Metrics and Fish-Passage Numbers by Spill Treatment for All Significant Passage Routes at TDA in Spring. Significant differences are denoted by *

Variable Tested	Diel Period	Results	p-value
Project Fish Passage Efficiency (FPE)	Day	64% > 30%	0.249
	Night	64% > 30%	0.028*
Spill Efficiency (SPY)	Day	64% > 30%	0.173
	Night	30% > 64%	0.028*
Spill Effectiveness (SPS)	Day	30% > 64%	0.028*
	Night	30% > 64%	0.028*
Sluice Efficiency Relative to Powerhouse	Day	64%>30%	0.345
	Night	64%>30%	0.345
Sluice Effectiveness Relative to Powerhouse	Day	30% > 64%	0.028*
	Night	30% > 64%	0.028*
Sluice Efficiency Relative to Total Project	Day	30% > 64%	0.436
	Night	30% > 64%	0.028*
Sluice Effectiveness Relative to Total Project	Day	30% > 64%	0.600
	Night	30% > 64%	0.046*
Spill Fish Passage	Day	30% = 64%	0.345
	Night	30% > 64%	0.173
Sluice Fish Passage	Day	30% > 64%	0.046*
	Night	30% > 64%	0.028*
Turbine Fish Passage	Day	30% > 64%	0.173
	Night	30% > 64%	0.028*

Overall Project FPE was estimated at 0.69 during the summer, 0.76 during 64-percent spill treatments, and 0.63 during 30-percent spill treatments. As in spring, summer nighttime FPE was significantly higher at 64-percent spill treatments ($p = 0.028$), but daytime differences were not significant (Figure 23, Table 5).

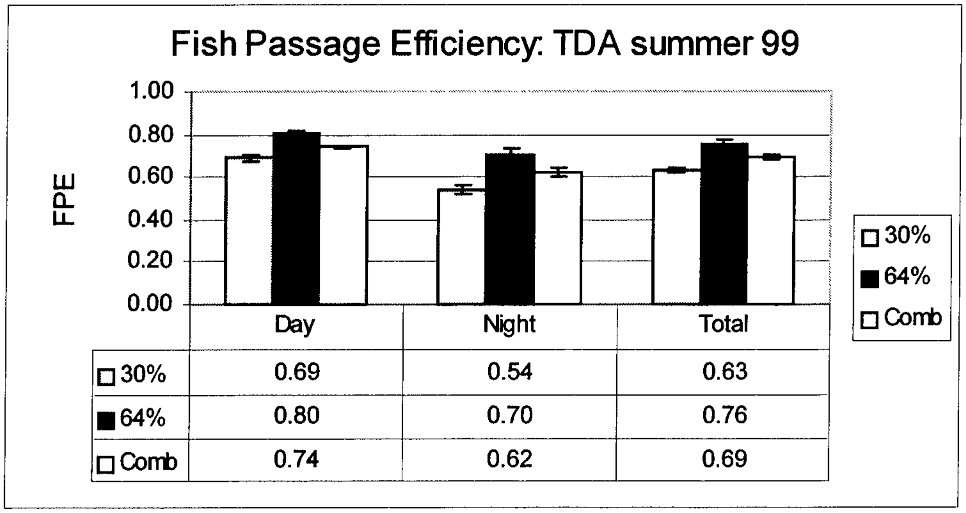
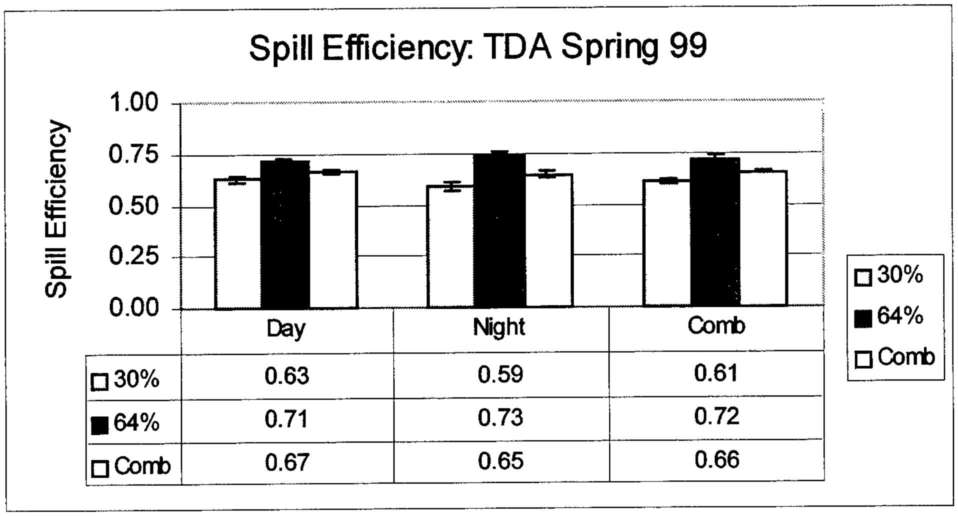


Figure 23. Histogram showing The Dalles project FPE by spill treatment and time of day in spring 1999

Table 5
Results of Wilcoxon Signed Rank Tests of Comparisons of Passage Metrics and Fish Passage Numbers by Spill Treatment for All Significant Exit Routes at TDA in Summer. Significant differences are denoted by *

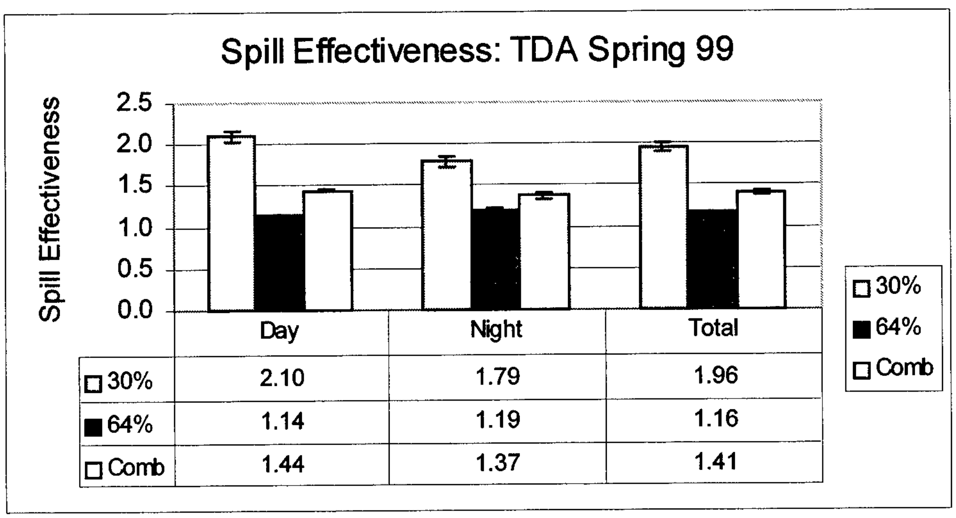
Variable Tested	Diel Period	Results	p-value
Project Fish Passage Efficiency (FPE_)	Day	64% > 30%	0.175
	Night	64% > 30%	0.028*
Spill Efficiency (SPY)	Day	64% > 30%	0.249
	Night	64% > 30%	0.028*
Spill Effectiveness (SPS)	Day	30% > 64%	0.028*
	Night	30% > 64%	0.028*
Sluice Efficiency Relative to Powerhouse	Day	64% > 30%	0.249
	Night	64% > 30%	0.028*
Sluice Effectiveness Relative to Powerhouse	Day	30% > 64%	0.463
	Night	30% > 64%	0.463
Sluice Efficiency Relative to Total Project	Day	64% > 30%	0.345
	Night	30% = 64%	0.600
Sluice Effectiveness Relative to Total Project	Day	64% > 30%	0.345
	Night	64% > 30%	0.249
Spill Fish Passage	Day	64% > 30%	0.917
	Night	64% > 30%	0.046*
Sluice Fish Passage	Day	64% > 30%	0.249
	Night	64% > 30%	0.463
Turbine Fish Passage	Day	30% > 64%	0.075
	Night	30% > 64%	0.046*

b. *Spillway efficiency and effectiveness.* The spill efficiency in spring 1999 averaged 66 percent and was 11 percent higher for the 64-percent treatment than for the 30-percent treatment. At night the difference was significant ($p = 0.028$, 64-percent spill was more efficient) but not during the day (Figure 24, Table 4). Spring spill effectiveness was significantly higher ($p = 0.028$) at the 30-percent spill level than at the 64-percent level during both day and night sampling (Figure 25, Table 4).



	Day	Night	Comb
30%	0.63	0.59	0.61
64%	0.71	0.73	0.72
Comb	0.67	0.65	0.66

Figure 24. Histogram showing the spill efficiency by spill treatment and time of day at TDA in spring 1999

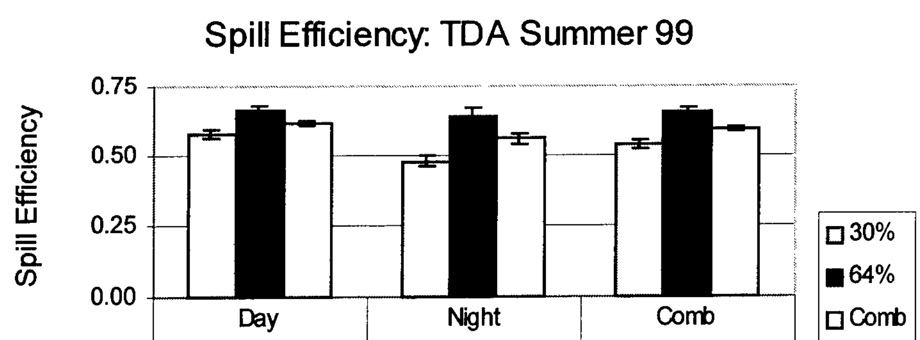


	Day	Night	Total
30%	2.10	1.79	1.96
64%	1.14	1.19	1.16
Comb	1.44	1.37	1.41

Figure 25. Histogram showing the spill effectiveness by spill treatment and time of day at TDA in spring 1999

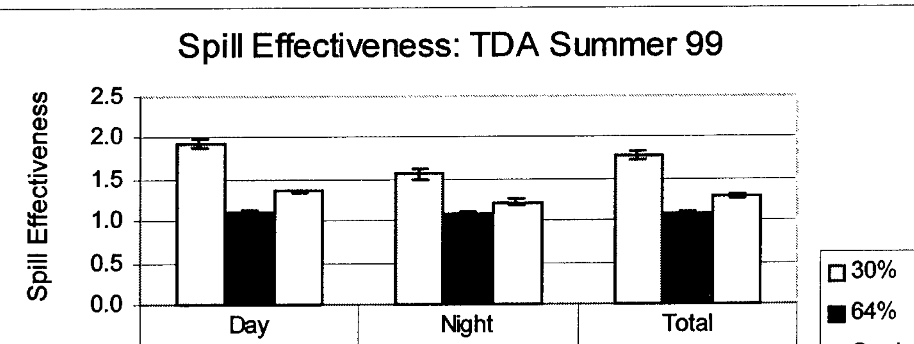
The spill efficiency in summer 1999 averaged 59 percent for all periods sampled. During night samples at 64-percent spill, efficiency averaged 64 percent and was significantly higher ($p = 0.028$) than night samples at 30-percent spill, which averaged 48 percent. Daytime efficiency was 67 percent during 64-percent spill and 58 percent during

30-percent spill. This difference was not significant (Figure 26, Table 5). As during the spring, summer spill effectiveness was significantly higher at the 30-percent spill level than at the 64 percent level during both day and night sampling (p = 0.028 for both day and night, Figure 27, Table 5).



	Day	Night	Comb
30%	0.58	0.48	0.54
64%	0.67	0.64	0.66
Comb	0.62	0.56	0.59

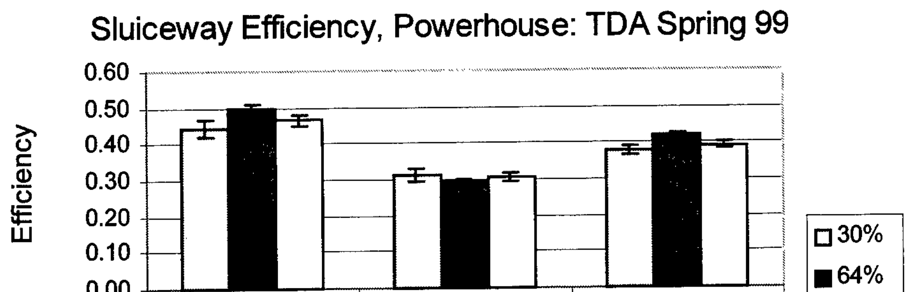
Figure 26. Histogram showing the spill efficiency by spill treatment and time of day at TDA in summer 1999



	Day	Night	Total
30%	1.93	1.57	1.78
64%	1.10	1.07	1.09
Comb	1.35	1.22	1.30

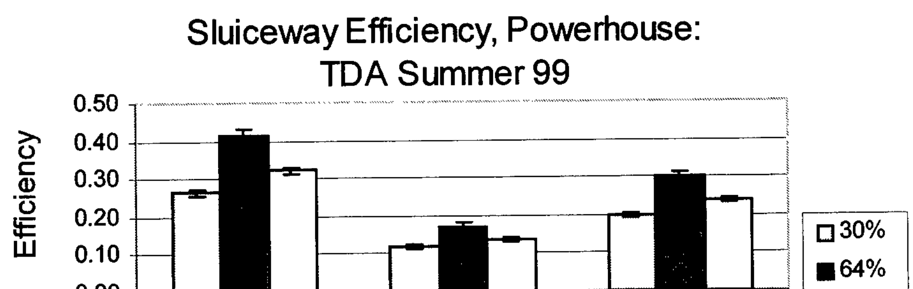
Figure 27. Histogram showing the spill effectiveness by spill treatment and time of day at TDA in spring 1999

c. *Sluiceway efficiency and effectiveness relative to powerhouse.* Relative to the powerhouse, the mean efficiency of the sluiceway (39 percent) during spring was not significantly different between the spill treatments, day or night, and was 16 percent higher during the day than at night (Figure 28, Table 4). In summer, the mean efficiency of the sluiceway relative to the powerhouse was 32 percent during the day and 14 percent at night (Figure 29). As in spring, we found no significant difference in sluiceway



	Day	Night	Comb
30%	0.44	0.31	0.38
64%	0.50	0.29	0.42
Comb	0.47	0.31	0.39

Figure 28. Histogram showing the sluiceway efficiency relative to the powerhouse by spill treatment and time of day at TDA in spring 1999

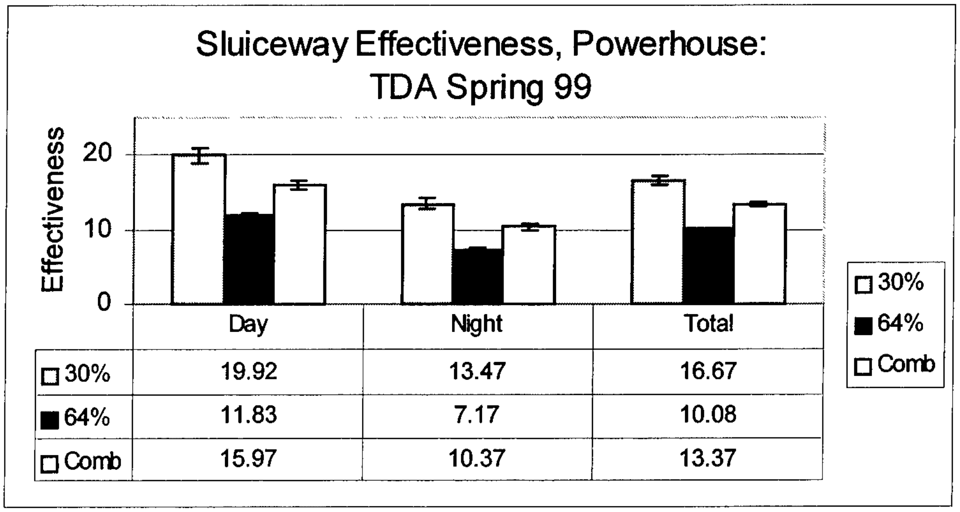


	Day	Night	Comb
30%	0.26	0.12	0.20
64%	0.42	0.17	0.30
Comb	0.32	0.14	0.24

Figure 29. Histogram showing the sluiceway efficiency relative to the powerhouse by spill treatment and time of day at TDA in summer 1999

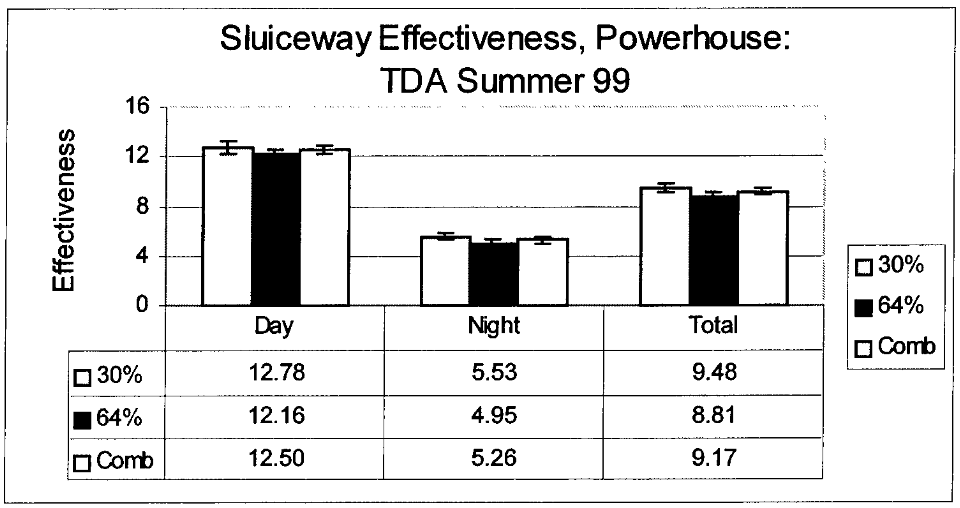
efficiency relative to the powerhouse between the spill treatments during the day, but sluiceway efficiency was significantly greater at night with 64-percent spill ($p = 0.028$, Figure 29, Table 5).

The effectiveness of the sluiceway relative to the powerhouse during spring tended to be higher during the day than at night, and it was significantly higher during the 30-percent spill treatment than during the 64-percent treatment at both night and daytime ($p = 0.028$, Figure 30, Table 4). In summer, the effectiveness of the sluiceway relative to the powerhouse tended to be much higher during the day than at night but not significantly different between the spill treatments by either night or day (Figure 31, Table 5).



	Day	Night	Total
30%	19.92	13.47	16.67
64%	11.83	7.17	10.08
Comb	15.97	10.37	13.37

Figure 30. Histogram showing the sluiceway effectiveness relative to the powerhouse by spill treatment and time of day at TDA in spring 1999



	Day	Night	Total
30%	12.78	5.53	9.48
64%	12.16	4.95	8.81
Comb	12.50	5.26	9.17

Figure 31. Histogram showing the sluiceway effectiveness relative to the powerhouse by spill treatment and time of day at TDA in summer 1999

d. *Sluiceway efficiency and effectiveness relative to total project.* Relative to the entire project, spring sluiceway efficiency was 16 percent during the day and 11 percent at night (Figure 32). The mean efficiency was significantly higher under the 30-percent ($p = 0.028$) spill treatment than under the 64-percent spill treatment at night but did not differ between the treatments during the day (Table 4). In summer, sluiceway efficiency was 11 to 14 percent higher during the day and 6 percent higher at night (Figure 33), but we found no significant difference between spill treatments during either day or night sampling (Table 5).

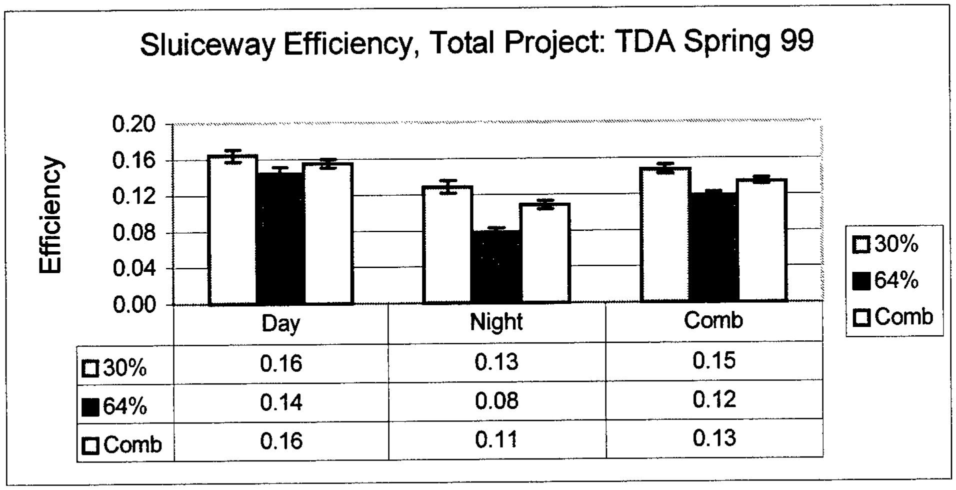


Figure 32. Histogram showing the sluiceway efficiency relative to the entire project by spill treatment and time of day at TDA in spring 1999

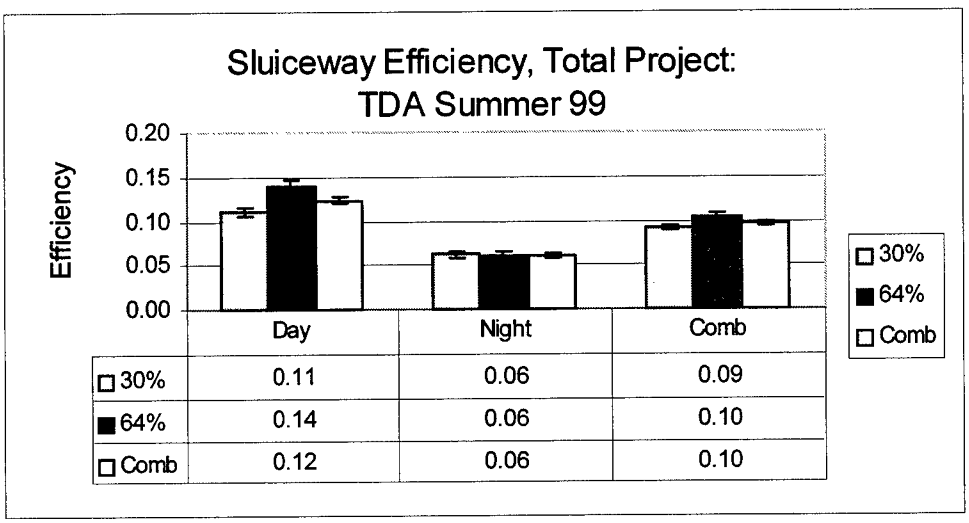
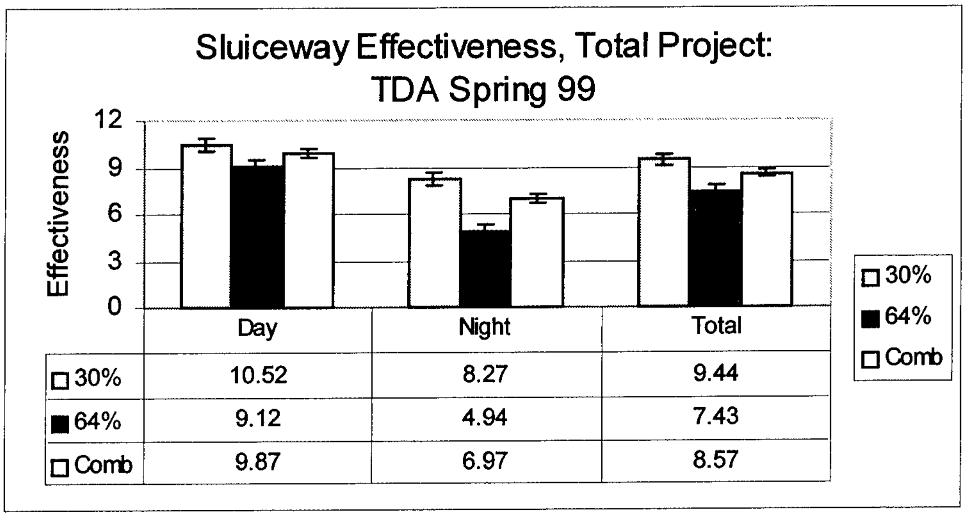


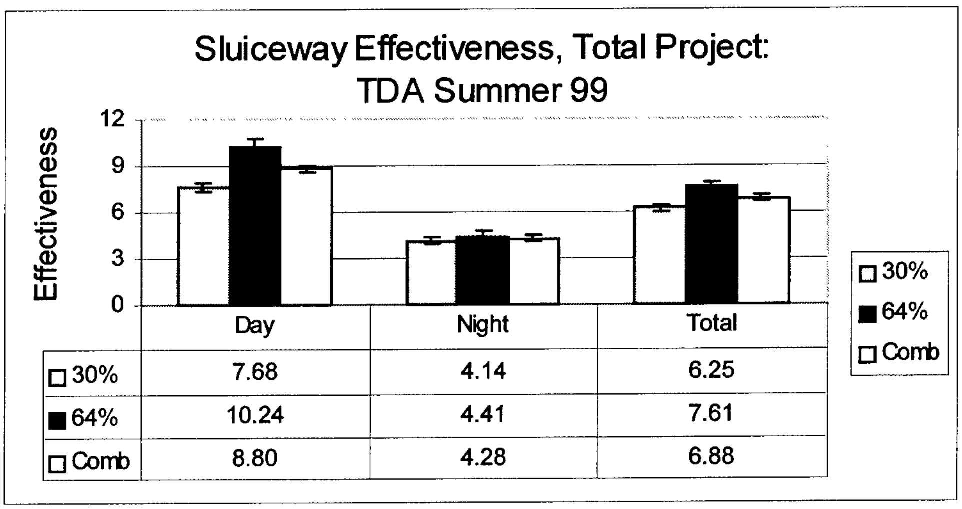
Figure 33. Histogram showing the sluiceway efficiency relative to the entire project by spill treatment and time of day at TDA in summer 1999

Mean sluiceway effectiveness was higher during the day (9.87) than at night (6.97; Figure 34) during spring. Relative to the entire project, sluiceway effectiveness was significantly ($p = 0.046$) higher at the 30-percent spill level than at the 64-percent level at night but was not significantly different during the day (Figure 34, Table 4). In summer, sluiceway effectiveness was higher during the day than at night during both treatments (Figure 35), but there was no significant effect of spill treatment on sluiceway effectiveness relative to the entire project during day or night (Table 5).



	Day	Night	Total
30%	10.52	8.27	9.44
64%	9.12	4.94	7.43
Comb	9.87	6.97	8.57

Figure 34. Histogram showing the sluiceway effectiveness relative to the entire project by spill treatment and time of day at TDA in spring 1999



	Day	Night	Total
30%	7.68	4.14	6.25
64%	10.24	4.41	7.61
Comb	8.80	4.28	6.88

Figure 35. Histogram showing the sluiceway effectiveness relative to the powerhouse by spill treatment and time of day at TDA in summer 1999

e. Passage metrics and spill volume. We examined the relationship between spill volume and the proportion of fish passing the project through each passage route. During spring, spill efficiency increased with increased spill discharge until a discharge level of approximately 150 thousand feet per second (kcfs) was reached. Above this discharge level, spill efficiency decreased (Figure 36). This decrease in spill efficiency was accompanied by increases in sluice efficiency and turbine fish passage through the powerhouse turbines at high spill discharge (Figure 36). In summer, the relationship between the passage metrics and spill discharge was linear over the range of the volume of water spilled. Spill efficiency increased slightly with increasing discharge, sluice efficiency stayed about the same, and turbine fish passage dropped slightly (Figure 37).

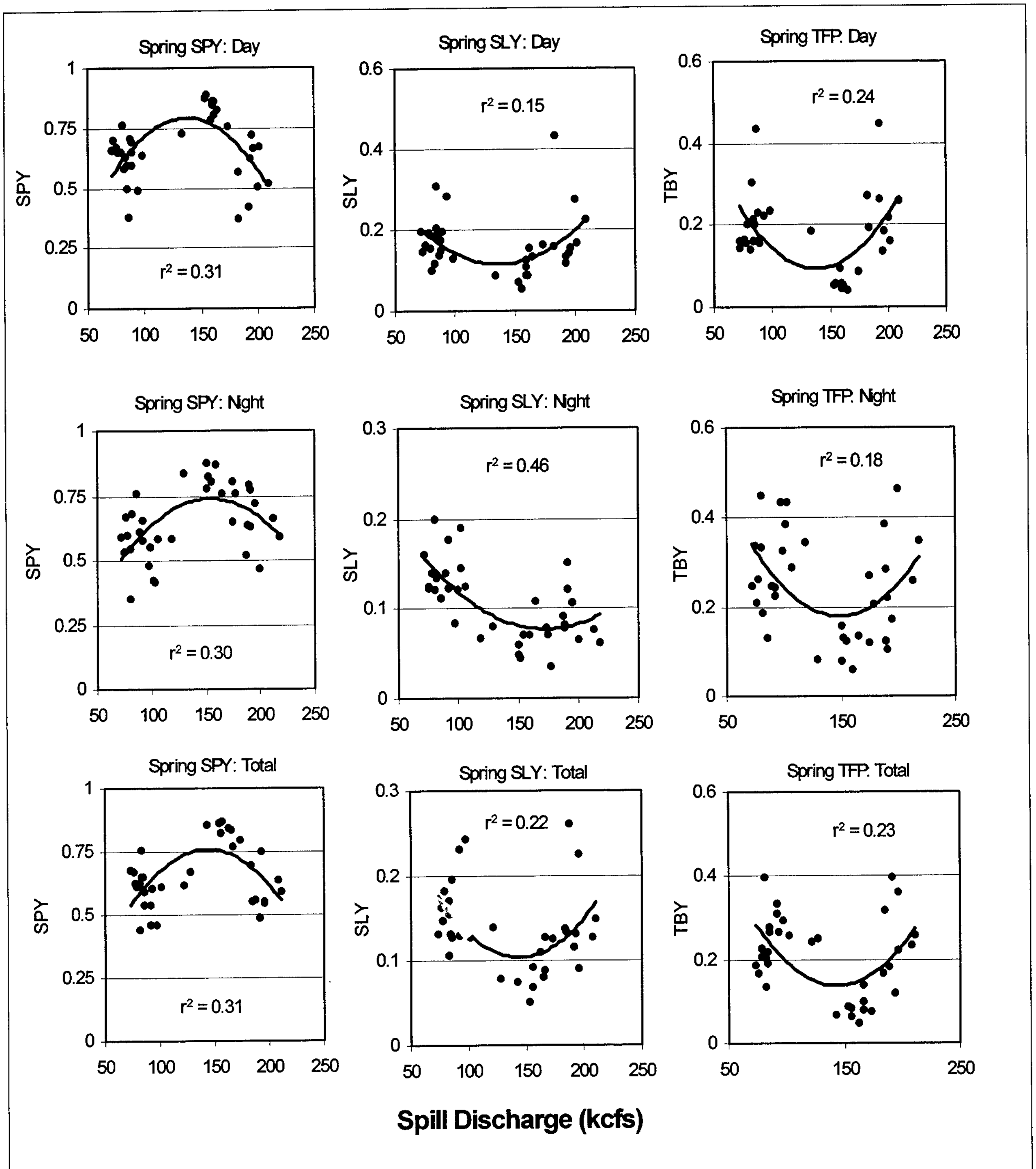


Figure 36. Plots of the efficiencies of the spillway (SPY - left), sluiceway (SLY - middle), and turbines (TFP - right) for passing fish as a function of spill discharge in spring

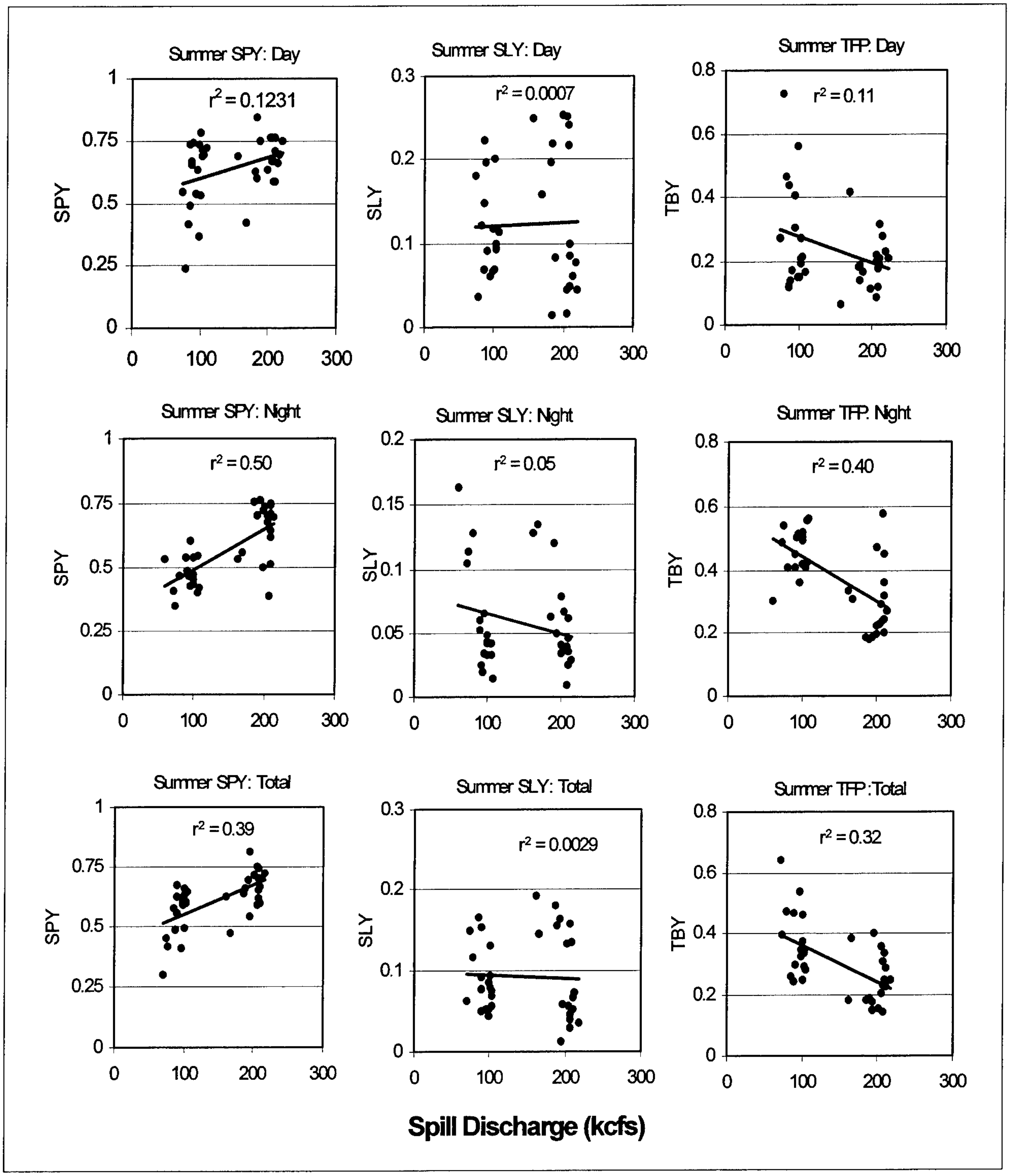


Figure 37. Plots of the efficiencies of the spillway (SPY – left), sluiceway (SLY – middle), and turbines (TFP – right) for passing fish as a function of spill discharge in summer

We examined the seasonal timing of both the ascending (spill efficiency increasing) and the descending (spill efficiency decreasing) legs of the spill efficiency curves in spring (Figure 38) to assess possible effects of species composition changes on the relationship. We found that both legs of the curve contained data taken during the full range of the sampling season. However, the periods of highest average daily spill discharge in spring occurred during the first half of the season.

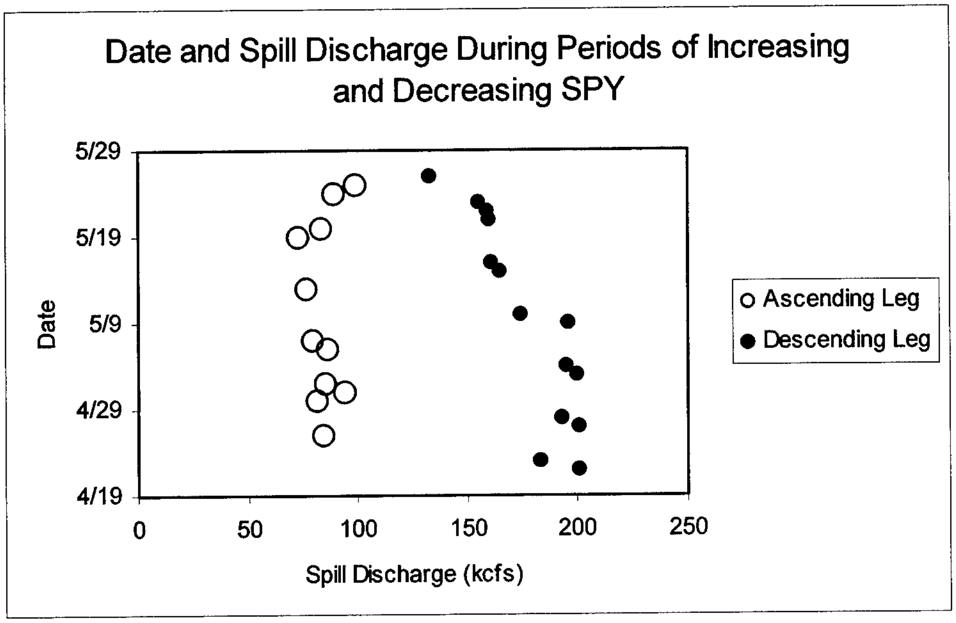


Figure 38. Date and spill discharge during periods of increasing and decreasing SPY during spring. This figure refers to the lower left plate in Figure 36

Fish passage

The total number of fish passing The Dalles project during the spring generally increased as the sampling season progressed (Figure 39), as did the index numbers from the John Day smolt passage facility (Figure 19). Passage estimates were stable during the first half of the spring, but after the John Day passage index rose nearly halfway through the season, total expanded fish counts began to fluctuate inversely with spill volume (Figure 39). Passage through the powerhouse was inversely related to spill volume during the second half of the spring (Figure 40). However, passage through the spillway did not appear to increase with increases in spill discharge (Figure 40).

Seasonal trends in fish passage estimates during the summer were similar to trends in the index numbers from the John Day smolt passage facility (Figure 21). Total fish passage, spillway passage, and powerhouse passage did not appear to fluctuate inversely with spill volume.

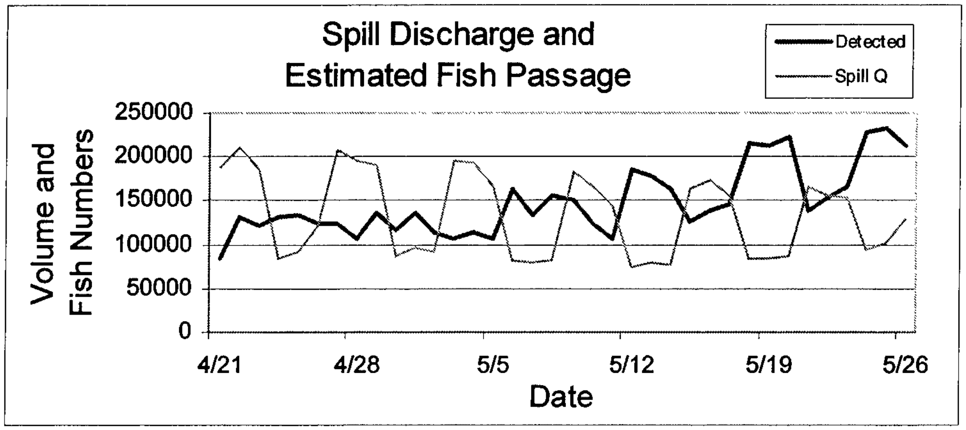


Figure 39. Total daily estimated fish passage compared with spill volume ft^3/sec at TDA in spring 1999

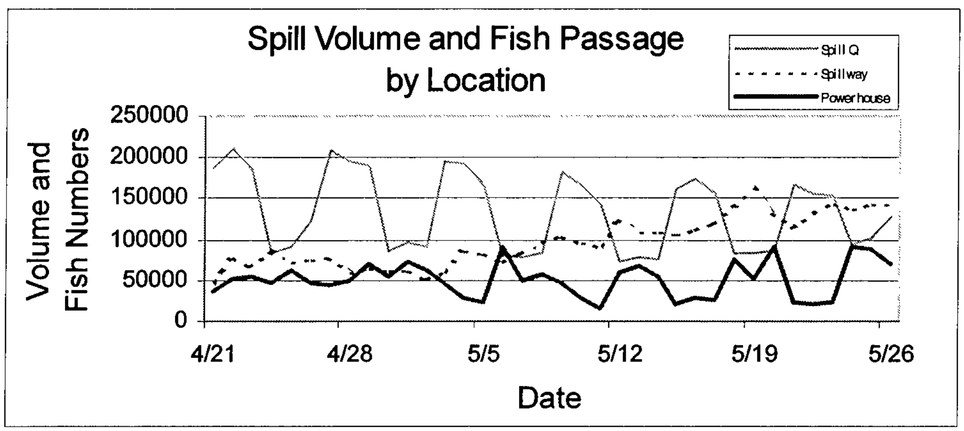


Figure 40. Total daily estimated fish passage at the powerhouse (turbines and sluiceway) and the spillway compared with spill volume ft^3/sec at TDA in spring 1999

Horizontal distribution

The horizontal distribution of fish passage in spring was skewed toward the downstream end of the powerhouse, much like the distribution of hours of turbine operation (Figure 41). The skewed distribution was mainly due to high fish passage at the downstream half of the powerhouse during 64-percent spill treatments; the distribution during a 30-percent spill was more evenly distributed (Figure 42). The horizontal distribution of turbine operations was very similar to that of fish passage (Figure 41), with the exception of those units underneath or downstream of the sluiceway openings (MU 1 and both fish units). Fish passage through all turbines upstream of the sluice openings at Unit 1 (Units 3 through 22) was highly correlated with the number of hours that turbines were operated ($r^2 = 0.71$). Fish counts were noticeably lower at MU 1 than at adjacent turbines.

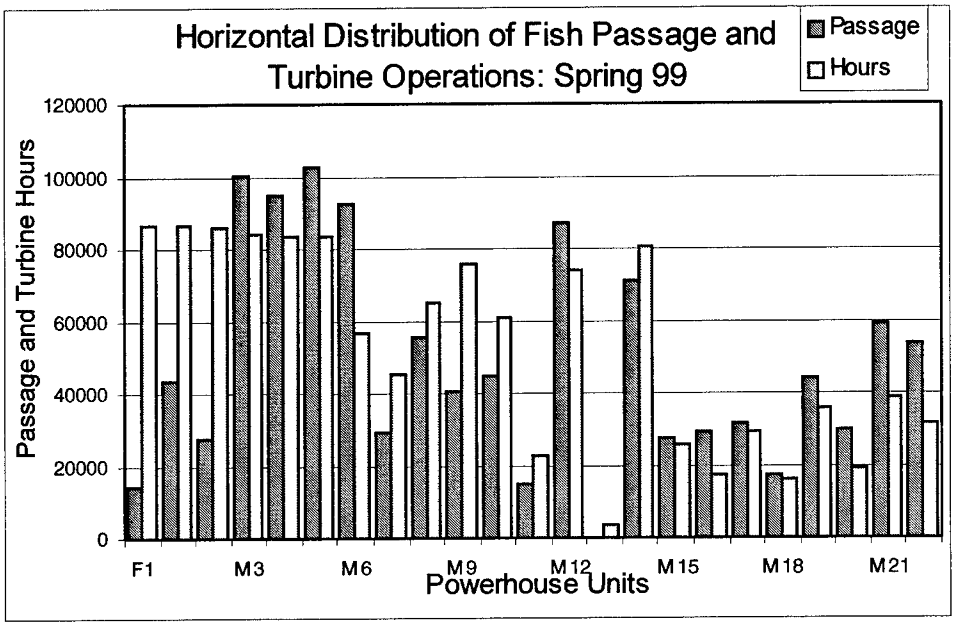


Figure 41. Histogram showing the horizontal distribution of estimated fish passage and turbine hours for TDA powerhouse in spring 1999. Turbine hours were multiplied by 100 for display purposes

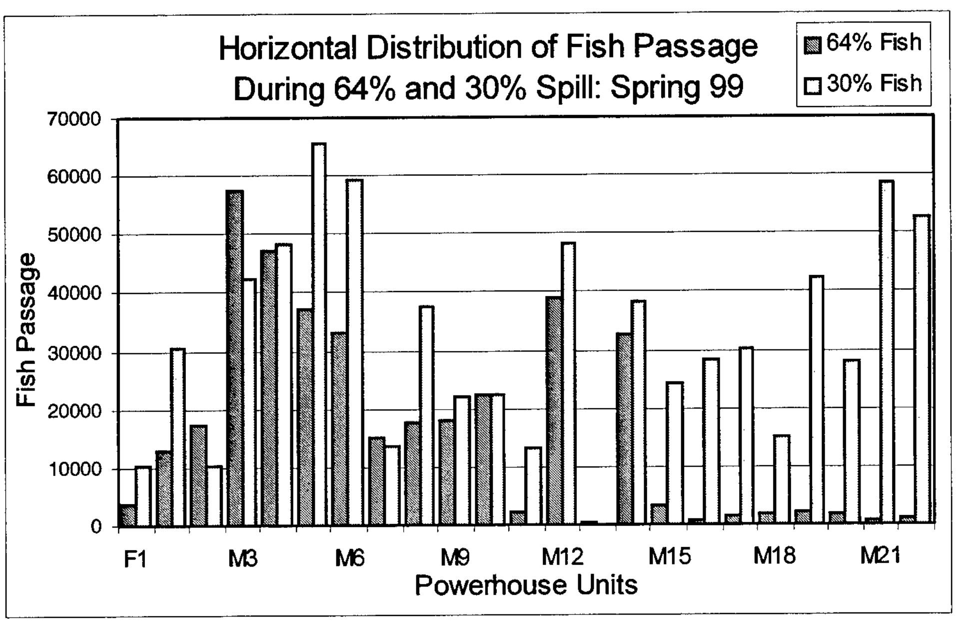


Figure 42. Histogram showing the horizontal distribution of estimated fish passage for TDA powerhouse by spill treatment in spring 1999

The horizontal distribution of fish passage in summer was also skewed toward the downstream end of the powerhouse, as were the hours of turbine operation (Figure 43). Fish passage through each turbine upstream of the sluice openings at Unit 1 was correlated with the runtime of each unit ($r^2 = 0.61$).

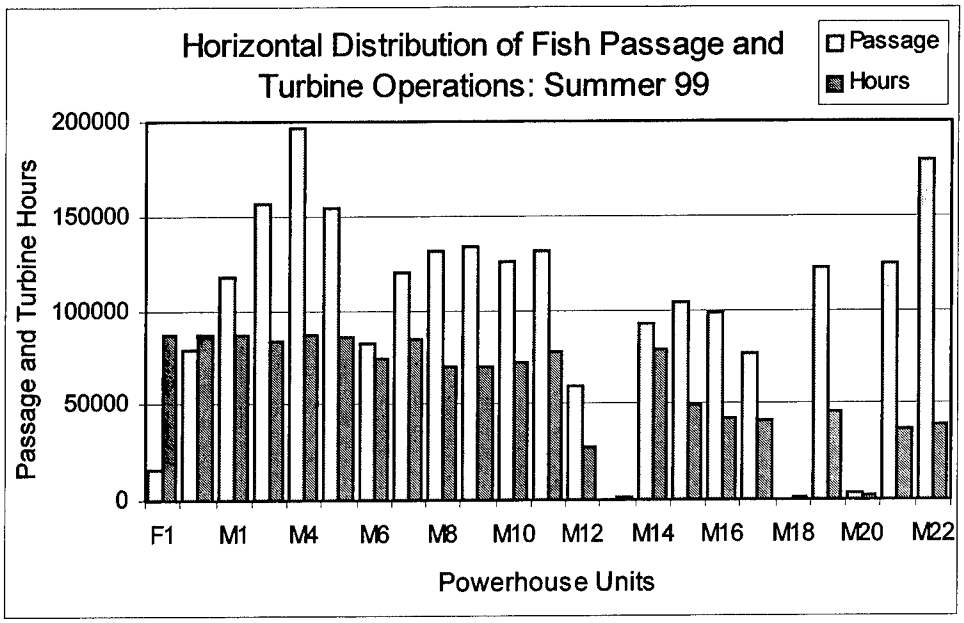


Figure 43. Histogram showing the horizontal distribution of estimated fish passage and turbine hours for TDA powerhouse in spring 1999. Turbine hours were multiplied by 100 for display purposes

To separate fish passage from turbine operation patterns, we examined fish passage rates, in fish per hour, for both spill treatments. During both spring and summer (Figures 44 and 45, respectively) we found high hourly passage at the upstream end of the powerhouse. These high rates were mostly the result of passage during a 30-percent spill in spring, because passage rates during a

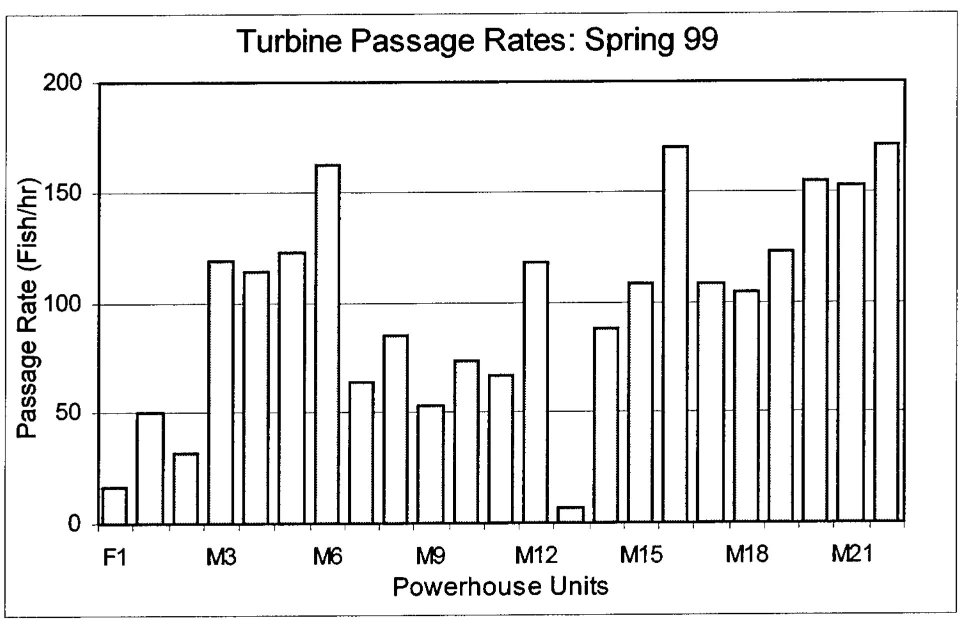


Figure 44. Histogram showing the horizontal distribution of the rate of fish passage for TDA powerhouse in spring 1999

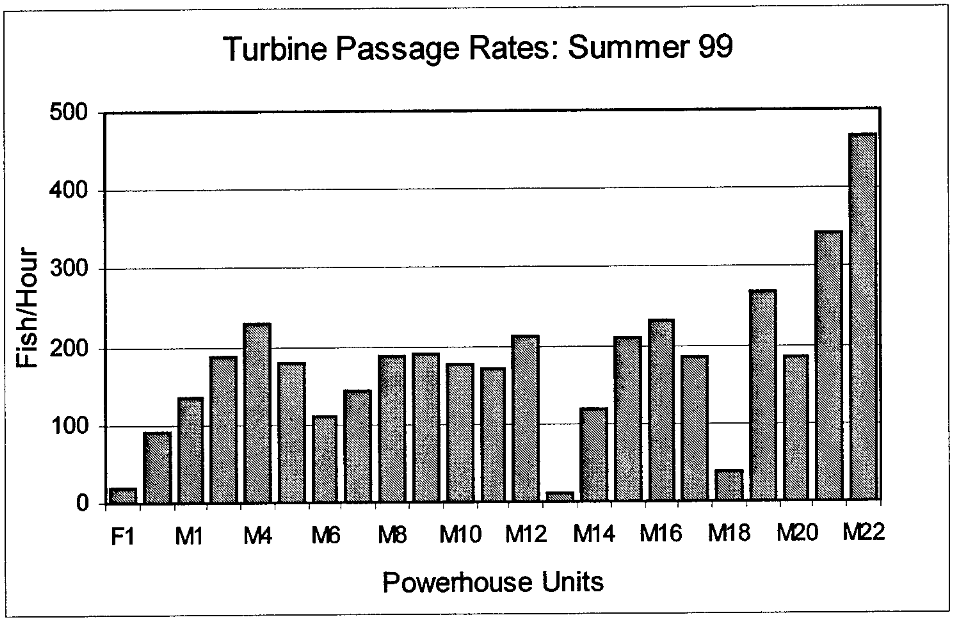


Figure 45. Histogram showing the horizontal distribution of the rate of fish passage for TDA powerhouse in summer 1999

64-percent spill were less skewed (Figure 46). Spring passage rates at Units 3 through 6 were high regardless of spill treatment (Figure 46). During the 64-percent spill in summer, passage rates at MU 19 through 22 were very high relative to rates at the lower end of the powerhouse (Figure 47).

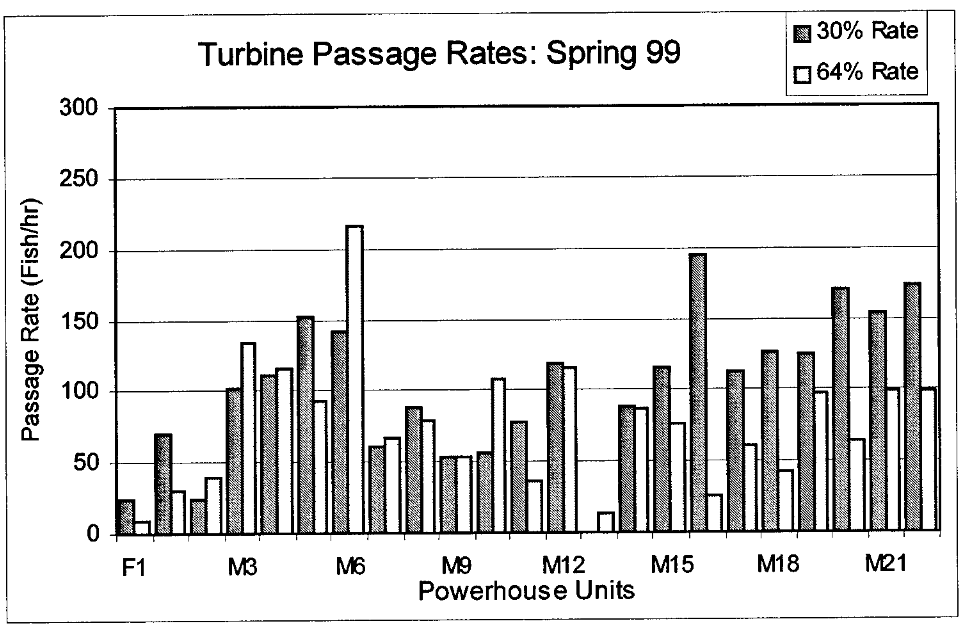


Figure 46. Histogram showing the horizontal distribution of the rate of fish passage by spill treatment for TDA powerhouse in spring 1999

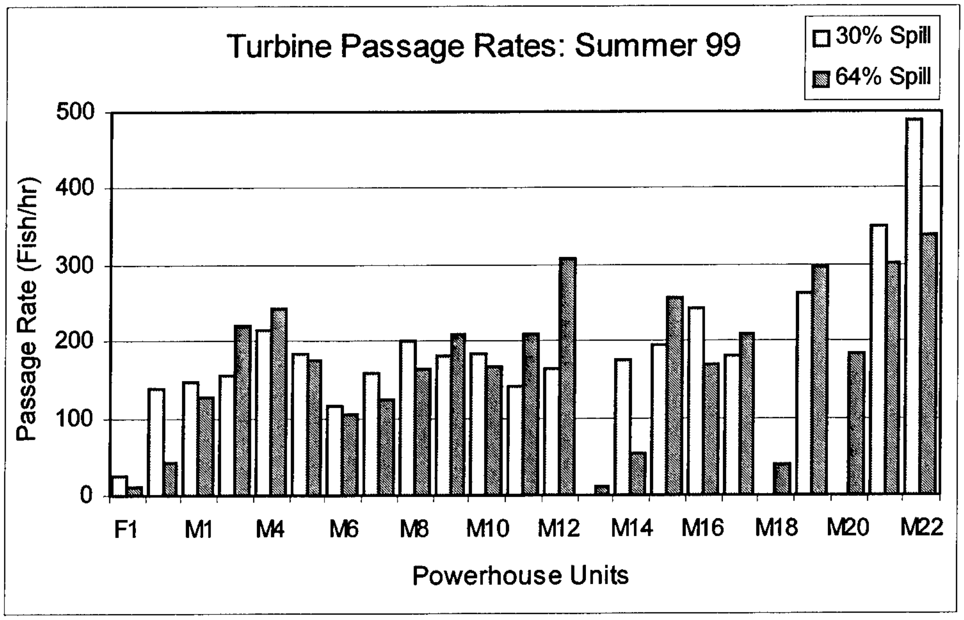


Figure 47. Histogram showing the horizontal distribution of the rate of fish passage by spill treatment for TDA powerhouse in summer 1999

Total fish passage at the spillway in spring tended to be higher at spill bays 3 through 13 than at bays 1 and 2 or 15 through 23, and the pattern was similar between spill treatments (Figure 48). In contrast, the pattern of fish-passage density was relatively uniform across the spillway and slightly skewed toward higher numbered bays at night (Figure 49).

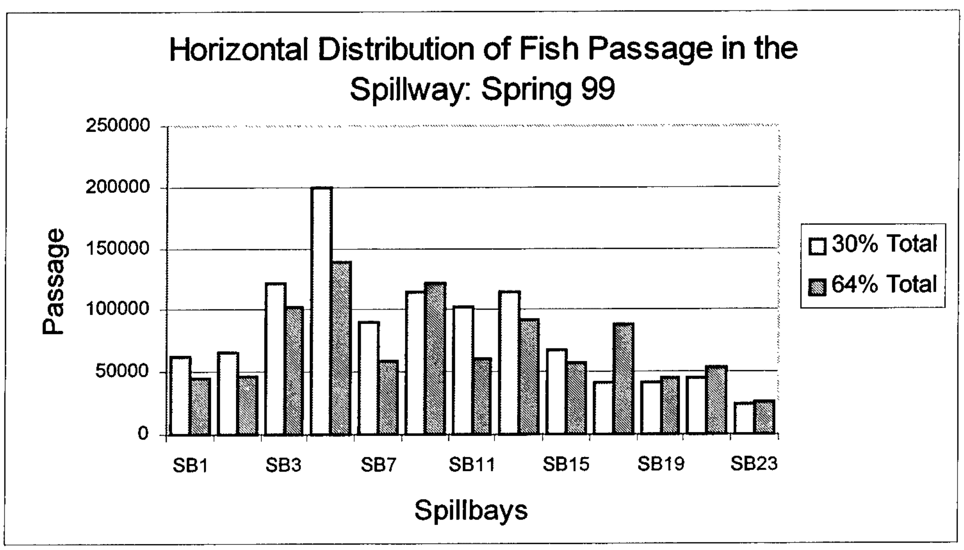


Figure 48. Histogram showing the horizontal distribution of estimated fish passage for TDA spillway by spill treatment in spring 1999

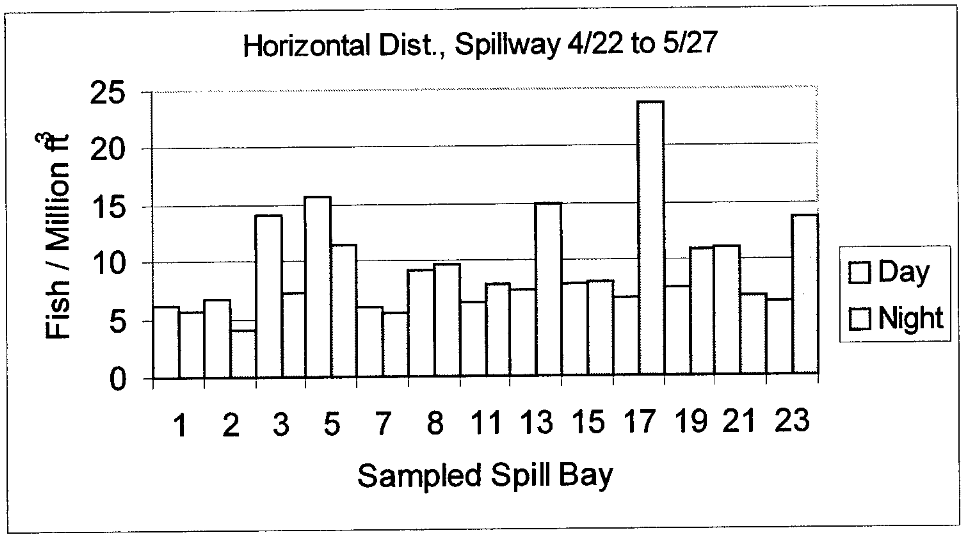


Figure 49. Horizontal distribution of fish-passage density at TDA spillway in spring during the day and night

In summer, fish passage at the spillway was high at spill bays 5 through 13 during a 30-percent spill and at bays 5, 8, and 13 during a 64-percent spill (Figure 50). Total passage during a 64-percent spill also was relatively high at bays 17 through 23, considering that these bays usually were opened less than lower-numbered bays or closed from 2000 until 0500 hr (Figure 50). In contrast, the density of fish passage, which was not affected by differences in spill-gate settings, was skewed toward higher-numbered bays (Figure 51) nearer midriver.

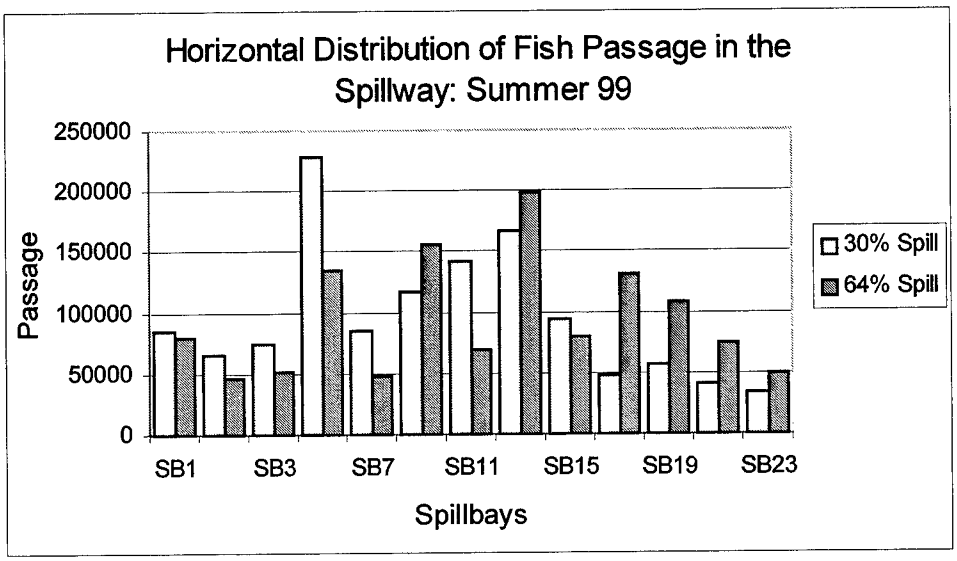


Figure 50. Histogram showing the horizontal distribution of estimated fish passage for TDA spillway by spill treatment in summer 1999

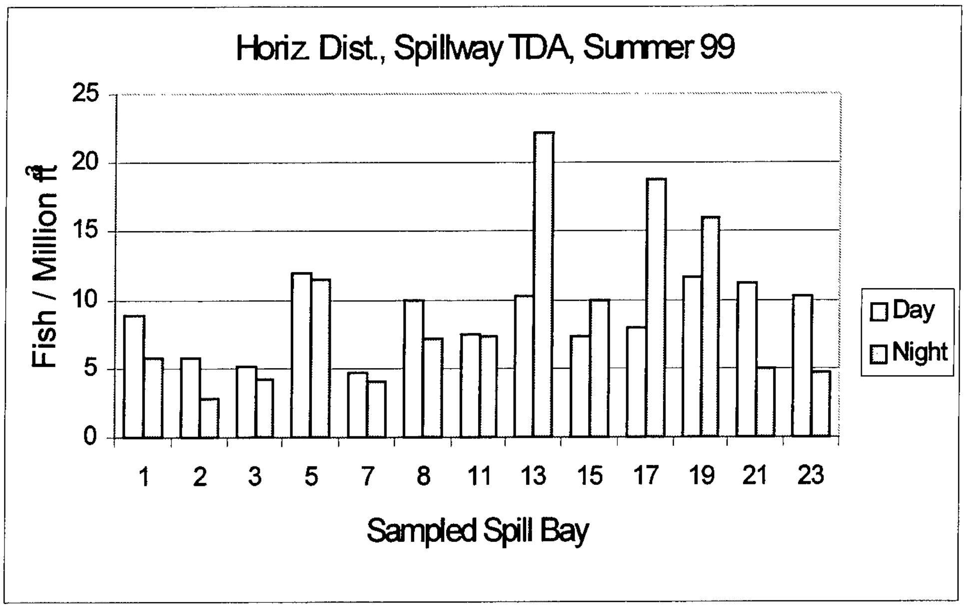


Figure 51. Horizontal distribution of fish-passage density at TDA spillway in summer during the day and night

In spring, the horizontal distribution of fish passage among the sluiceway openings above turbine intakes 1-1, 1-2, and 1-3 was slightly skewed toward the sluiceway opening at intake 1-1 (the most downstream sluiceway opening) during the day while the spill level was at 30 percent. We detected nearly identical numbers of fish during the night while spilling was at 30 percent and during day sampling with spilling at 64 percent. Distribution of night passage at 64-percent spill was slightly skewed toward intake 1-3 (Figure 52).

In summer, before sluice gates were opened above intakes 2-1 and 2-2, fish passage through the sluiceway openings above turbine intakes 1-1 and 1-2 were slightly higher than at intake 1-3 (Figure 53). After the additional sluice gates were opened, however, sluiceway fish passage was highly skewed toward intake 2-2 (Figure 54).

Diel Distribution

In spring, the diel distribution of fish passage in the spillway was similar between spill treatments. The proportion of spillway fish passage was relatively uniform except for a substantial peak between 2000 and 2100 hr (Figures 55 and 56). In summer, the hourly proportions of spillway fish passage during 30-percent spill were highest from 0600 to 0700 hr and from 2000 to 2200 hr (Figure 57). Fish passage during 64-percent spill peaked slightly at 0200 hr and again from 1800 to 1900 hr (Figure 58).

In spring, fish passage in the sluiceway during a 30-percent spill was highest during the morning hours and in the early evening (Figure 59). Passage was lowest at midday and midnight. In contrast, turbine passage during 30-percent

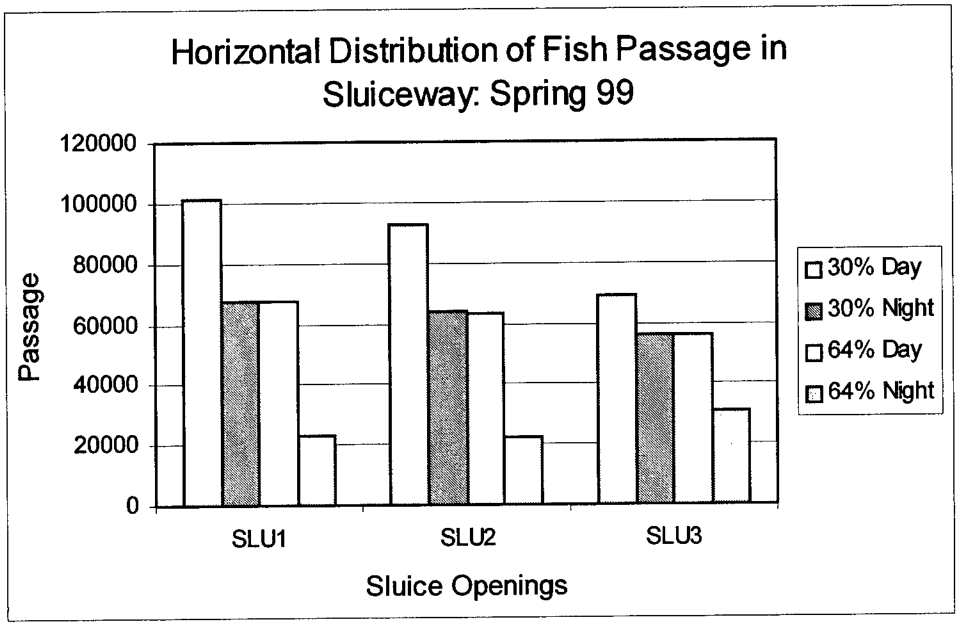


Figure 52. Histogram showing the horizontal distribution of estimated fish passage for TDA sluiceway in spring 1999

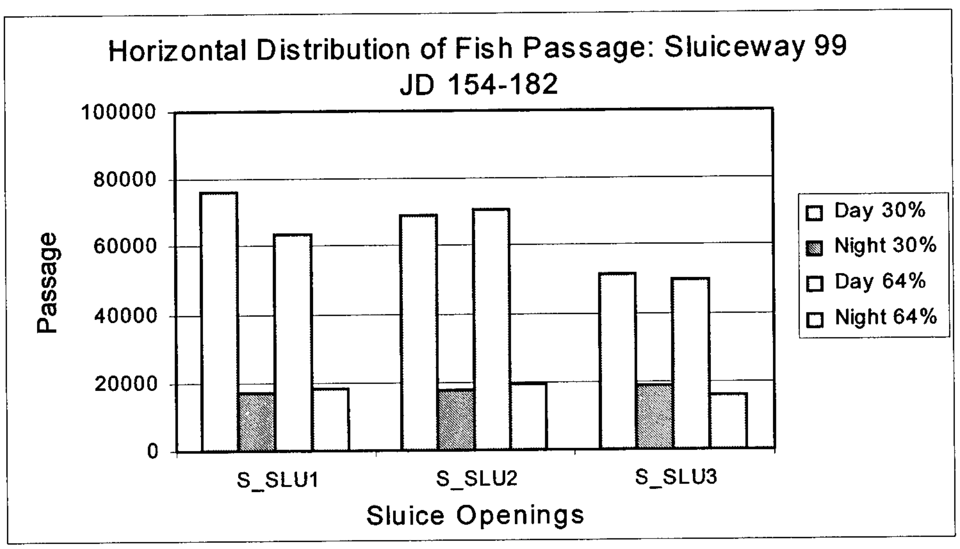


Figure 53. Histogram showing the horizontal distribution of fish passage at TDA sluiceway in summer 1999 before the sluice gates above intakes 2-1 and 2-2 were opened

spill was highest at night and lowest from late morning to early evening (Figure 59). During a 64-percent spill in spring, fish passage in the sluiceway peaked between 0500 and 0800 hr and was lowest during night hours (Figure 60). Diel turbine passage during a 64-percent spill was less variable than during a 30-percent spill and was lowest from 1100 to 1900 hr (Figure 60). In summer, the sluiceways had a distinctive diel pattern of fish passage during both spill treatments with higher passage during the daylight hours (0500 to 1900 hr) and lower

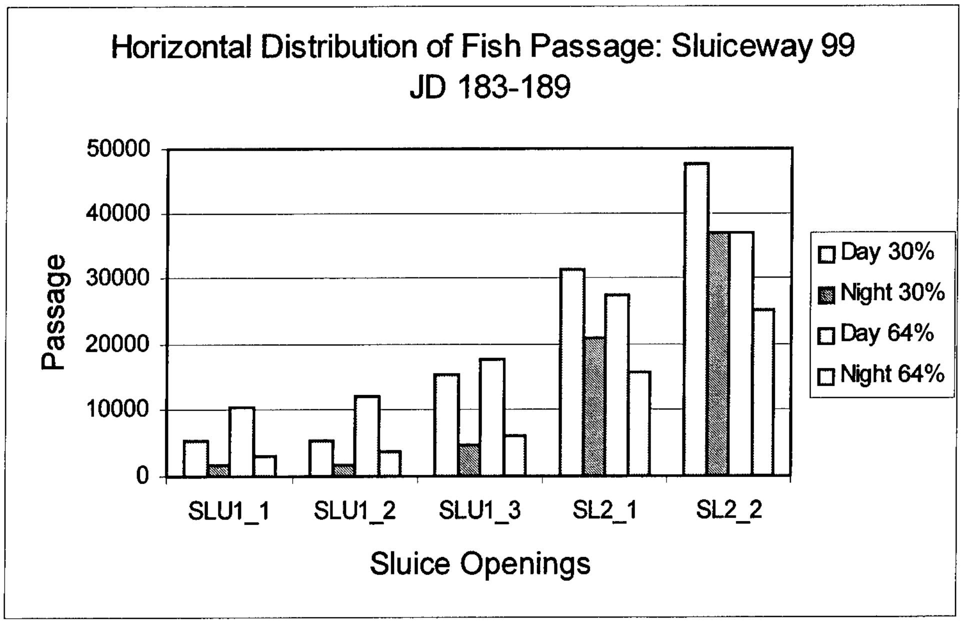


Figure 54. Histogram showing the horizontal distribution of fish passage at TDA sluiceway in summer 1999 after the sluice gates above intakes 2-1 and 2-2 were opened. Data at SL 2-1 were interpolated from those at SL 1-3 and SL 2-2

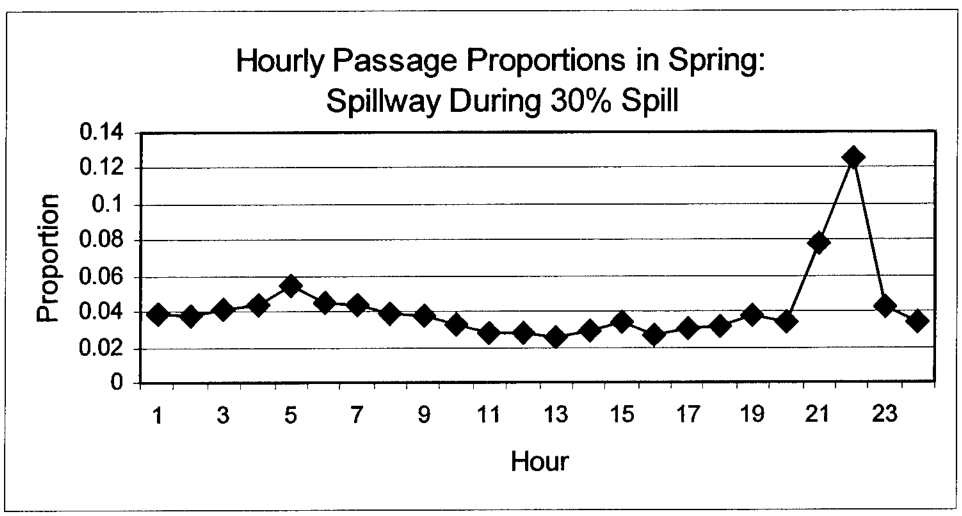


Figure 55. Plot of the proportion of fish passage by hour of the day for TDA spillway during 30-percent spill in spring.

passage at night (Figures 61 and 62). Summer turbine passage was highest at night (2300 to 0400 hr) and lowest during the day, with the exception of a peak in passage from 1400 to 1500 hr during 30-percent spill (Figures 61 and 62).

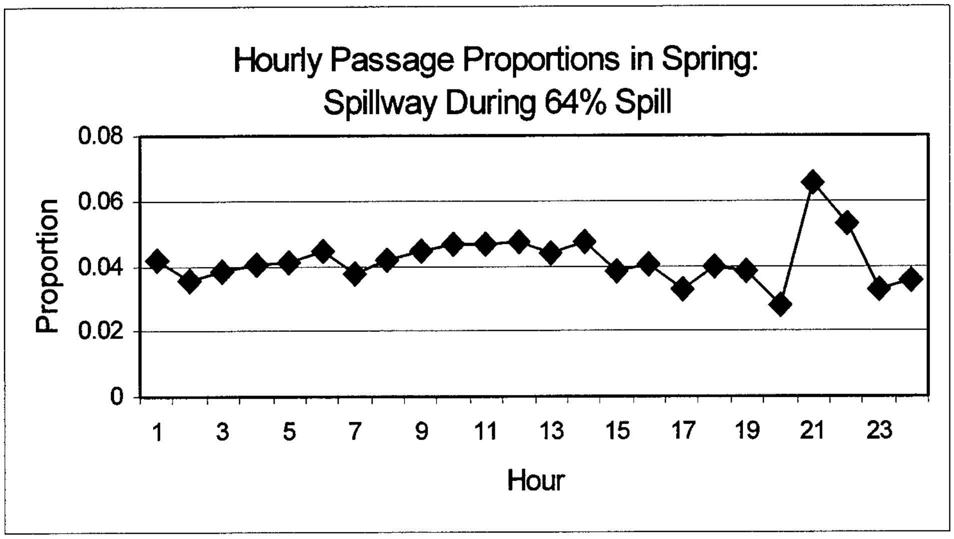


Figure 56. Plot of the proportion of fish passage by hour of the day for TDA spillway during 64-percent spill in spring

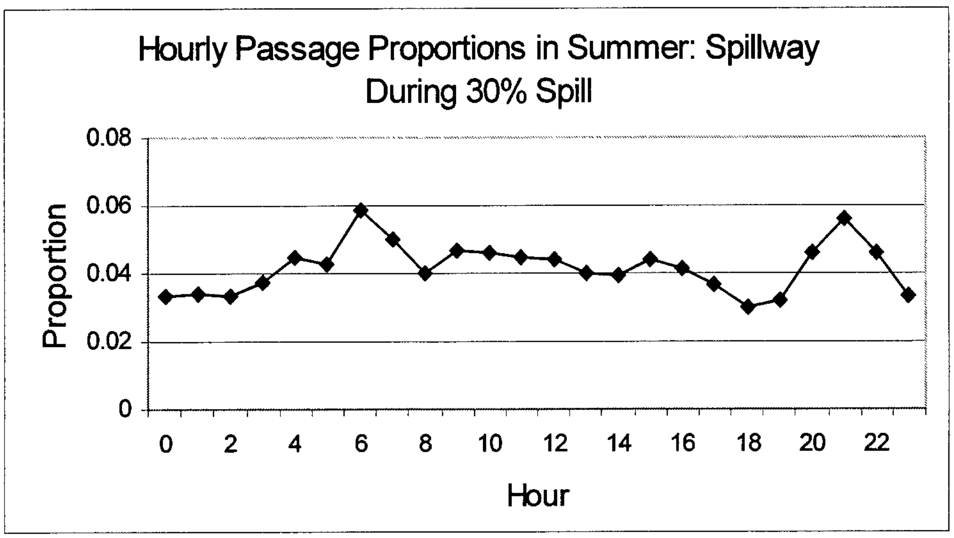


Figure 57. Plot of the proportion of fish passage by hour of the day for TDA spillway during 30-percent spill in summer

Vertical distributions

The vertical distribution of fish in the sluiceway was concentrated in the upper portion of the water column, with 65percent of the fish passing above the overflow-weir elevation (Figure 63). In turbines, fish were distributed slightly deeper during a 30-percent spill than during a 64-percent spill (Figures 64 and 65). There also were slightly more fish at greater depths at night than during the day during the 30-percent spill, but day and night distributions were similar during the 64-percent spill. Over 80 percent of the fish were at ranges exceeding 7 m (< 20 m deep).

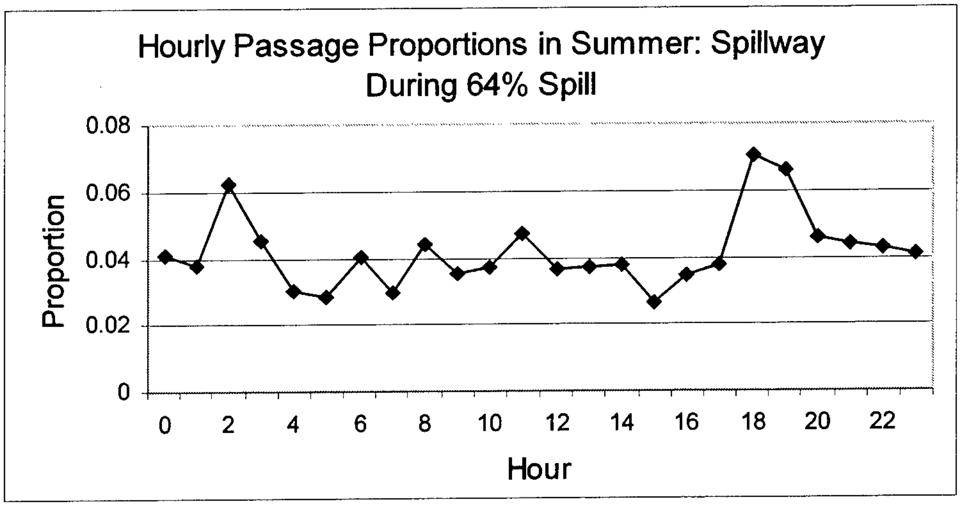


Figure 58. Plot of the proportion of fish passage by hour of the day for TDA spillway during 64-percent spill in summer

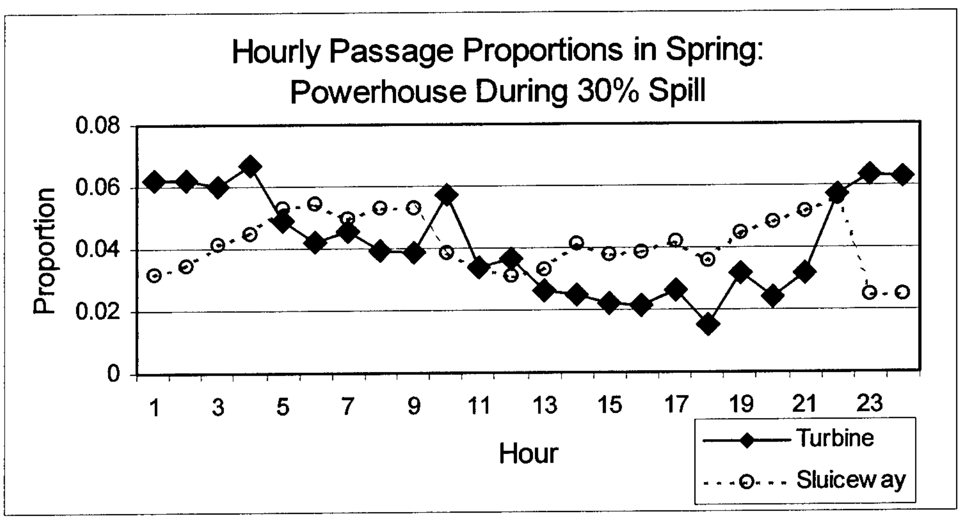


Figure 59. Plot of the proportion of fish passage by hour of the day for TDA powerhouse during 30-percent spill in spring

In summer, fish in turbines tended to be deeper at night than they were during the day, regardless of spill treatment (Figure 66). At the spillway, fish passed deeper during the day than at night, but vertical distributions were similar during the two spill treatments (Figures 67 and 68).

Comparing results to prior studies

Results for spring and summer 1999 are close to the range of values reported in earlier studies except for turbine passage in summer (Table 6). Fish passage for turbines was particularly low in 1998, relative to estimates in 1996 or in this study. Sluiceway efficiencies in this study were lower than those reported in

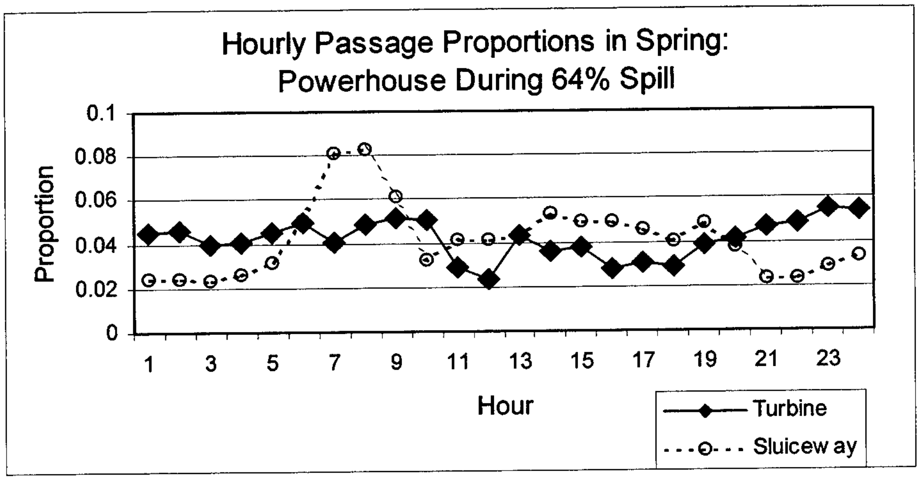


Figure 60. Plot of the proportion of fish passage by hour of the day for TDA powerhouse during 64-percent spill in spring

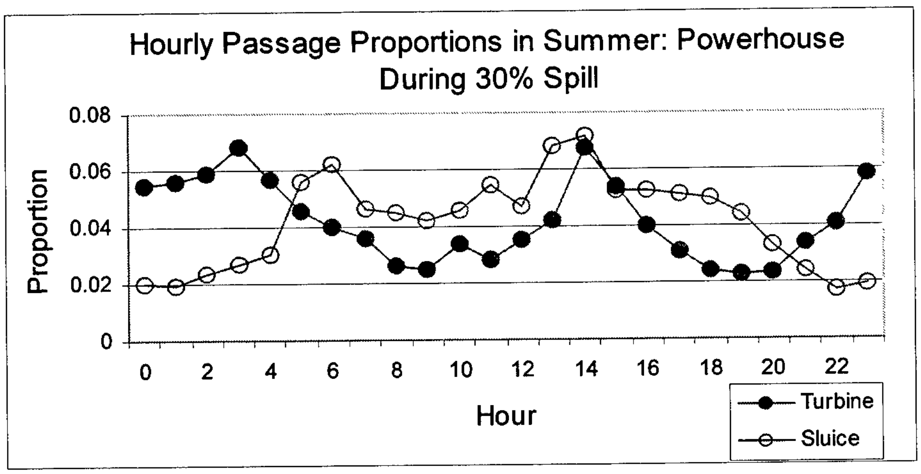


Figure 61. Plot of the proportion of fish passage by hour of the day for TDA powerhouse during 30-percent spill in summer

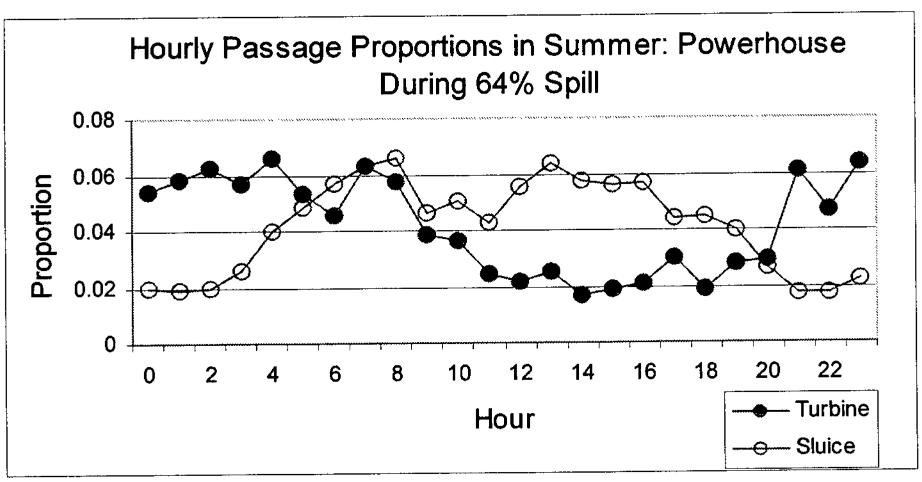


Figure 62. Plot of the proportion of fish passage by hour of the day for TDA powerhouse during 64-percent spill in summer

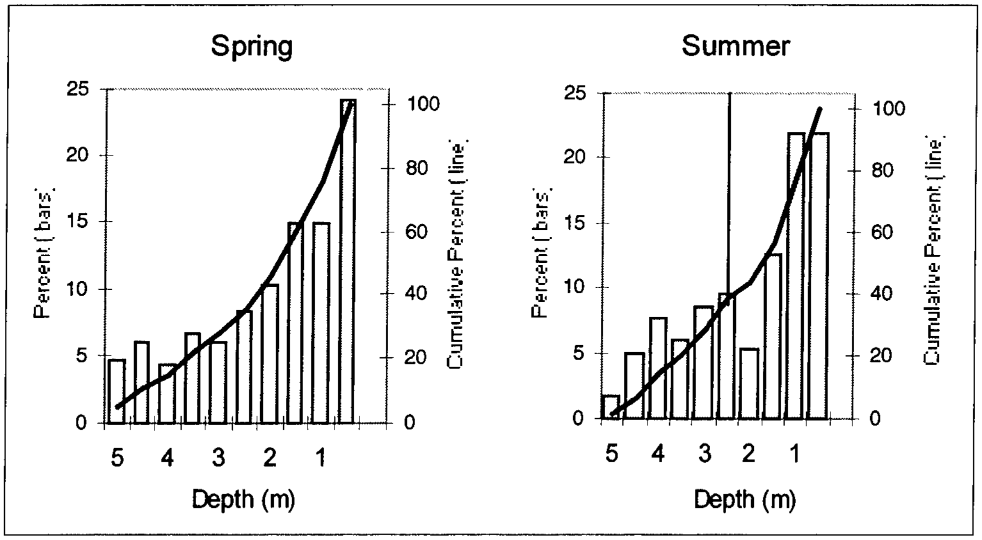


Figure 63. Vertical distribution of fish passing into TDA sluiceway openings in spring and summer

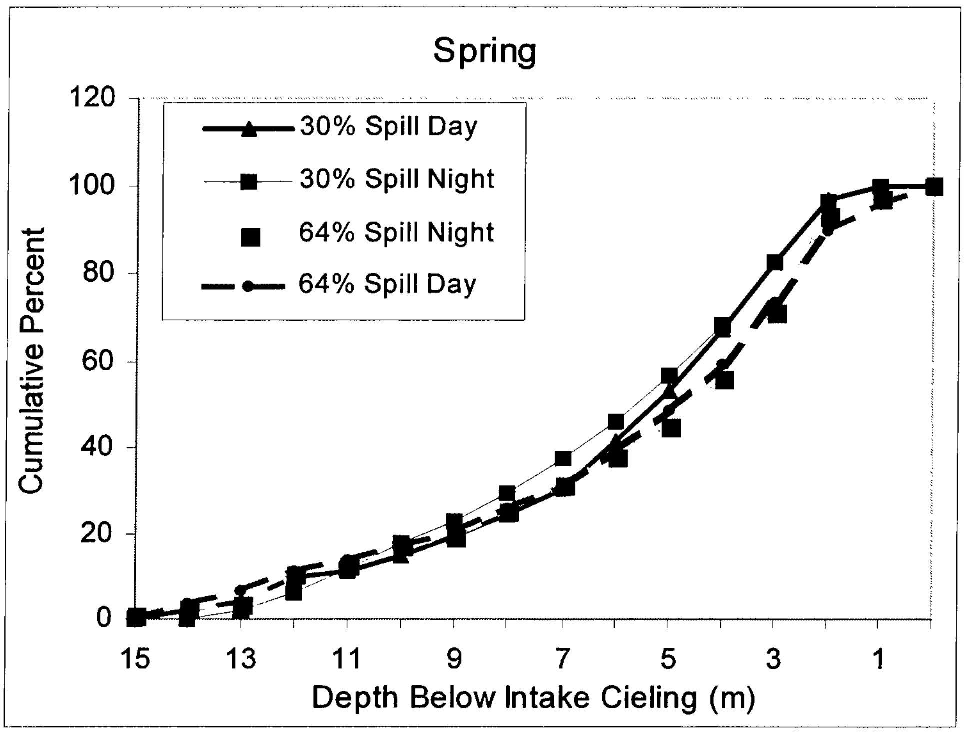


Figure 64. Plot of the vertical distributions of fish in TDA turbines in spring

1998 and slightly higher than those reported in 1996. Earlier studies (Steig and Johnson 1986, AFB and Parametrix 1987) have not been included in this analysis, since the methods they employed (transducers mounted and aimed upstream of the trash racks) were deemed incomparable to the other studies which employed "in-turbine" sampling downstream of the trash racks.

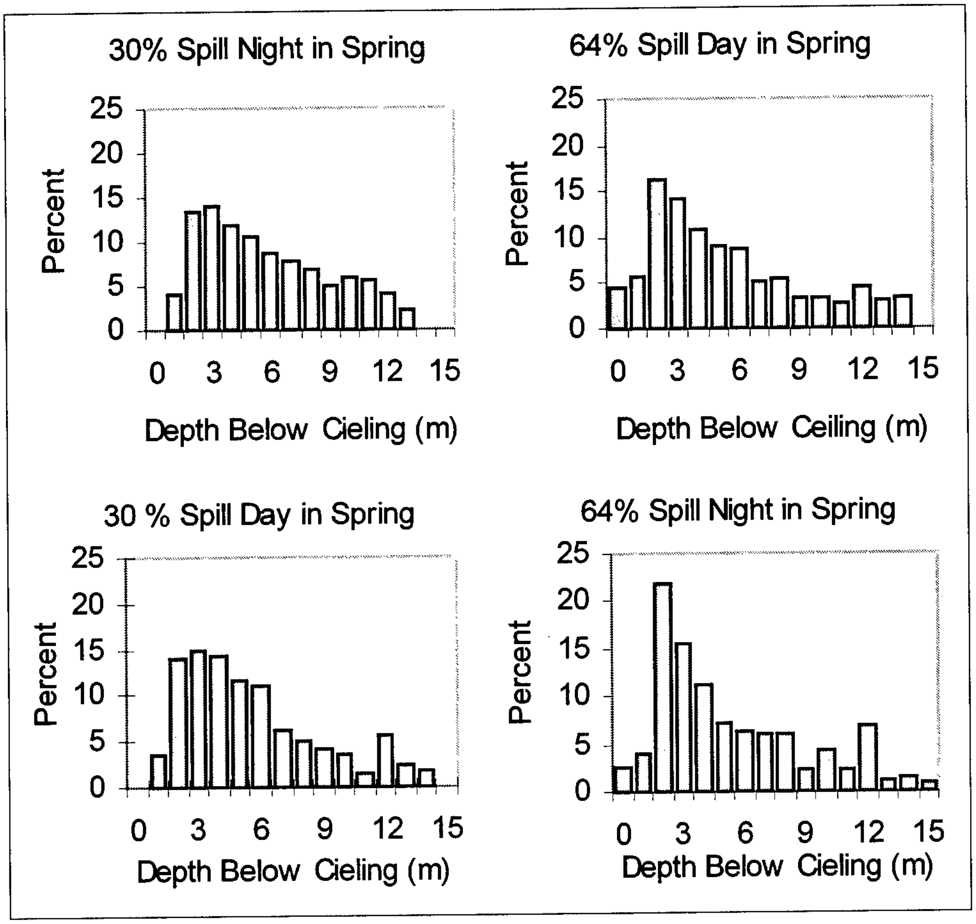


Figure 65. Vertical distribution of fish in TDA turbines in spring

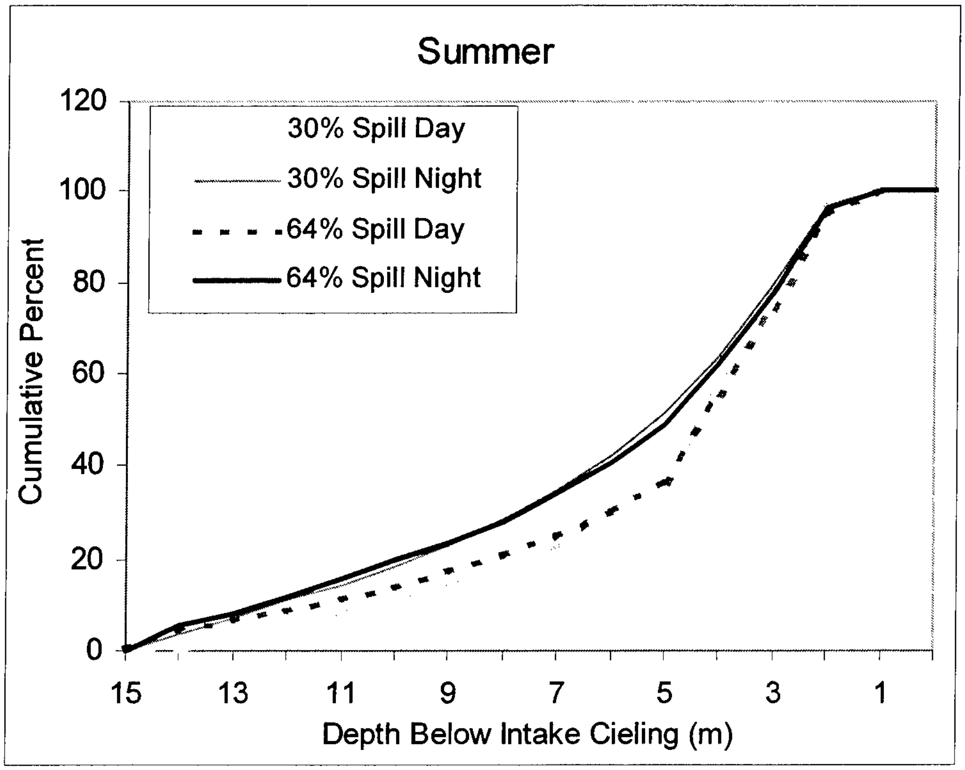


Figure 66. Plot of the vertical distributions of fish in TDA turbines in summer

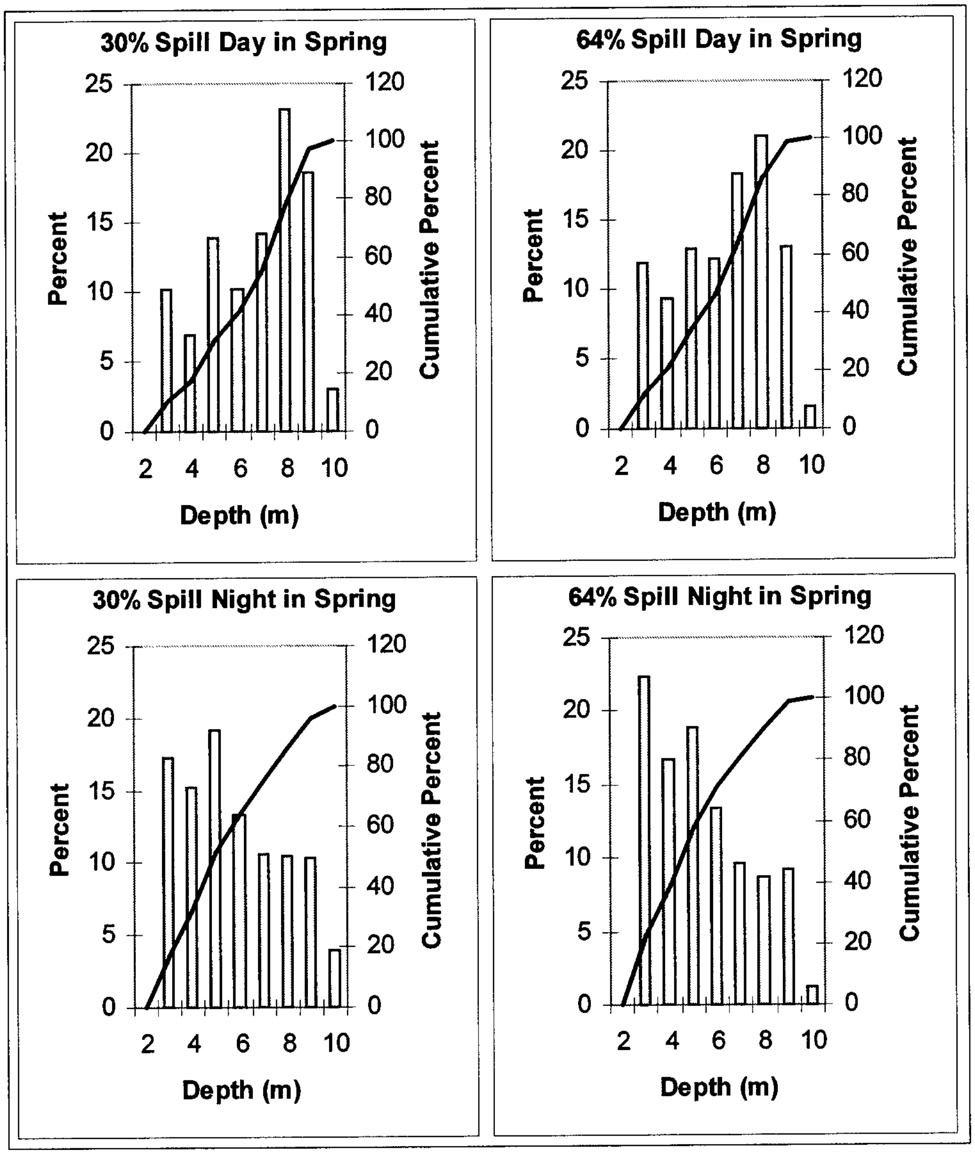


Figure 67. Vertical distributions of fish at TDA spillway in spring. Depth refers to the depth below the transducer, which was at 47 m el (154 ft). The ogee was located 9.5 to 9.6 m below the transducer, so the 9- to 10-m stratum was incomplete

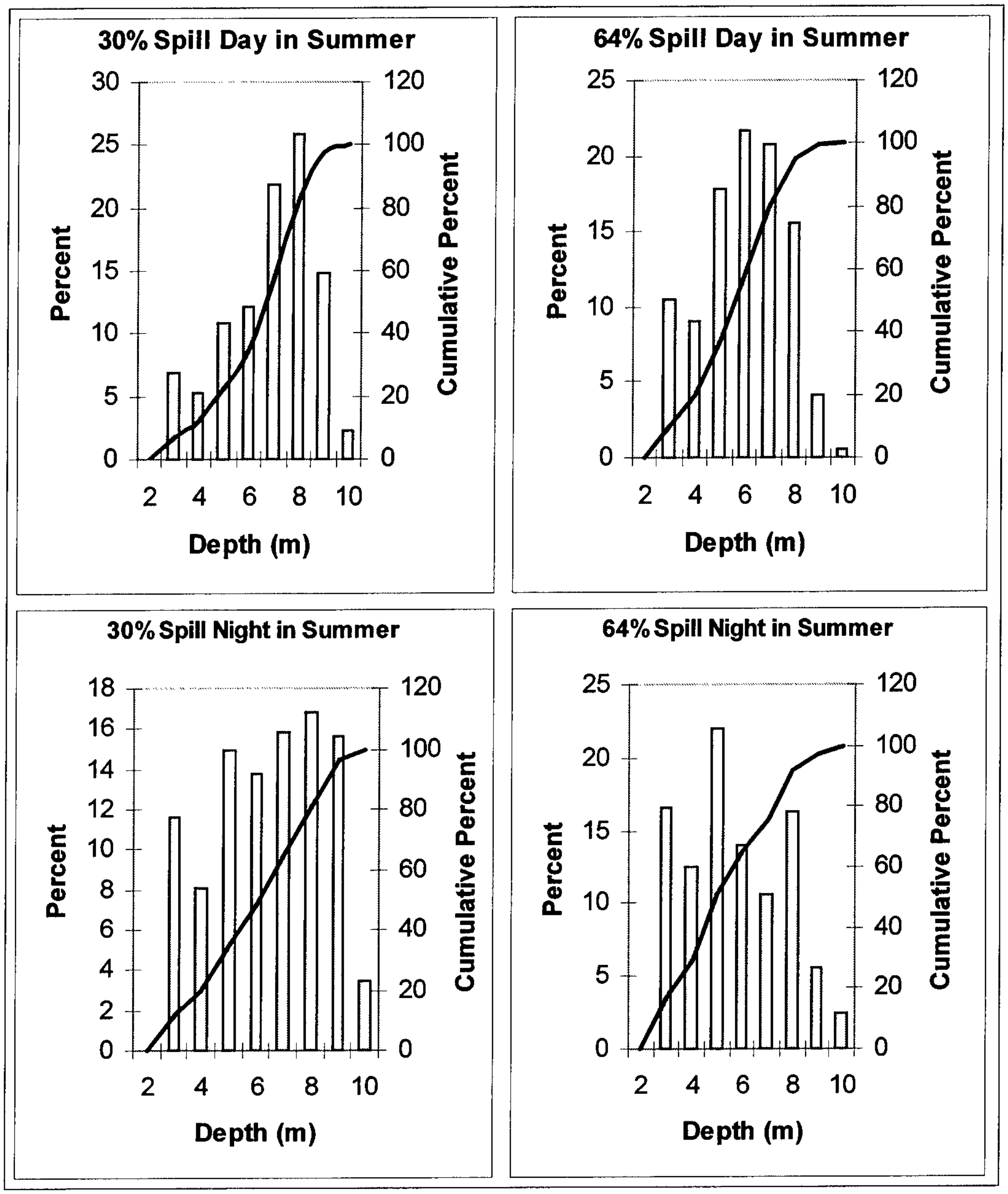


Figure 68. Vertical distributions of fish at TDA spillway in summer. Depth refers to the depth below the transducer, which was at 47 m el (154 ft). The ogee was located 9.5 to 9.6 m below the transducer, so the 9-to 10-m stratum was incomplete.

Table 6
Comparison of 1999 Results with Those Obtained in Prior Years

Year-Season	1999-SP	1999-SU	1998-SP	1998-SU	1996-SP	1996-SU	1989-SU
Period	4/22-5/27	6/3-7/9	4/20-5/27	6/7-7/6	5/6-6/11	6/17-7/26	6/6-8/23
# days	36	35	38	30	22	20	73
Turbine (#fish/day)	30,865	65,854	8,774	10,821	31,945	31,227	n/a
Spill (#fish/day)	97,491	126,125	87,947	71,316	31,839	108,293	10,075
Sluice (#fish/day)	19,935	25,665	49,729	38,109	14,844	22,862	n/a
Spill %Q	0.466	0.458	0.47	0.47	0.51	0.47	n/a
Sluice %Q	0.016	0.014	0.016	0.016	0.01	0.014	n/a
FPE	0.79	0.70	0.94	0.91	0.59	0.81	n/a
Spill Efficiency	0.66	0.58	0.60	0.60	0.40	0.67	n/a
Sluice Efficiency	0.13	0.12	0.340	0.31	0.19	0.14	n/a
Spill Effectiveness	1.41	1.27	1.28	1.28	0.79	1.42	n/a
Sluice Effectiveness	8.57	8.36	21.22	19.33	18.88	10.06	n/a

References and Notes
Efficiency and effectiveness were estimated from #/day in this table and therefore differ slightly from those reported in the text of this report.
1999 Ploskey et al. (in preparation)
1998 BioSonics, Inc. (1998)
1998 spill and sluice % approx.
1996 days off to allow forebay to equilibrate
1989 McFadden (1990)

4 Discussion

Interpretation

Although the research conducted during the 1999 season is referred to as a test of the effects of spill level on aspects of fish passage at TDA, the spill-level treatments were always coupled with different operational schemes at the powerhouse. Powerhouse operations result from power generation, pool management, and experimental considerations. The 64 -percent spill treatment was associated with much lower generation levels than was the 30-percent treatment, particularly in the upstream end of the powerhouse. Therefore, the tests were between different suites of operations, both at the spillway and at the powerhouse. Although we often refer to the treatments as "30- and 64-percent spill" treatments for expediency, the inferences that we make from our data more properly compare the effects of those two different suites of dam-wide operations that were used to achieve the two spill-level treatments.

Detectability

We used a hybrid approach to modeling hydroacoustic detectability that incorporated effects of target strength distribution as determined by split-beam sampling and effects of range. The BioSonics model we used to estimate effective beam angle as a function of range does not consider the effect of target-strength distribution on detectability. Our approach incorporated both range and target-strength effects in spatial expansions. Ignoring target-strength effects in detectability modeling may explain why hydroacoustic estimates are often lower than are simultaneous estimates by physical capture devices (e.g., Ploskey and Carlson 1999). In this study, effective beam angles were from 0.5 deg (single-beam in-turbine) to 2.5 deg (single-beam spillway) narrower than would be predicted from modeling the effects of range alone or from a nominal -3 dB beam angle. For further discussion of detectability and the appropriateness of the acoustic screen model, refer to Appendix B.

Flow data for TDA spillway (Figure 7) revealed that modeling hydroacoustic detectability there was much more complicated than was previously thought (Figure 8). These results indicate how importance of having accurate flow data for modeling detectability. The assumption of equal detectability among sampled passage routes is a cornerstone of hydroacoustic estimation of FPE and spill metrics. Detectability must be accurately modeled to develop accurate spatial expansion factors and assure the validity of the equal-detectability assumption.

Data Processing

Intertracker variation

In our effort to provide the most unbiased and defensible estimates of fish passage possible, we have identified intertracker variation as an important potential source of error (Ploskey et al. in preparation). If not properly controlled, individual differences among trackers could provide a source of systematic bias that could compromise the reliability of analyses based upon hydroacoustic data. The step in data reduction from echogram files to fish counts, which are the source of our estimates, is no less important than the calibration and aiming of transducers or detectability modeling. The step from echogram file to fish count is a transduction step, like the step from sound in water to electronic input, and so requires careful calibration. In the case of ratio estimates, such as fish-guidance efficiency (FGE), the potential for systematic error is especially clear.

We perceive a general concern with intertracker variability and it seems that most hydroacoustic efforts should employ some method to detect and correct extreme tracker bias (Ploskey et al. 2000). We can find no established method, however, for the quantitative evaluation of differences between and among trackers, be they human or computer, and we find no established standards for evaluation and control. It should be made clear that we mean the evaluation and control of the precision (similarity among separate counts made from the same data) among trackers and not accuracy (correctness of any of the counts), which is more complicated and unknown unless physical capture of fish is conducted.

For the turbine data, we find that similarity among our three student trackers is very good by all of the measures (Figures 10 and 11, and Table 3). The nonparametric Wilcoxon Signed Rank Test ($p = 0.89$) does not reject the hypothesis that the students provide the same counts from echograms for turbines. The other measures (cumulative percent error = 4.2 percent, Pearson Correlation Coefficient = 0.97, and linear $r^2 = 0.94$) also support that conclusion. The Index of Average Percent Error (9.12 percent) and Mean Coefficient of Variation (12.89), which are very highly correlated, also indicate low intertracker differences for turbine data.

For the turbine data, the case might be made that our trackers were interchangeable, but that was not true for spillway or sluiceway data. All measures indicate that precision is lower for sluiceway and spillway data. Three student trackers processed the human-tracked files used to calibrate the autotracker equally. For the human-tracked sluiceway data, it is well that we distributed data among trackers through time so that the bias was not cumulative. To minimize intertracker bias, it would be best to distribute data based upon the shortest time increment that is practical.

The scatter of human results in our tests is a form of noise. We suspect that there is a strong connection between the level of that "tracker" noise and the level of acoustic noise, much of it probably from entrained air. The in-turbine data that were used to test the three students happened to be very clean, with much less noise from entrained air than is the case in the data from the relatively shallow and turbulent spillways and sluiceways. It is not surprising that the level of hydroacoustic noise is high much of the time in the often very windy forebay at TDA. With very clean hydroacoustic data, well-trained and competent people using clearly defined criteria can produce fish counts that are very similar to each other.

Some measures (cumulative error, index of average percent error, and mean coefficient of variation) were improved by considering only the three students with the sluiceway data. The cumulative percent error, for example, dropped from 35 to 21 percent when sluiceway tracking results from the three students alone were examined, compared to tracking results from the eight sluiceway trackers (Table 3). However, the results of the hypothesis test are unchanged and the linear r^2 value for the three students (0.77) is 9 percent lower than for the eight trackers (0.86). Even with the same three trackers, all trained together and very similar on turbine data, noisier sluiceway data resulted in greater intertracker error and reduced tracking precision.

Autotracking

An autotracker requires careful, routine calibration against trained manual trackers to assure that it is performing properly. However, a calibrated autotracking program will yield identical counts of fish from the same echograms as long as filtering criteria are constant. An autotracker is not affected by factors that may result in intra-tracker variations with human trackers (e.g., fatigue). The calibration for one time or location cannot assure adequate performance for all times and locations because noise conditions can alter performance temporally and spatially. Therefore, our calibration regressions of manual tracker counts on autotracker counts were based upon many transducer locations within the powerhouse and spillway and >100 hr from a variety of days in spring and summer (Figure 16).

Differences in tracking conditions at the spillway and turbines produced regression lines with different slopes (Figure 16). On average, the autotracker tracked only 6 percent more fish than did manual trackers at the spillway. This was because it was designed to avoid tracking in or near areas of dense acoustic noise composed of echoes off of entrained air bubbles. On the relatively cleaner in-turbine echograms, the autotracker found 15 percent more fish than did the manual trackers. The use of regression lines to convert autotracker counts into human tracker counts provided a quality control check on the autotracker and a way of standardizing counts by the autotracker for the spillway and turbines with counts by people for the sluiceway.

Interpolation to estimate passage at unsampled spill bays

Our examination of interpolation approaches suggest that estimates interpolated from nearby sampled spill bays, as presented in this report, usually are more appropriate than are fish-passage estimates weighted by spill discharge (Appendix C). The assumption that fish passage is proportional to water discharge usually is false and too simplistic. Smolt behavior, particularly for yearling fish, and run timing are critical factors that make time-based estimates more reliable than flow-based estimates. We found that a linear extrapolation based on the average of sample-based estimates from Spill Bays 1 and 3 were closer approximations of our sample-based estimates at Spill Bay 2 than were estimates weighted by flow. Normalizing the linear extrapolation from the sampled bays by flow improved the correlation slightly. Appendix C presents a complete discussion of interpolating fish-passage estimates for unsampled spill bays.

Passage metrics

Failure to reject any null hypothesis (in this case, H_o = the passage metric is not different with the two treatment levels) raises the issue of experimental power, especially in a case where the differences in efficiency are large (e.g., 10 percent). Dr. John Skalski performed a power analysis for a slightly different experimental design with nine 4-day blocks (2 days/spill treatment) in spring and 10 similar blocks in summer. Under that design, and using previous years' variances, he calculated that one could detect a difference of 0.096 (nearly 10 percent) in spill efficiency (SE) with a power (the probability of not making a Type II error by not detecting a real difference) of 95 percent. The experimental design was subsequently changed to one with six blocks of two 3-day spill treatments in spring and six similar blocks in summer. That is a considerably smaller sample size than was originally planned, but the powers that Dr. Skalski calculated are very high and even though our nonparametric test (Wilcoxon Signed Rank Test) is less powerful than is an equivalent parametric t-test, we can have some confidence in the negative (no difference) hypothesis tests that we have reported here for $\alpha > 0.05$.

To assist the reader and to consolidate the results of our hypothesis tests, we present Table 7 in which both seasons are presented with only the cases with significant differences recorded. It includes all of the tests from Tables 4 and 5 (Chapter 3), but comparisons for which the test statistic did not fall in the 0.05 rejection region are left blank and p-values are not given. The one exception is the daytime turbine passage test. Although the p-value for that test ($p = 0.075$) is clearly greater than our chosen α of 0.05 and, therefore, does not permit rejection of H_o, it is small enough to be worthy of noting.

Table 7 indicates that the treatment level (64-percent spill and less generation vs 30-percent spill and more generation) was more often associated with a significant difference in passage metrics at night (12 tests significant) than during days (5 tests significant, excluding summer day turbine passage with $p = 0.075$). Daytime significant differences occurred only in two effectiveness measures (spill effectiveness in days in both seasons and sluice effectiveness relative to the powerhouse in spring days—30-percent treatment higher for both), sluiceway

Table 7
Summary of Results from Wilcoxon Signed Rank Tests Performed on Paired Sample Data in Spring and Summer (n = 6, α = 0.05 for each test) at TDA in 1999. (Blank cells indicate no significant difference. The Turbine Fish Passage result in summer was not significant at the chosen level but is included because of its relatively low p-value)

Fish Passage Metric	Day/Night	Spring	Summer
Project Fish-Passage Efficiency	Day		
	Night	64% Higher	64% Higher
Spill Efficiency	Day		
	Night	64% Higher	64% Higher
Spill Effectiveness	Day	30% Higher	30% Higher
	Night	30% Higher	30% Higher
Sluice Efficiency Relative to Powerhouse	Day		
	Night		64% Higher
Sluice Effectiveness Relative to Powerhouse	Day	30% Higher	
	Night	30% Higher	
Sluice Efficiency Relative to Project	Day		
	Night	30% Higher	
Sluice Effectiveness Relative to Project	Day		
	Night	30% Higher	
Spillway Fish Passage	Day		64% Higher
	Night		
Sluiceway Fish Passage	Day	30% Higher	
	Night	30% Higher	
Turbine Fish Passage	Day		p = 0.075; 30% Higher
	Night	30% Higher	30% Higher

passage in spring days (30 percent higher), and spillway passage in summer days (64 percent higher). Turbine passage was also higher with the 30-percent treatment during summer days with an insignificant but fairly low p-value.

These data suggest that night passage may be more amenable to improvement by operational changes involving spill and generation than day passage. They also suggest that increasing spill volume while reducing generation can improve project- and spill-passage efficiency in both seasons and sluice efficiency in summer. However, that effectiveness is not improved. Conversely, lower spill volumes and higher generation may be associated with higher spill and sluiceway effectiveness (but not efficiency) and perhaps sluice efficiency (relative to the project at night in spring) but at night in both seasons and perhaps during summer days lower spill and higher generation also involves higher turbine passage.

It is not surprising that increasing spill and reducing generation increased FPE, which is the proportion of fish passing the project by nonturbine routes. Nor is it surprising that more generation relative to spill is associated with higher turbine and lower spillway passage and, therefore, with lower project FPE. It is surprising, however, that the higher spill volume-lower generation treatment (64 percent) did not produce higher spillway passage except during summer days.

Our spring data (Figure 36) suggest that after about 150 kcfs of spill, there may be a diminishing return in fish passage. After that point, fish-pill efficiency declines while sluice efficiency and turbine passage increase. This relationship holds for day and night in spring but does not hold at all in summer (Figure 37) when fish are smaller and therefore less able to resist higher flows and when they tend to travel deeper than in spring (see paragraph entitled "Passage Metrics and Spill Discharge" on following page).

Fish-passage efficiency

The 1999 Fish-Passage Efficiency (FPE) estimates were 7 to 9 percent higher in spring and 11 to 16 percent higher in summer under 64-percent spill treatments than under the 30-percent spill treatments. These differences were significant during night for both seasons but were not significantly different during days in either season (Tables 4 and 5), indicating that the higher level of spill and its concomitant lower generation level was associated with higher FPE than was the lower spill and higher-generation treatment. The difference in spring estimates was similar to differences in estimates made with radio telemetry (i.e., about 10 percent higher under 64-percent spill than under 30-percent spill (Hansel and Beeman 1999). We assumed that juvenile steelhead and yearling chinook occurred in equal proportions and averaged those estimates from Hansel and Beeman (1999).

Spillway passage, efficiency, and effectiveness

Absolute spillway passage was not significantly different by treatment in spring days or nights or summer nights, although summer days spilled significantly more fish with the 64-percent treatment. However, as compared to the other passage routes, the 64-percent spill treatment passed more fish through the spillway than did the 30-percent spill treatment. At night, the 64-percent spill treatment produced spillway efficiencies that were higher for all blocks in both seasons than did the 30-percent spill treatment. Those differences were significant during both spring and summer nights, but during the day the spill efficiencies were not significantly different.

With the 64-percent spill treatment, fewer fish per volume of water were passed through the spillway, as compared to the other passage routes, than with the 30-percent spill treatment. In both spring and summer and day and night, effectiveness (a measure of fish passed per volume of water passed) was greater under 30-percent spill than with 64-percent spill. Although the 30-percent spill treatment passed fewer fish by spill as compared with other passage routes than did the 64-percent spill treatment, the lower spill treatment passed more fish per unit of water volume. The trend of increased effectiveness with reduced flows also was apparent in comparison of the effectiveness of sluiceways and spillways. The sluiceways were much more effective than was the spillway.

Sluiceway passage, efficiency, and effectiveness

At the sluiceway there was a clear difference between spring and summer results as well as between day and night results. In spring days and nights, the 30-percent spill treatment passed significantly more fish through the sluiceway than did the 64-percent spill treatment. In summer there was no significant difference in sluiceway passage, day or night.

There was no significant difference is sluice efficiency relative to the powerhouse during either day or night in spring or during days in summer, whereas there was a significant difference (the 64-percent spill treatment was more efficient) at night in the summer. In the spring, sluice efficiency relative to the entire project was significantly better with the 30-percent spill treatment during spring nights, but there was not a significant difference during days. Neither days nor nights are significantly different in summer.

In the spring, sluice effectiveness relative to the powerhouse was higher, day and night, with the 30-percent treatment. In summer, however, differences were not significant. Summer sluice effectiveness relative to the entire project was significantly better with the 30-percent treatment during days, but nights were not different. In summer, sluice effectiveness relative to the project did not vary by treatment, day or night. The lack of differences in sluice passage, effectiveness, and efficiency relative to spill and generation treatment may reflect the deeper migration depth typical of summer out-migrants.

Passage metrics and spill discharge

We found marked differences in the relationships between the passage metrics and the spill discharge between spring and summer during the 64-percent spill treatment. Spill discharge during the 64-percent spill treatment ranged from 143 to 218 kcfs in spring and from 156 to 220 kcfs in summer. When spill discharge was approximately 200 kcfs in spring, spill efficiency was lower than it was when spill discharge was about 150 kcfs. Powerhouse passage metrics had the opposite trend; they were higher during the highest spill level than during moderate discharge. During summer, spill efficiency was highest when spill discharge was at its peak and powerhouse metrics did not rise during times of high spill discharge as they did during spring.

The positive relationship between spill discharge and spill efficiency seen in summer would be expected if the proportion of fish passing through the spillway is solely dependent on spill discharge. The lowered spill efficiency during high spill levels seen in the spring, however, suggests that the factors regulating spill efficiency may be more complex than the simple perception of high spill = high spillway passage.

The relationship between spill efficiency and spill discharge in spring did not appear to be related to species composition. Species composition of the smolt population could influence spill efficiency, since different salmonid species and runs may exhibit different migration behaviors and have different tendencies and capacities to move relative to flow. These differences may contribute to the determination of spill efficiencies. Species composition was similar during the periods of high and moderate flow during the spring. Based on the John Day Dam smolt index, yearling chinook composed 61 percent of the smolt population during high discharge and 52 percent during moderate discharge. It is unlikely that small differences in species composition would have produced the observed decrease in spill efficiency as spill discharge increased.

The trend in spill efficiency may indicate reduced detectability in the spillway during periods of high discharge. However, this trend did not occur during the summer, when fish were smaller and more likely to present detectability problems. Additionally, declines in spill efficiency during very high spill levels in spring were accompanied by increases in powerhouse passage metrics. This indicates that some fish passed through the powerhouse rather than the spillway in spring during times of very high spill when the powerhouse was generating less than during lower spill periods.

Reduced spill efficiency during high spill discharge in spring may be a result of behavioral responses to water velocities or other phenomena that occurred upstream of the spillway. High velocity and turbulence or physical vibrations from the spill gates, both of which may be associated with high spill discharge, may have elicited an avoidance response. The larger, stronger fish present during the spring may have been better able to avoid high-velocity areas than subyearling fish in summer, and instead pass the project by a powerhouse route. The fact that spill efficiency did not diminish during high discharge periods in summer leads us to speculate that some morphological, physiological, or behavioral difference between the spring and summer smolt populations may have contributed to the different findings.

Fish passage

During the second half of the spring season, total numbers of detected fish at TDA fluctuated inversely with the amount of water spilled. Passage numbers during this time dropped during 64-percent spill treatments and rose during a 30-percent spill. The fluctuations were primarily due to changes in the total number of fish detected at the powerhouse (sluiceways and turbines combined; Figure 40). We detected more fish during spring in the sluiceway and the turbines during a 30-percent spill than we did during a 64-percent spill. However, there was no significant corresponding increase in the number of fish passing at the spillway when powerhouse passage declined during the 64-percent spill (Figure 40). Spillway fish numbers did not vary significantly between spill treatments during spring. This was a surprising result. We had expected to detect more fish in the spillway during the 64-percent spill than during the 30-percent spill. In summer, there were significantly more fish passed in the 64-percent spill treatment at night, but there was not a significant difference during summer days. Low spillway counts during the 64-percent spill may have resulted from variations in run timing or behavioral differences as a result of the species composition of the smolt population. The spring smolt run consisted primarily of yearling chinook salmon and steelhead trout. Telemetry results from previous years indicate that it is unlikely that chinook or steelhead would have lingered in the forebay during high spill discharge. We obtained run timing information from the John Day smolt index, but it is not necessarily a good indicator of run timing because it often varied inversely with spill volume (Figure 19). After midspring, the index was directly proportional to the fraction of project flow directed through the turbines and inversely proportional to the fraction spilled. Unless spill at John Day Dam is constant, observed variations in the smolt-monitoring index most likely reflect dam operations rather than naturally occurring phenomena.

Low detectability during high flows near the spillway ogee also may have contributed to the lower-than-expected numbers of fish detected in late spring during the 64-percent spill. However, our modeling of and corrections for detectability should have been adequate for velocities that occurred during 64-percent spill treatments. Detectability was not zero at ranges > 8 m under 64-percent spill treatments, although fish would have had to pass near the axis of the hydroacoustic beam to yield the minimum criterion of four echoes and be tracked. If some degree of detectability exists in the fastest flows, as was the case this year, then it should be possible to adjust for diminished detectability. The average number of echoes in the 9-m range strata when gates were wide open was about six during day and night under both spill treatments (Figure 9). We estimated and used smaller effective beam angles for ranges near the ogee and for wider spill-gate openings to correct for diminished detectability.

These data are not consistent with serious detectability problems. Average daily spill discharge was highest during summer and early spring, but we did not see the lower-than-anticipated spill passage during these times. Additionally, fish were smaller and harder to detect in early spring and in summer than in late spring. High spill volume and small fish size would be expected to contribute significantly to any detectability limitations, yet the pattern of lower-than-expected spillway passage during a 64-percent spill occurred when average fish size was highest and spill discharge was relatively low. Nevertheless, better water velocity data are needed to more accurately model detectability under high discharge at the spillway. The velocity data we used were calculated from simple conservation-of-mass numerical calculations and some samples with an acoustic Doppler velocity meter, which could not measure velocities > 3.7 m/sec.

Our data suggest that the relationship between spill treatment (30 and 64 percent) and passage by spill is, at best, a loose one. Spill passage only differed by treatment during summer nights, when a 64-percent spill passed more fish. From this year's data, we cannot determine conclusively whether these results were influenced by detectability or other experimental factors, and we recommend sampling with a pulse repetition rate higher than 24 pings/sec and incorporating better hydraulic data into detectability models. Potential problems with higher pulse repetition rates include hardware switching limitations and volume reverberation. Volume reverberation becomes a problem at very high sampling (ping) rates if transducers are aimed 8 deg downstream of vertical, so that the beam is tucked in the opening between the Tainter gate and ogee.

The fluctuations in total fish passage during the second half of spring occurred because fish counts at the powerhouse varied inversely with spill volume, as expected, but counts at the spillway did not. In the summer, a different trend in fish passage was observed. We detected more fish in the spillway during a 64-percent spill at night but found no difference in spillway passage between treatments during the day. As during spring, turbine passage was higher during a 30-percent spill both day and night. Spring sluiceway passage was significantly higher, both day and night, with 30-percent spill. In summer, sluiceway passage did not differ between treatments, likely reflecting greater migration depths typical of subyearling chinook.

Horizontal distributions

Horizontal distribution data indicate large numbers of fish entering the turbines at the downstream half of the powerhouse in 1999. Previous researchers have also reported high concentrations of fish at the downstream half of the powerhouse, especially during spring (Magne, Nagy, and Maslen 1983; Steig and Johnson 1986; Johnson, Johnson, and Weitkamp 1986; BioSonics 1998). Total entrainment into the turbine openings closely followed turbine operations, particularly during spring sampling. When powerhouse flow was reduced during the 64-percent spill treatment, most of the reduction in flow occurred in the upstream half of the powerhouse. As a result, the proportion of fish entrained into the downstream half of the powerhouse was highest during the 64-percent spill, when flow through the upstream half was minimized. Although the proportion of fish detected in the downstream end of the powerhouse was lower during the 30-percent spill, the total numbers of fish detected in the downstream half of the powerhouse was fairly equal between spill treatments.

Fish passage into the upstream half of the powerhouse was dominated by high numbers of fish detected during 30-percent spill treatments. Again, entrainment at the upstream end followed dam operations. Fish passage into the upstream half of the powerhouse during 30-percent spill was nearly equal to passage into the downstream half, which reflected turbine usage. Passage into the upstream half during 64-percent spill was low because those turbines were often off-line during 64-percent spill.

Our examination of the rate at which fish were entrained into the turbines was an attempt to separate dam operations from fish passage observations. Passage rates predominately reflect large-scale forebay flow patterns, fish approach pathways, and fish behavior rather than turbine operations. We found that during 30-percent spill, when dam operations were relatively equal along the length of the powerhouse, passage rates were highest at the upstream turbines. Passage rates at the upstream half of the powerhouse also were high during 64-percent spill, particularly in summer. Although passage rates at the fish units appear low, each fish unit only passes 20 to 30 percent of the flow passed through a main unit. A fish-passage metric relative to the volume discharged, analogous to spillway or sluiceway effectiveness, likely would show very high numbers per unit volume at the fish units. Unfortunately, flow data for individual turbines were not available in 1999.

High-passage rates at the upstream end of the powerhouse indicate that fish are readily available for entrainment into upstream turbines. The opportunity for entrainment exists primarily because approach pathways into the forebay are predominately located near the south shore. Mobile telemetry indicates that most radio-tagged subyearling and yearling chinook salmon approached the dam along the south shore (Sheer et al.1997; Holmberg et al. 1998). Fixed-site telemetry studies report that the majority of first contacts of subyearling and yearling chinook salmon, and wild and hatchery steelhead trout at TDA occurred at the upstream end of the powerhouse (Sheer et al.1997; Holmberg et al. 1998; Hensleigh et al. 1999).

Out-migrating smolts approaching TDA along the south shoreline encounter strong flows from many turbine units before they become available to a relatively safe passage route at the sluiceways or spillway. Our examination of fish-passage rates indicates that large numbers of fish are entrained into upstream turbines during periods of high turbine output. It is clear from our data that powerhouse passage and turbine operations are strongly related. Turbine passage in a given section of the powerhouse is strongly related to flow into that section of the powerhouse. It is likely that sluiceway passage is also related to the presence of attracting flows created by turbine units adjacent to the sluiceway openings. Smolt approach paths derived from telemetry data from the last several years and the turbine-passage rates reported here represent new data concerning fish-passage trends at TDA powerhouse. It would be prudent to reinvestigate the configuration of the sluiceway openings in light of these new data.

The openings to the sluiceway were situated above turbine Unit 1 based on recommendations by the Oregon Department of Fish and Wildlife in the late 1970's and early 1980's (Stansell et al. 1990). Low-passage rates during the spring at MU 1 suggest that the sluiceway openings above Unit 1 may effectively reduce entrainment into the intakes below the sluice openings. It is apparent from our data that there are still many opportunities for surface collection at the downstream end of the powerhouse. It is also evident that there are high concentrations of fish at the upstream end of the powerhouse when those turbines are operating. An additional surface-collection route located at the upstream end of the powerhouse may prove beneficial at reducing turbine entrainment rates.

The juvenile spill pattern was effective in redistributing total juvenile passage toward the middle and Washington side of the spillway. While the density of fish passage (i.e., fish per unit discharge) at the spillway was relatively uniform or even slightly skewed toward the Oregon side, total passage usually predominated at middle spill bays (3 or 4 through 13). The distribution of total passage was clearly affected by the extent and duration of gate openings, whereas the distribution of fish-passage density was independent of operations.

Vertical distributions

The vertical distribution in turbines varied among spill treatments in spring and between day and night in summer, whereas distributions at the sluiceway were relatively consistent. Having proportionally more fish deeper in turbines during 30-percent spill than during 64-percent spill in spring may be a function of the rate at which fish move downstream along the powerhouse. When they move along faster under 64-percent spill, they likely are exposed to downward flows into turbines for a shorter time than fish passing during 30-percent spill. In both seasons and under both spill treatments, 60 to 65 percent of the fish in front of the sluiceways were above the elevation of the overflow weirs.

During 30- and 64-percent spill treatments in spring, we found that vertical distributions of fish at the spillway were skewed toward the surface at night and toward the ogee during the day. These trends are the opposite of those reported in the past at Columbia River dams (e.g., Johnson, Johnson, and Weitkamp 1986; and Johnson, Sullivan, and Erho 1992). However, we could not explain the day and night differences based upon differences in detectability. Although spill gates were opened wider at night than they were during the day because of the juvenile spill pattern, water velocities near the ogee are similar for the 30-percent night spill and the 64-percent day spill. Nevertheless, the day and night differences persisted. Acquired data indicate that fish in the 8- to 9-m range stratum had an average of six echoes during day and night under both spill treatments.

More fish pass at the powerhouse and pass slightly deeper, under the lower spill treatment. That treatment involves higher turbine operation levels to balance energy needs and to maintain "Run of River" pool levels. Therefore, the "Low Spill" treatment involves not only lower flows to the spillway area but higher and more numerous flows downward into the turbine intakes. It is reasonable to suspect that both of these factors were important in delivering or attracting fish to the various passage routes. In the "Low Spill" case, lower bulk flows downstream to the spillway competed with greater downward turbine flows at more turbines. It is reasonable to suspect that fish passed the powerhouse more slowly and encountered more numerous and extensive turbine flow nets (both absolutely and as compared to spillway-bound flow) in the "Low Spill" case with more generation than in the "High Spill" case with less generation.

Diel distribution

Peaks in passage during the evening crepuscular period characterized the diel distribution of fish passage in the spillway. This may have been as a result of behavioral responses to changes in light levels. It also may have been a response to changes in dam operations, as the spill pattern was changed from the daytime adult pattern to the nighttime juvenile pattern at 2000 hr. The diel distribution at the powerhouse followed the same general trend during both spring and summer. We saw low passage in the sluiceways at night, higher passage during the day, and the opposite for turbine passage.

Comparisons with other years

Our estimates of FPE for TDA in 1999 were 14 percent (spring) and 21 percent (summer) lower than those estimated in 1998 (Table 6). Because sampling duration and flows were similar in both years, we have to examine the components of FPE (spill + sluice passage) / (spill + sluice + turbine passage) to understand the differences.

The biggest single difference in the components of FPE between 1998 and 1999 was in the estimates of turbine passage in the 2 years. Our daily turbine-passage estimates in 1999 were 3.5 and 6.1 times higher than the respective spring and summer estimates in 1998. Thresholds for data acquisition were the same in both years (-56 dB || 1 μPa at 1m), but our pulse repetition rate (14 pings/sec) was 40 percent higher than the 10 pings/sec used in 1998. Also, in expanding detected fish to the width of the turbine intakes, we used an effective beam angle based upon detectability modeling of range and target strength effects instead of range effects alone as was done in 1998. Our effective beam angle was about 0.5 deg smaller than a simple range-dependent beam angle at any particular range. Detectability curves as a function of range in this study and the 1998 study are virtually identical, so the 0.5-deg difference was entirely the result of considering target-strength distribution effects. However, it is difficult to explain the difference in FPE among years solely by differences in effective-beam angle because we used the same approach to expanding detected fish at all passage routes.

The next biggest difference in FPE components between 1998 and 1999 was in the sluiceway passage estimates. Our estimates were 40 and 67 percent (spring and summer, respectively) of 1998 estimates. We know that 20 percent of these differences can be ascribed to our exclusion of fish that were not swimming toward the sluiceway opening based upon split-beam sampling at Sluice Gate 1-3. Eighty percent of the fish detected upstream of the sluiceway opening in spring and summer were moving toward the opening. We reduced all single-beam counts in 1999 at the sluiceway by a factor of 0.8, which seems reasonable. If we assume the same factor may have been appropriate in 1998, the sluiceway estimates would have differed only by 40 and 13 percent in the respective seasons.

Spillway estimates in 1999 and 1998 were within 10 percent of one another in spring, but in summer the 1999 estimates were 69 percent higher than the 1998 estimates. Pulse repetition rates were 24 pings/sec in this study and 20 pings/sec in 1998. Given the exceptionally high-water velocities that can occur near the spillway ogee when gates are wide open (e.g., > 6 m/sec; Figure 7), it would be prudent to use the highest sampling rates possible in all future studies there. The lower ping rate in 1998 might help explain the lower summer counts as compared to the 1999 data. On the other hand, the 1999 spillway transducer mounts were designed to reduce multiple counting of individuals by sampling only fish that were committed to passage and that would likely reduce 1999 spillway counts relative to those from 1998.

We found consistent and significant differences in the target strength distributions of fish for the spillway and powerhouse. The mean target strength of detected fish at the spillway was smaller than the mean target strength of fish detected at the powerhouse. We do not know whether the differences resulted from differences in fish aspect (orientation) as they passed through the hydroacoustic beam or whether fish passing the spillway tended to be smaller than fish passing through the powerhouse. Whatever the reason, target strength differences at the two passage sites would make fish less detectable at the spillway than at the powerhouse, particularly in summer when out-migrating fish are smaller than in spring. We adjusted spatial expansion factors to adjust for these differences in detectability, and this adjustment may explain higher estimates in 1999 than in 1998.

Our estimates of project FPE in spring and summer were 20 percent higher than spring estimates and 11 percent lower than summer estimates made in 1996 (Table 6). For spring, the difference was primarily the result of higher estimates of fish in spill in 1999 than in 1996. For summer, the difference was predominantly because of higher estimates of turbine passage in 1999 than in 1996. Higher estimates in 1999 than in 1996 may be attributed to among year differences in the numbers of fish because estimates of passage at most other routes and times showed similar differences. There also were differences in data acquisition procedures (e.g., higher ping rates), and processing (i.e., detectability modeling based upon target strength and range) between the 2 years.

Our sluiceway estimates were lower than those reported in 1998 and a little higher than those reported in 1996. Detectability adjustments of fish-passage estimates for the spillway and sluiceway increased our preliminary estimates by about 30 and 100 percent, respectively, but they still were lower than in 1998. As mentioned before, 20 percent of the reduction in numbers from 1998 to 1999 resulted from our use of fish swimming direction as a criterion for counting fish entering the sluiceway.

Recommendations

a. *The acoustic screen model and detectability.* Our analysis of the acoustic screen model has resulted in a set of guidelines that will aid hydroacoustic researchers who conduct similar studies. These guidelines are listed and explained in detail in Appendix B. Briefly, we recommend collecting split-beam data at the same locations that single-beam data are collected. This will aid attempts to collect and analyze data in such a manner that the assumptions of the acoustic screen model are not violated. Proper consideration of minimizing spatial and temporal bias is also necessary for accurate estimates. We also found that detailed water velocity information is critical for assuring the accuracy of detectability calculations and, therefore, of hydroacoustic estimates.

In addition to providing accurate information used in detectability modeling, our split-beam system at the sluiceway provided important fish direction data that enabled recognition of the percentage of nonentrained fish there. This is an important application that should be considered when designing hydroacoustic evaluations in locations where the net movements of fish may not be uniform in direction and fish may not be committed to passing.

b. *Hydroacoustic sampling.* We recommend that the use of faster ping rates in the spillway be explored to compensate for the narrow effective beam widths that occur there during times of high spill, particularly at night.

c. *Tracker error.* We have attempted to collect and report experimental data evaluating the potential error that may be inherent when more than one person (or tracking program) is used to produce fish counts from hydroacoustic data. We suggest that carefully designed and analyzed tests to evaluate tracker error, explicitly reported to sponsors, can improve the quality of our science and the reliability and defensibility of the deliverables that we produce. We suggest that, unless human trackers can be shown to be interchangeable, data should be distributed to trackers at the smallest practical temporal scale to control tracker error.

   Acoustic noise, especially bubble noise, may be a main cause of tracker error and limits autotracker reliability. Dense clouds of bubbles produce echo returns that can obscure fish traces. Quantitative measures of acoustic noise and tracker noise should be carefully evaluated and controlled as much as possible, and explicitly reported. As sources of error they might also be included in calculation of the confidence limits on estimates. We are investigating methods that have been developed by workers in related fields including aerial and foot surveys of adult salmon (Jones, Quinn, and Van Allen 1998), production fish aging (Morison, Robertson, and Smith 1998) and shipboard surveys of pelagic dolphin abundance (Gerrodette and Perrin 1991; Barlow, Gerrodette, and Perryman 1998).

d. *Opportunity for improved surface collection.* We have provided strong evidence that hourly passage in turbines are skewed towards the upstream end of the powerhouse during periods when most turbine units are operating. Telemetry results from the last several years have consistently indicated that the majority of smolts enter TDA forebay along the south shoreline and first contact the dam at the upstream end of the powerhouse. The first nonturbine passage route available to out-migrating fish is the sluiceway opening at the downstream end of the powerhouse. An additional surface collection route at the upstream end of the powerhouse, e.g., a split-opening configuration of the existing sluiceway system, may reduce entrainment. This configuration was examined in the past (1980), but new data and a different hydraulic environment within the forebay caused by current dam operations suggest that further evaluation may be warranted.

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Appendix A[1]
Synopsis of the Statistical Design and Analysis of The Dalles Dam Hydroacoustic Studies, 1999

Introduction

This document summarizes the statistical design and planned analysis of the fixed-location hydroacoustic investigations at The Dalles Dam in 1999. This statistical plan summarizes the transducer deployment and objectives of the study which lead to the estimators of smolt passage. The overall objective of this study is to compare passage performance under two spill levels, 30 and 64 percent, using a number of response variables. This statistical plan will be reviewed by the U.S. Army Corps of Engineers (USACE) staff, contractors, and statistical consultants prior to the 1999 investigation.

Transducer Deployment

Turbine units

The Dalles Dam has 22 primary turbine units and 2 additional fish units. At the primary turbine unit, one transducer will be randomly allocated to one of the three turbine slots per unit. Within the turbine slots selected, the transducer will be randomly located to the left, right, or middle trisection. The primary turbine units will be sampled for fifteen 1-min intervals per hour.

Fish units 1 and 2 have two intake slots each. One of the two intake slots will be randomly selected for transducer placement. The transducers will be randomly located to the left, right, or middle trisection of the selected slot. These intake slots will be sampled for fifteen 1-min intervals per hour.

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[1] This appendix was prepared by Dr. John Skalski, School of Fisheries, University of Washington.

Sluiceway

Above turbine unit #1, there are three sluiceway openings. Each of the three sluiceway openings will be equipped with a transducer. The sluiceway transducers will be sampled for fifteen 1-min intervals per hour.

Spillway

The spillway at The Dalles Dam has 23 spillbays. In 1999, the odd-numbered spillbays will be hydroacoustically monitored. For spillbays 1, 5, 7, 9, 11, 15, 17, 19, 21, and 23, one transducer will be randomly positioned to the left, right, or middle trisection at each spillbay. For spillbays 3 and 13, three transducers will be positioned, one each in the left, right, and middle trisections of the spillbays. For purposes of estimating smolt passage and its variance, spillbays 1-3, 4-7, 8-11, 12-15, 16-19, and 20-23 will be considered spatial blocks. Spillbay transducers will be sampled for three 2.5-min time intervals per hour.

Estimating Smolt Passage

Turbine unit passage

For the 22 primary turbine units and 2 fish units:

x_{ijkl} = weighted number of smolt in the lth time interval $(l=1,\ldots,N)$ of the kth hour $(k=1,\ldots,24)$ of the jth day $(j=1,\ldots,D)$ for the ith turbine unit $(i=1,\ldots,24)$

Total turbine passage is then estimated by:

$$\hat{T}=\sum_{i=1}^{22}\sum_{j=1}^{D}\sum_{k=1}^{24}\frac{3N}{n}\sum_{l=1}^{n}x_{ijkl}+\sum_{i=23}^{24}\sum_{j=1}^{D}\sum_{k=1}^{24}\frac{2N}{n}\sum_{l=1}^{n}x_{ijkl} \qquad (1)$$

where the first term estimates smolt passage for the primary turbine units 1 through 22 and the second term estimates smolt passage for the two fish units i = 23, 24. Nominally, turbine slots will be sampled for n = fifteen 1-min intervals from N = 60 possible intervals per hour.

The variance of $\hat{T}$ can be approximated by the expression

$$V\hat{a}r\left(\hat{T}\middle|T\right)=\sum_{i=1}^{22}\sum_{j=1}^{D}\sum_{k=1}^{24}\left[9N^2\frac{\left(1-\frac{n}{N}\right)s_{x_{ijk}}^2}{n}\right]+\sum_{i=23}^{24}\sum_{j=1}^{D}\sum_{k=1}^{24}\left[4N^2\frac{\left(1-\frac{n}{N}\right)s_{x_{ijk}}^2}{n}\right] \qquad (2)$$

where

$$s^2_{x_{ijk}} = \frac{\sum_{l=1}^{n}\left(x_{ijkl} - \overline{x}_{ijk}\right)^2}{(n-1)}$$

and where

$$\overline{x}_{ijk} = \frac{\sum_{l=1}^{n} x_{ijkl}}{n}$$

Variance expression (2) is downwardly biased, for it does not incorporate the between-slot, within-turbine variation, since only one of three or one of two slots per unit is sampled in 1999.

Sluiceway passage

For the sluiceways:

y_{ijkl} = weighted number of smolt in the lth time interval $(l = 1,\ldots,M)$ of the kth hour $(k = 1,\ldots,24)$ of the jth day $(j = 1,\ldots,D)$ for the ith sluiceway opening $(i = 1,\ldots,3)$

Total sluiceway passage is then estimated by

$$\hat{W} = \sum_{i=1}^{3}\sum_{j=1}^{D}\sum_{k=1}^{24}\frac{M}{m}\sum_{l=1}^{m} y_{ijkl} \qquad (3)$$

Nominally, m = fifteen 1-min intervals will be sampled from a possible $M = 60$ intervals within 1 hr at a sluiceway.

A variance estimator for $\hat{W}$ can be expressed as

$$V\hat{a}r\left(\hat{W}\middle|W\right) = \sum_{i=1}^{3}\sum_{j=1}^{D}\sum_{k=1}^{24}\left[\frac{M^2\left(1-\frac{m}{M}\right)s^2_{y_{ijk}}}{m}\right] \qquad (4)$$

where

$$s^2_{y_{ijk}} = \frac{\sum_{l=1}^{m}\left(y_{ijkl} - \overline{y}_{ijk}\right)^2}{(m-1)}$$

and where

$$\bar{y}_{ijk} = \frac{\sum_{l=1}^{m} y_{ijkl}}{m}$$

Spillway passage

Three or four consecutive spillbays within the spillway will be conceptualized as forming a spatial stratum (i.e., spillbays 1-3, 4-7, 8-11, 12-15, 16-19, 20-23). The sampling then consists of a two-stage sampling design; (1) the spillbays within the strata, (2) temporal sampling within spillbays.

Define

z_{gijkl} = weighted number of smolt in the lth time interval $(l = 1,\ldots,Q)$ of the kth hour $(k = 1,\ldots,24)$ of the jth day $(j = 1,\ldots,D)$ for the ith spillbay $(i = 1,\ldots,B)$ of the gth stratum $(g = 1,\ldots,6)$

The estimate of total spillway passage can be calculated as

$$\hat{S} = \sum_{g=1}^{6}\left[\frac{B_g}{b_g}\sum_{i=1}^{b_g}\sum_{j=1}^{D}\sum_{k=1}^{24}\frac{Q}{q}\sum_{l=1}^{q} z_{gijkl}\right] \tag{5}$$

For stratum 1 (i.e., spillbay 1-3), $B_1 = 3$ and $b_1 = 2$. For the remaining strata, $B_i = 4$, $b_i = 2$ for $i = 2,\ldots,6$. Estimator (5) is based on the assumption of a random sample of b_i of B_i spillbays within a stratum, while in reality, the spillbays were systematically selected. Typically, the variance formula based on simple random sampling will overestimate the actual variance of systematic sampling. Nominally, sampling will consist of q = three 2.5-minute samples out of a possible Q = 24 per hour at a spillbay.

The variance of $\hat{S}$ will be estimated by the expression

$$\hat{Var}\left(\hat{S}\middle|S\right) = \sum_{g=1}^{6}\frac{B_g^2\left(1-\frac{b_g}{B_g}\right)s_{\hat{S}_g}^2}{b_g} + \sum_{g=1}^{6}B_g\left[\frac{\sum_{i=1}^{b_g}\hat{Var}\left(\hat{S}_{gi}\middle|S_{gi}\right)}{b_g}\right] \tag{6}$$

where

$$s_{\hat{S}_g}^2 = \frac{\sum_{i=1}^{b_g} \left(\hat{S}_{gi} - \bar{\hat{S}}_g \right)^2}{\left(b_g - 1 \right)}$$

$$\bar{\hat{S}}_g = \frac{\sum_{i=1}^{b_g} \hat{S}_{gi}}{b_g}$$

$$V\hat{a}r\left(\hat{S}_{gi} \middle| S_{gi} \right) = \sum_{j=1}^{D} \sum_{k=1}^{24} \left[\frac{Q^2 \left(1 - \frac{q}{Q} \right) s_{z_{gijk}}^2}{q} \right]$$

$$s_{z_{gijk}}^2 = \frac{\sum_{l=1}^{q} \left(z_{gijkl} - \bar{z}_{gijk} \right)^2}{\left(q - 1 \right)}$$

$$\bar{z}_{gijk} = \frac{\sum_{l=1}^{q} z_{gijkl}}{q}$$

Performance Measures

Fish-passage efficiency (FPE)

Fish-passage efficiency will be defined as

$$FPE = \frac{S + W}{S + W + T}$$

and estimated by the expression

$$F\hat{P}E = \frac{\hat{S} + \hat{W}}{\hat{S} + \hat{W} + \hat{T}} \qquad (7)$$

Using the Delta method,[1] the variance of $F\hat{P}E$ can be approximated by

$$V\hat{a}r\left(F\hat{P}E \middle| FPE \right) = F\hat{P}E^2 \left(1 - F\hat{P}E \right)^2 \left[\frac{V\hat{a}r\left(\hat{T} \right)}{\hat{T}^2} + \frac{V\hat{a}r\left(\hat{W} \right) + V\hat{a}r\left(\hat{S} \right)}{\left(\hat{W} + \hat{S} \right)^2} \right] \qquad (8)$$

[1] Seber, G. A. F. (1982). *The estimation of animal abundance and related parameters.* MacMillan, New York, 7-11.

Spill efficiency (SE)

Spill efficiency will be defined as

$$SE = \frac{S}{S + W + T}$$

and estimated by the expression

$$\hat{SE} = \frac{\hat{S}}{\hat{S} + \hat{W} + \hat{T}} \tag{9}$$

Using the Delta method, the variance of the spill efficiency estimator can be estimated by the expression

$$V\hat{a}r\left(\hat{SE}\middle|SE\right) = \hat{SE}^2\left(1 - \hat{SE}\right)^2\left[\frac{V\hat{a}r\left(\hat{S}\right)}{\hat{S}^2} + \frac{V\hat{a}r\left(\hat{W}\right) + V\hat{a}r\left(\hat{T}\right)}{\left(\hat{W} + \hat{T}\right)^2}\right] \tag{10}$$

Spill effectiveness (SEF)

Spillway effectiveness will be defined as

$$SEF = \frac{\dfrac{S}{F_{SP}}}{\dfrac{(S + W + T)}{(F_{SP} + F_{SL} + F_{TUR})}} = SE\frac{(F_{SP} + F_{SL} + F_{TUR})}{(F_{SP})}$$

where

F_{SP} = flow through spillway

F_{SL} = flow through sluiceway

F_{TUR} = flow through turbines

The estimator of spill effectiveness can then be calculated as

$$S\hat{E}F = \hat{SE} \cdot \left(\frac{F_{SP} + F_{SL} + F_{TUR}}{F_{SP}}\right) \tag{11}$$

with associated variance estimator

$$V\hat{a}r\left(S\hat{E}F\middle|SEF\right) = \left(\frac{F_{SP} + F_{SL} + F_{TUR}}{F_{SP}}\right)^2 \cdot V\hat{a}r\left(\hat{SE}\middle|SE\right) \tag{12}$$

Powerhouse sluiceway efficiency (SLE$_P$)

The powerhouse sluiceway efficiency (SLE_P) is defined as

$$SLE_P = \frac{W}{W+T}$$

and estimated by the quantity

$$\hat{SLE}_P = \frac{\hat{W}}{\hat{W}+\hat{T}} \tag{13}$$

An approximate variance calculation for $\hat{SLE}_P$ is

$$\hat{Var}\left(\hat{SLE}_P \middle| SLE_P\right) = SLE_P^2\left(1-SLE_P\right)^2\left[\frac{\hat{Var}\left(\hat{W}\right)}{\hat{W}^2}+\frac{\hat{Var}\left(\hat{T}\right)}{\hat{T}^2}\right] \tag{14}$$

Powerhouse sluiceway efficiency (SLEF$_P$)

The powerhouse sluiceway efficiency ($SLEF_P$) is defined as

$$SLEF_P = \frac{\dfrac{W}{F_{SL}}}{\dfrac{(W+S)}{(F_{SL}+F_{TUR})}} = SLE_P\left(\frac{F_{SL}+F_{TUR}}{F_{SL}}\right)$$

and is estimated by the quantity

$$SL\hat{E}F_P = \hat{SLE}_P\left(\frac{F_{SL}+F_{TUR}}{F_{SL}}\right) \tag{15}$$

The variance for $SL\hat{E}F_P$ can be calculated by the expression

$$\hat{Var}\left(SL\hat{E}F_P \middle| SLEF_P\right) = \hat{Var}\left(\hat{SLE}_P \middle| SLE_P\right)\left(\frac{F_{SL}+F_{TUR}}{F_{SL}}\right)^2 \tag{16}$$

Total project sluiceway efficiency (SLE$_T$)

The total project sluiceway efficiency (SLE_T) is defined by

$$SLE_T = \frac{W}{S+W+T}$$

and estimated by the quotient

$$\hat{SLE}_T = \frac{\hat{W}}{\hat{S} + \hat{W} + \hat{T}} \quad (17)$$

The variance for $\hat{SLE}_T$ can be estimated by the expression

$$\hat{Var}\left(\hat{SLE}_T \middle| SLE_T\right) = \hat{SLE}_T^2\left(1 - \hat{SLE}_T\right)^2\left[\frac{\hat{Var}\left(\hat{W}\right)}{\hat{W}^2} + \frac{\hat{Var}\left(\hat{S}\right) + \hat{Var}\left(\hat{T}\right)}{\left(\hat{S} + \hat{T}\right)^2}\right] \quad (18)$$

Total project sluiceway effectiveness ($SLEF_T$)

The total project sluiceway effectiveness ($SLEF_T$) is defined by

$$SLEF_T = \frac{\left(\frac{W}{F_{SL}}\right)}{\frac{(S + W + T)}{(F_{TUR} + F_{SL} + F_{SP})}} = SLE_T\left(\frac{F_{TUR} + F_{SL} + F_{SP}}{F_{SL}}\right)$$

and can be estimated by the product

$$\hat{SLEF}_T == \hat{SLE}_T\left(\frac{F_{TUR} + F_{SL} + F_{SP}}{F_{SL}}\right) \quad (19)$$

The variance for $\hat{SLEF}_T$ can be calculated by the expression

$$\hat{Var}\left(\hat{SLEF}_T \middle| SLEF_T\right) = \hat{Var}\left(\hat{SLE}_T \middle| SLEF_T\right)\left(\frac{F_{TUR} + F_{SL} + F_{SP}}{F_{SL}}\right)^2 \quad (20)$$

The seven performance measures described above will be estimated seasonally for each of the two spill levels (i.e., 30 and 64 percent). These estimates will summarize overall seasonal performance as well as day and nighttime passage performance.

Spill Experiment

In 1999, a two-treatment experiment will be performed to compare smolt passage performance under 30- and 64-percent spill levels. A randomized block design will be used to compare treatment conditions. Separate tests will be performed during the spring and summer seasons. During spring, six blocks with 3 days per treatment will be performed. During summer, nine blocks with 3 days per treatment will be performed (Table A1).

Table A1
Proposed Schedule for Spill Trials at The Dalles Dam in 1999

Spring			Summer					
Date	Block	Spill Level	Date	Block	Spill Level	Date	Block	Spill Level
4/22	1	30	6/1	1	30	7/7	7	30
4/23		30	6/2		30	7/8		30
4/24		30	6/3		30	7/9		30
4/25		64	6/4		64	7/10		64
4/26		64	6/5		64	7/11		64
4/27		64	6/6		64	7/12		64
4/28	2	30	6/7	2	30	7/13	8	30
4/29		30	6/8		30	7/14		30
4/30		30	6/9		30	7/15		30
5/1		64	6/10		64	7/16		64
5/2		64	6/11		64	7/17		64
5/3		64	6/12		64	7/18		64
5/4	3	30	6/13	3	30	7/19	9	30
5/5		30	6/14		30	7/20		30
5/6		30	6/15		30	7/21		30
5/7		64	6/16		64	7/22		64
5/8		64	6/17		64	7/23		64
5/9		64	6/18		64	7/24		64
5/10	4	30	6/19	4	30			
5/11		30	6/20		30			
5/12		30	6/21		30			
5/13		64	6/22		64			
5/14		64	6/23		64			
5/15		64	6/24		64			
5/16	5	30	6/25	5	30			
5/17		30	6/26		30			
5/18		30	6/27		30			
5/19		64	6/28		64			
5/20		64	6/29		64			
5/21		64	6/30		64			
5/22	6	30	7/1	6	30			
5/23		30	7/2		30			
5/24		30	7/3		30			
5/25		64	7/4		64			
5/26		64	7/5		64			
5/27		64	7/6		64			

The effect of spill levels on smolt passage will be assessed using five performance measures as follows:

a. *FPE*

b. *SE*

c. *SEF*

d. SLE_T

e. $SLEF_T$

These performance measures will be estimated for the 3-day test periods within each test block. Tests of effects will be performed at a significance level of $\alpha = 0.10$ two-tailed. Actual P-values for each test will be reported along with treatment means and variances. A standard degree-of-freedom table for a two-way analysis of variance (ANOVA) is presented below.

ANOVA

Source	DF
Total	$2B$
Mean	1
$Total_{Cor}$	$2B-1$
Treatment	1
Blocks	$B-1$
Error	$B-1$

B = Number of blocks.

Appendix B[1] Assessment of the Acoustic Screen Model to Estimate Smolt Passage Rates at Dams: Case Study at The Dalles Dam in 1999

Preface

This study was undertaken for the U.S. Army Corps of Engineers, Engineering Research and Development Center (ERDC), Waterways Experiment Station (WES), Environmental Laboratory (EL), Fisheries Engineering Team. BioAnalysts, Inc., Vancouver, WA, performed the work under contract to WES (BAA 99-3089) within the Broad Agency Announcement for general area conservation and research area EL-17 fish guidance and bypass systems. The products of this study were three reports: preliminary assessment report (April 1999); draft final report (November 1999); and final report (February 2000). The last two reports were included as appendices in WES reports on the fixed-location hydroacoustic study at The Dalles Dam in 1999. In conjunction, specific data from hydroacoustic research at The Dalles Dam in 1999 are included in this assessment of the acoustic screen model to estimate smolt passage rates at dams.

Mr. Marvin Shutters, U.S. Army Engineer District (USAED), Portland, helped motivate this assessment of the acoustic screen model. Messrs. Dean Brege and Mike Gessel, National Marine Fisheries Service (NMFS), and Mr. Rick Klinge, Douglas County Public Utility District, East Wenatchee, WA, provided fyke net data. Ms. Duane Harrell, Duke Power Company, Charlotte, NC, supplied a report on a fish entrainment study in Southeastern United States. Messrs. Mike Hanks, Peter Johnson, Larry Lawrence, Ms. Deborah Patterson, and Mr. Carl Schilt, Fisheries Engineering Team, ERDC/WES, collected and processed the hydroacoustic passage data. Mr. Bill Nagy, USAED, Portland, wrote the fish tracking programs. Messrs. Jim Dawson, BioSonics, Inc.,

[1] This appendix was prepared by Gary E. Johnson, BioAnalysts, Inc., 11807 N.E. 99th Street, #1160, Vancouver, WA 98682.

Seattle, WA, John Ehrenberg, Hydroacoustic Technology, Inc., Seattle, WA, and John Hedgepeth, Tenerra, Inc., San Louis Obispo, CA, reviewed the report and provided valuable comments. Dr. John Nestler, ERDC/WES, managed contractual and scientific processes. Mr. Gene Ploskey, Fisheries Engineering Team, ERDC/WES, provided integral technical interaction and insight.

Introduction

The acoustic screen[1] model is the basis for all fixed-location hydroacoustic studies that generate estimates of smolt passage rates. It is one of the most elementary methods in scientific fisheries acoustics. Since its origin in 1980 by Carlson et al. (1983),[2] the acoustic screen model has been applied in over 100 studies at the 13 mainstem Columbia and Snake River dams where downstream fish passage is a concern. The applications included most of the main initiatives to improve smolt passage, e.g., spill, intake screens, and surface bypass (Thorne and Johnson 1993). For the most part, these studies have produced reasonably reliable data. The studies with ambiguous or doubtful results, however, demonstrate that it is critical for hydroacoustic researchers to carefully apply the acoustic screen model so that decision makers can be confident in the data. As regional and national interest in Pacific Northwest smolt passage issues intensifies, a nonobtrusive technique with high sampling power like fixed-location hydroacoustics will continue to be an important monitoring and evaluation tool. Thus, critical assessment of the acoustic screen model is timely and desirable.

Historically, the acoustic screen model has been indirectly examined by comparing hydroacoustic and fyke net estimates of smolt passage. When the passage estimates from hydroacoustics and net catches comported, the acoustic screen model was validated. Ransom et al. (1996) reviewed studies in the Columbia Basin with simultaneous hydroacoustic and net samples of fish passage. They reported numerous instances where the correlation between estimates from the two techniques was statistically significant ($P<0.05$), such as work at Ice Harbor, Lower Granite, Rocky Reach, and Wanapum Dams. Ploskey and Carlson (1999) thoroughly compared hydroacoustic and net counts at John Day Dam in 1996. They found bias in the hydroacoustic count data and recommended that hydroacoustic studies have an independent means to assess the validity of their estimates. Thorne and Kuehl (1989) assessed the effects of acoustic system threshold on estimates of fish guidance efficiency (FGE) and compared hydroacoustic and net estimates of FGE. As long as the thresholds used for guided and unguided passage estimates were equivalent, hydroacoustic FGE estimates were comparable to fyke net FGE estimates, especially over long (seasonal) time periods. When hydroacoustic and net counts did not comport, e.g., Intake 13A at Bonneville Dam in summer 1988 (Magne et al. 1989), assumptions of the acoustic screen model were questioned. One lesson from the ground-truth studies is that it is essential to compare results from studies using the acoustic screen

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[1] The acoustic screen represents the sample volume for a fixed-location hydroacoustic transducer. The acoustic screen model and its assumptions are described in detail in section entitled "Description and Assessment of Acoustic Screen Model."

[2] References for this appendix are listed on page B24.

model to comparable independent results. These studies also showed that the assumptions of the acoustic screen model must be examined.

The most recent critical assessment of the acoustic screen model for Columbia Basin smolt passage was by Thorne (1988). He examined sources of error in the model, including target strength, calibration, and pattern recognition. He concluded that complete knowledge of target strength structure and variability of the population, horizontal distribution, and hydroacoustic system performance were necessary to analyze potential errors in relative and absolute estimates.

The acoustic screen model can be used to make relative or absolute smolt passage rate estimates. The Principle of Equivalency is applied to make relative estimates. It says that the model is valid as long as elements of the acoustic screen model, such as detectability, are equivalent from location to location. For example, the model is valid for relative estimates if detectability is 80 percent of nominal at both spillway and powerhouse sample locations. In this example, absolute estimates would obviously have been in error. Most fixed-location hydroacoustic studies in the Columbia Basin have made solid relative estimates in the form of ratios, e.g., FGE, spill efficiency, surface bypass efficiency. Some studies in the early to mid 1980s attempted absolute estimation, but suffered from unknown variation in target strength and subsequent effects on effective beam angle. The jump from relative to absolute estimates using the acoustic screen model is difficult and should be avoided if possible. Whether relative or absolute estimates are made, however, the assumptions of the acoustic screen model must be assessed each time the model is applied.

The purpose of this study is to critique the acoustic screen model using data from a case study at The Dalles Dam (TDA) in 1999 provided by Ploskey et al. (Draft 1999). The objectives are to:

a. Describe the acoustic screen model and its underlying assumptions.

b. Assess the assumptions and identify critical uncertainties requiring monitoring and research.

c. Apply data from the TDA hydroacoustic study and elsewhere to validate or invalidate the uncertain assumptions.

d. Recommend specific ways to improve the acoustic screen model and its application.

The study progresses from the introduction into a description and assessment of the acoustic screen model. Methods for applying data from TDA are presented, followed by Results and Discussion, Conclusions and Recommendations, and Literature Cited. Dr. John Ehrenberg's memorandum on effective beam angle concludes Appendix B. The interested reader should see MacLennan and Simmonds (1992) for a description of fisheries acoustics methods and Urick (1983) for principles of underwater sound.

Description and Assessment of Acoustic Screen Model

The acoustic screen model (Figure B1) is an echo counting procedure by which passage rates are estimated from a fixed transducer sample location. MacLennan and Simmonds (1992 pp 137-147) describe echo counting. The technique relies on detection of single echoes from fish. It is limited by noise sources, such as electrical, wind-generated turbulence, and reverberation from structures. The transducers forming acoustic screens are typically single-beam, although the acoustic screen model applies to split- and dual-beam as well when they are used to generate passage estimates.

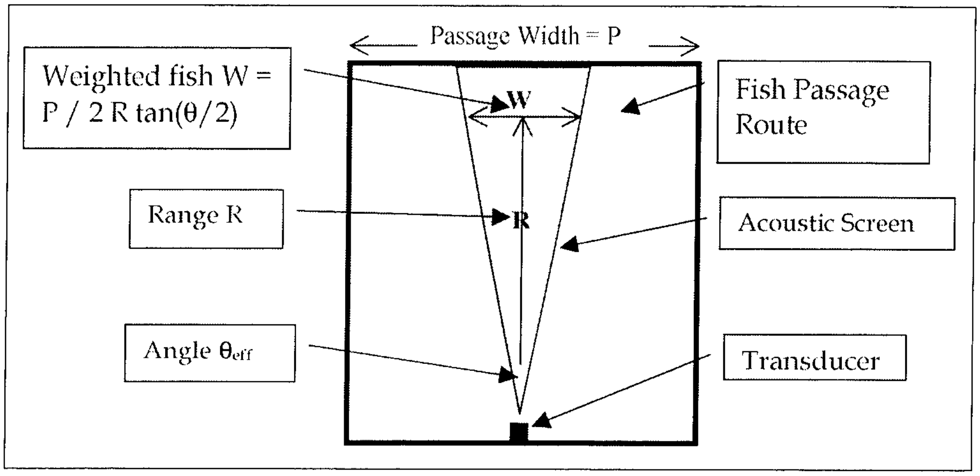


Figure B1. Schematic of the acoustic screen model showing the equation for spatial weighting

The acoustic screen is based on the acoustic sampling volume. The sound field created by the transducer is placed in a region of expected fish passage. This volume has user defined start and stop ranges. Inside this volume, acoustic intensity is strongest in the center (acoustic axis) and decreases with angular distance from the axis. The technical edge of the beam is defined as the angle where the sound intensity has dropped by half (-3 dB angle). The intensity typically drops dramatically beyond this angle. The real or effective beam angle defining the edge of the beam is formed by the interaction between the echo detection threshold and the level of the returning echo (echo level) for single-beam systems. The edge of the beam may be mathematically defined for dual- and split-beam applications. The acoustic volume expands with range as the sound waves spread, and usually has a conical or elliptical shape. All echoes inside the sample volume whose amplitude is higher than the threshold should be detected. But, since the objective is to count fish instead of echoes, a spatial correlation (trace formation) algorithm is applied to convert echoes into fish. This conversion process relies on overlap in the ensonified volumes between successive acoustic transmissions (Kieser and Mulligan 1984). Thus, the conversion from fish echoes to traces reduces the overlapping sample volumes into a sampling plane or "Acoustic Screen."

The acoustic screen can be regarded as a trapezoidal shape bounded by the start and stop ranges and the effective beam angle (Figure B1). A "number of echoes" criterion is applied in the spatial correlation algorithm and is a critical parameter in determining fish detectability. Other parameters affecting detectability include the angle between fish trajectory and the plane, target strength, threshold, and echo sounder pulse repetition rate.

The acoustic screen model is used to spatially extrapolate fish detections at specific ranges from the transducer into the entire width of the passage route (see equation in Figure B1). This spatial extrapolation is the heart of the acoustic screen model. Fish detected near the transducer are extrapolated more than those further away because the acoustic screen is narrower near the transducer than it is further away. The most important parameter is the effective beam angle (θ_{eff}), because it is difficult to know accurately. In summary, the critical parameters in the acoustic screen model include the effective beam angle in the echo counting process and the "number of echoes" criterion in the trace formation process. These parameters and others are the subject of certain assumptions in the acoustic screen model.

We organized the assumptions of the acoustic screen model around the fish passage estimation process: detection, identification, and weighting. We only included assumptions pertinent to this study; there are many more in other applications of quantitative hydroacoustics, e.g., marine biomass estimation. The Principle of Equivalency applies to all assumptions when relative passage rate estimates are made.

Detection

Detection has to do with the ability of the hydroacoustic system to accurately acquire fish echo data. We assume a scientific quality hydroacoustic system is used, i.e., one that has an accurate and stable time-varied-gain, adjustable ping rate and pulse width, and known source level, receiving sensitivity, and beam pattern directivity. The detection assumptions are:

a. The sound energy does not affect fish behavior.

b. All targets of interest within the effective beam angle are detected, i.e., targets of interest are not truncated.

c. Minimum detectability exists such that at least a certain number of echoes (usually 4) are recorded for each fish in the beam.

d. Detectability by range from transducer is known.

e. System performance is stable during a study.

Identification

Identification is the process of extracting fish traces from the echo data. This is also called trace formation or pattern recognition. The identification assumptions are:

a. Targets do not overlap, i.e., no masking or multiple targets.

b. There are no false targets.

c. Fish counted at a particular passage route actually pass by that route.

d. The same fish is not identified (counted) more than once, i.e., no multiple counts.

e. The identification process is consistent over transducer locations and time.

Weighting

Weighting is the analysis step where individual fish detections (traces) from the acoustic sample are extrapolated to the full width of the passage route being sampled. The weighting assumptions are:

a. Effective beam angle (θ_{eff}) for each fish or the total population is known.

b. Population target strength (mean) is the same among sample locations.

c. Horizontal distribution across the passage route width (P in Figure B1) for a given range from the transducer is uniform.

The results of the assessment of the assumptions are presented in Table B1. Only one assumption is unequivocally true. Five of 13 assumptions are usually true and have negligible consequences. Four of 13 might not be true and should be monitored. For 3 of 13, truth is unknown and should be researched. We monitored and researched selected assumptions of the acoustic screen model during the TDA study in 1999.

Methods

A case study to evaluate the acoustic screen model was undertaken using data from the larger hydroacoustic study of fish passage at The Dalles Dam (TDA) in spring and summer 1999. The analysis, much of which uses split-beam data from the three types of passage route (spill, sluice, turbine), assumes these sampling locations are representative of other like locations. Monitoring and research tasks listed in Table B2 address uncertainties in some of the assumptions listed in Table B1 (scores = 3 or 4). Two of the uncertain assumptions in Table B1 (minimum detectability and identification) were addressed by Ploskey et al. (1999) during conduct of the 1999 hydroacoustic study at TDA; this work will not be repeated here.

Table B1
Assessment of Assumptions in the Acoustic Screen Model. Scores Are: (1) Unequivocally True; (2) Usually True and Consequences on the Estimation Process Are Negligible; (3) Might Not Be True and Should Be Monitored or Measured; (4) Truth Unknown or Uncertain and Extent of Any Problem Should Be Researched

No.	Assumption	Score	Comment
1	Fish behavior	2	At 420 kHz, sound cannot be sensed by smolts, but must know that other frequencies are not produced inadvertently. Need spectrum (frequency distribution) produced by the transducer.
2	Truncation	3	Must monitor target strength distribution to see if it is being truncated by the threshold for the smallest fish of interest.
3	Minimum detectability	3	Must estimate and compare detectability at each type of sample location.
4	Detectability by range	4	Fish velocity and trajectory may vary by range and should be researched.
5	System performance	1	Scientific quality hydroacoustic systems are stable.
6	Overlapping targets	2	High frequency (420 kHz) and short pulse widths (0.2-0.4 m sec) allow individual smolts to be detected.
7	False targets	2	Echoes from debris, turbulence, etc. can be mistaken for fish; this must be assessed, but risk of bias can be contained.
8	Route	2	Care must be taken during transducer deployment and fish identification to be assured that detected fish are actually migrating through the dam.
9	Multiple counts	2	W/ proper transducer location/orientation, this shouldn't be an issue.
10	Identification	3	Consistent identification may be more of a problem than we know. Proper QA/QC schemes and/or automated tracking needed.
11	Effective beam angle	4	This may be one of the most important sources of bias.
12	Target strength	3	Species and size composition are probably similar between spill and turbine locations, but acoustic aspect may be different. Also, depth and temp. effects on xducer performance may affect echo strengths.
13	Horizontal dist.	4	This critical assumption must to be researched.

Truncation

Target strength distribution data from the TDA split-beam transducers at the spillway, sluiceway, and turbines showed whether the data were truncated. The split- and single-beam systems were set up the same, i.e., same on-axis threshold of –56 dB. Frequency distributions revealed any truncation.

Target strengths for individual fish were used because they were available, whereas target strengths for individual echoes were not. In future investigations of truncation, target strengths for individual echoes should be used.

Table B2 Monitoring and Research Tasks Associated with Assumptions of the Acoustic Screen Model (Table B1)	
Assumption	**Research Task**
Truncation	Measure target strength distribution at sluice, spill, and turbine intake sample locations. Look for truncation at the threshold.
Detectability by range	At typical sample locations, measure or acquire water or fish velocity data for various ranges and run detectability models.
Effective beam angle	At typical sample locations (sluice, spill, and turbine), compare passage rate results using the six methods described below. Recommend a preferred method.
Target strength	Estimate population target strength at each sample location.
Horizontal distribution	A. Sample passage at north, middle, and south positions in two spill bays and compare passage rates. B. Review horizontal distribution data from fyke net studies that used multiple nets completely across a particular passage route.

Detectability by range

Detectability was estimated using a geometry-based model separately for the spillway, sluiceway, and turbine sample locations. This model accounted for fish velocity, ping rate, minimum number of echoes per detected fish, nominal beam angle, transducer aiming orientation and angle, and fish trajectory (Table B3). Spillway detectability was modeled for various fish velocities resulting from different water velocities depending on spill gate height. Water velocity was measured by WES for various gate heights using an acoustic doppler velocimeter. This analysis assumes water velocity represented fish velocity. This assumption is conservative, because actual fish velocity at the sample locations was probably rarely faster than water velocity, based on fish movement observations at dams (e.g., Johnson et al. 1999).

Table B3 Parameters Used in the Detectability Model			
Parameter	**Spillway**	**Sluiceway**	**Turbine**
Fish velocity (m/s)	depended on gate ht.	2.1	1.2
Ping rate (#/sec)	24	14	14
Minimum # echoes for detection	4	4	4
Beam angle along direction of travel	10	6	7
Beam angle perpendicular to travel	10	6	7
Transducer aiming orientation	downward	upward	upward
Orientation from vertical	8	6	34
Angle of fish trajectory (relative to orthogonal to the beam)	Mean 45°	15.7	-10

Effective beam angle by range is output from the detectability model. To compare detectability for transducers with different nominal beam angles, the detectability output was normalized to one by dividing the effective beam angle by the nominal angle. This detectability model does not account for target strength and other parameters in the sonar equation.

Effective beam angle

The effective beam angle assumption was examined using split-beam data from the spillway and sluiceway. We did not use the turbine split-beam data because there were too few fish sampled for the purposes of this analysis. Effective beam angle (XXX_ANGLE) was estimated using the following seven methods. Units for effective beam angle are degrees. Also shown is the corresponding weighting factor (WT_XXXX). The weighting factor is dimensionless.

1. Nominal – This is the angle listed by the transducer manufacturer.

   For the sluiceway,

   N_ANGLE = 6

   WT_NOM =

   8.23/(2*MID_R*tan((N_ANGLE/2)*(3.1416/180)))

   where, MID_R is the mid range of the fish detection

   For the spillway,

   N_ANGLE = 12

   WT_NOM =

   15.239/(2*MID_R*tan((N_ANGLE/2)*(3.1416/180)))

2. Half Power – This is the angle at the half power point (-3 dB) on the transducer's directivity pattern. H_ANGLE was read directivity from a hard copy of the directivity pattern.

   For the sluiceway,

   H_ANGLE = 5.8

   WT_HALF = 8.23/(2*MID_R*tan(H_ANGLE/2*3.1416/180))

   For the spillway,

   H_ANGLE = 12.6

   WT_HALF =

   15.239/(2*MID_R*tan((H_ANGLE/2)*(3.1416/180)))

3. Individual Target Strength – This method uses the target strength for individual fish (TS_{indiv}) measured in situ to estimate the beam pattern factor (BMINI) based on the system threshold (TH). The effective beam angle was derived by applying the beam pattern factor to the directivity pattern for that transducer. The directivity pattern was represented by a polynomial approximation. Thus, a unique weighting was performed for each fish.

For the sluiceway, TH = -56 dB

BMINI = -1*((TH - TS_{indiv})/2)

I_ANGLE = 2*(-0.0059*BMINI^4+0.0921*BMINI^3-

0.5402*BMINI^2+1.8022*BMINI+0.4416)

WT_INDTS = 8.23/(2*MID_R*tan(I_ANGLE/2*3.1416/180))

For the spillway, TH = -56 dB

BMINI = -1*((TH-X_DB)/2)

I_ANGLE = 2*(-0.0011*BMINI^4+0.1681*BMINI^3-

0.9884*BMINI^2+3.5614*BMINI+1.038)

WT_INDTS =

15.239/(2*MID_R*tan((I_ANGLE/2)*(3.1416/180)))

4. Population Target Strength – This method is similar to that for individual target strength, except a target strength estimate for the entire population (TS_{pop}) within a season is used. Target strength data came from the split-beam systems.

For the sluiceway, in spring TS_{pop} = -46.522525 dB and in summer TS_{pop} = -46.866116 dB

BMINP = -1*((TH- TS_{pop})/2)

P_ANGLE = 2*(-0.0059*BMINP^4+0.0921*BMINP^3-

0.5402*BMINP^2+1.8022*BMINP+0.4416)

WT_POPTS =

8.23/(2*MID_R*tan((P_ANGLE/2)*(3.1416/180)))

where, BMINP is the beam pattern factor

For the spillway, in spring TS_{pop} =-49.44361781and in summer TS_{pop} =-49.25366382

BMINP = -1*((TH- TS_{pop})/2)

P_ANGLE = 2*(-0.0011*BMINP^4+0.1681*BMINP^3-

0.9884*BMINP^2+3.5614*BMINP+1.038)

WT_POPTS =

15.239/(2*MID_R*tan(P_ANGLE/2*3.1416/180))

5. Detectability – This approach uses the effective beam angle output from a detectability model. A logistic equation was fitted to the detectability curve for the normalized effective beam angle (NOR_ANGLE). Then, the normalized angle was multiplied by the half-power angle to get effective beam angle based on detectability (D_ANGLE).

For the sluiceway,

a=0.998 b=-2.726 c=0.571 d=-40.808

NOR_ANGLE = (a-d)/(1+(MID_R/c)**b)+d

D_ANGLE = NOR_ANGLE*H_ANGLE

WT_DETEC =

8.23/(2*MID_R*tan((D_ANGLE/2)*(3.1416/180)))

For the spillway,

NOR_ANGLE = -0.009*MID_R^2+0.0494*MID_R+0.9294

D_ANGLE = NOR_ANGLE*H_ANGLE

WT_DETEC =

15.239/(2*MID_R*tan((D_ANGLE/2)*(3.1416/180)))

6. Rayleigh – This method uses a statistical model for back-scattering cross-section (σ_{bs}) to determine effective beam angle relative to the half power angle as a function of $\overline{\sigma_{bs}}$ and the system threshold. It is based on the "Ehrenberg Memo" reproduced in the final section of Appendix B. Peterson et al. (1976) and Ehrenberg et al. (1981) showed that the on-axis echo envelope is Rayleigh distributed (Urick 1983, pp 282 for a description) when the ratio of fish length to acoustic wavelength is large (> 25). Scattering at TDA was Rayleigh distributed, as this ratio was about 35 for 125 mm of fish and a 420-kHz acoustic system.

$TS_{pop} = 10 \log (\overline{\sigma_{bs}})$

For the sluiceway, DIF = TS_{pop}-TH

RATIO = R_ANGLE / H_ANGLE =

-0.0002*DIF^3+0.0025*DIF^2+0.069*DIF+0.2333

R_ANGLE = RATIO*H_ANGLE

WT_RAY = 8.23/(2*MID_R*tan((R_ANGLE/2)*(3.1416/180)))

For the spillway,

RATIO = R_ANGLE / H_ANGLE =

-0.0002*DIF^3+0.0025*DIF^2+0.069*DIF+0.2333

R_ANGLE = RATIO*H_ANGLE

WT_RAY =

15.239/(2*MID_R*tan((R_ANGLE/2)*(3.1416/180)))

7. Detectability/Rayleigh Combined – This approach incorporates detectability with the Rayleigh characteristics of the target strength distribution.

For the sluiceway,

DR_ANGLE = D_ANGLE*RATIO

WT_DETRAY =

8.23/(2*MID_R*tan((DR_ANGLE/2)*(3.1416/180)))

For the spillway,

DR_ANGLE = D_ANGLE*RATIO

WT_DETRAY =

15.239/(2*MID_R*tan((DR_ANGLE/2)*(3.1416/180)))

Target strength

The target strength assumption was investigated using data from the split-beam systems. Mean fish target strengths were estimated for spring and summer for spillway, sluiceway, and turbine sample locations.

Horizontal distribution

The horizontal distribution assumption was examined with data from multiple transducers at TDA spill bays in 1999 and in-turbine fyke net studies. Fyke net data from full arrays (usually 3 columns by 7 rows) were available from NMFS's extended-length screen studies at John Day, Little Goose, McNary, and The Dalles dams (Brege et al. 1997, Gessel et al. 1994 and 1995, McComas et al. 1993 and 1994, and Absolon et al. 1995, respectively). At TDA in 1999 at both Spill Bays 3 and 13, three single-beam 10° transducers were deployed uniformly across each bay (designated North, Middle, South). The purpose of this sampling effort was to examine the horizontal distribution assumption of the acoustic screen model.

A key response variable in the horizontal distribution analysis was the proportion of total fish passage that were captured or detected in the middle location (MID_PRO). Analyses of variance and multiple comparisons analyses were performed on MID_PRO.

Results and Discussion

Results from the TDA 1999 hydroacoustic study are presented that address the following assumptions in the acoustic screen model (Tables B1 and B2): truncation, detectability by range, effective beam angle, target strength, and horizontal distribution.

Truncation

Fish target strengths at TDA in 1999 did not appear truncated (Figure B2). That is, researchers probably did not miss fish because the threshold for the acoustic system was too high. However, raw echo target strength should be analyzed in future studies because they provide a more thorough understanding of truncation than fish target strengths.

The truncation assumption is especially important if the acoustic screen model is used to make absolute passage estimates. When relative estimates are made, the model assumes any truncation is equivalent among locations.

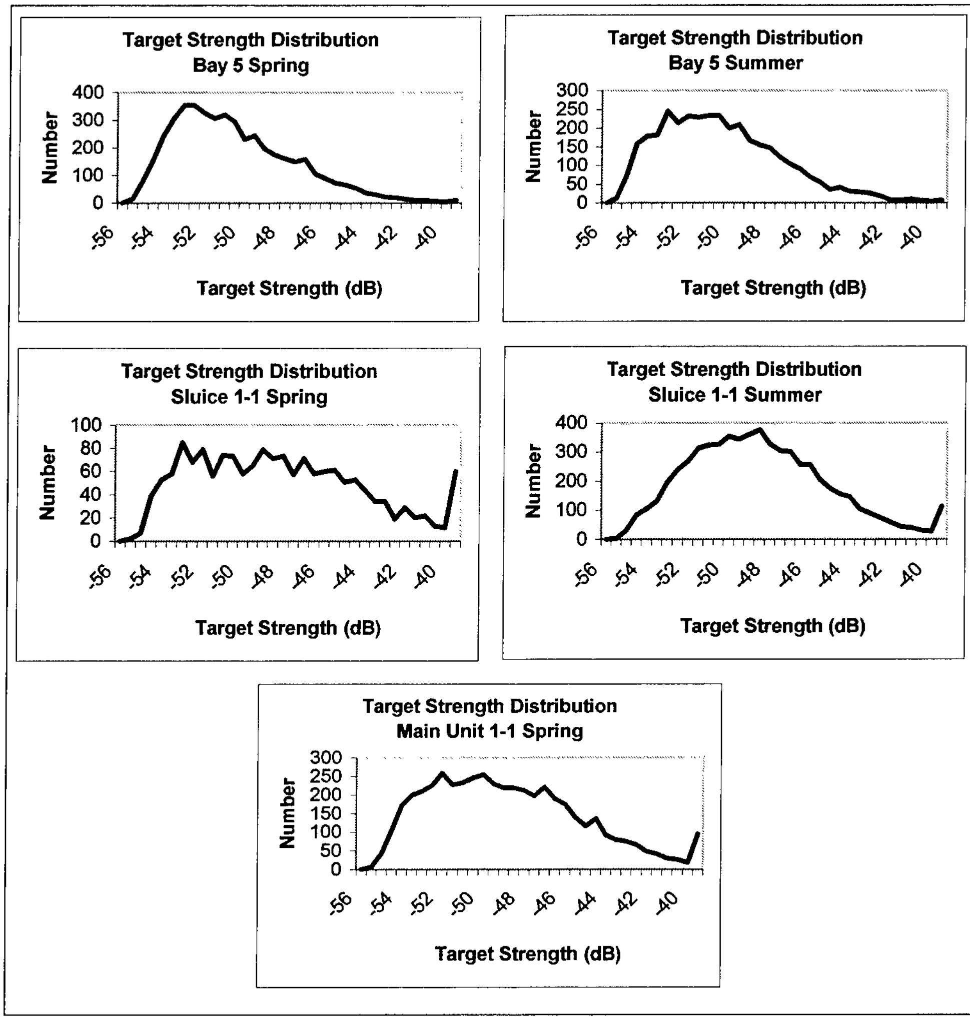


Figure B2. Frequency distribution of target strength data from split-beam transducers at the three main sample locations at TDA in 1999: spillway, sluiceway, and main units. The split-beam at Main Unit 1 was not available in summer 1999

Detectability by range

Detectability at the spillway was dependent on gate height and, hence, water velocity (Figure B3). Detectability started to decrease around 6.1 m below the spillway transducers. This pattern is opposite that shown below for sluiceway and turbine locations, because fish velocity increases with range at the spillway location and not at the sluiceway or turbine locations. At the maximum range of 9.5 m, the effective beam angle was about 80, 60, 20 and 10 percent of the nominal value for gate heights of 1.2, 1.8, 2.4, and 3.1 m, respectively. The detectability assumption for the spillway at TDA in 1999 was not valid but was accounted for during data analysis.

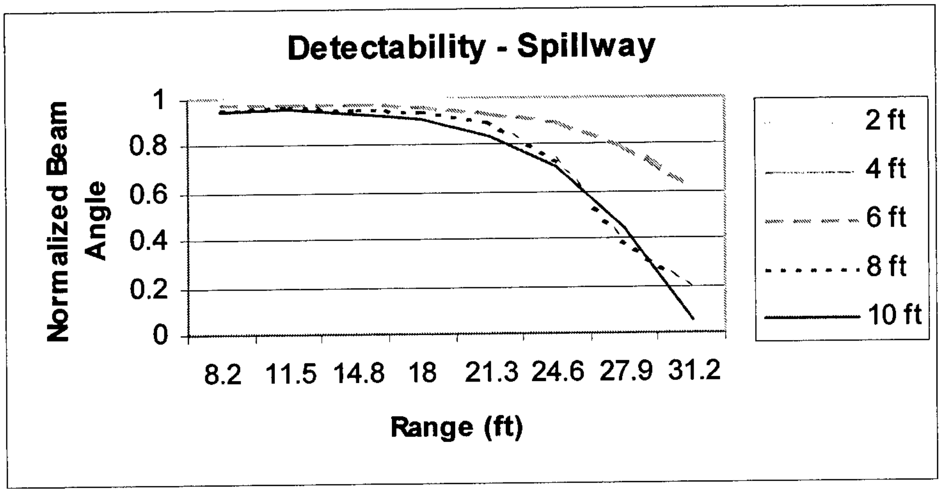


Figure B3. Detectability at the spillway at TDA in 1999. Detectability data are presented for various spill gate openings, i.e., water velocities

Detectability at the sluiceway increased with range from the transducer (Figure B4). At the cut-off range to include targets in the sluiceway passage estimate, detectability was about 90 percent of normal. Sluiceway detectability was good; the assumption was valid.

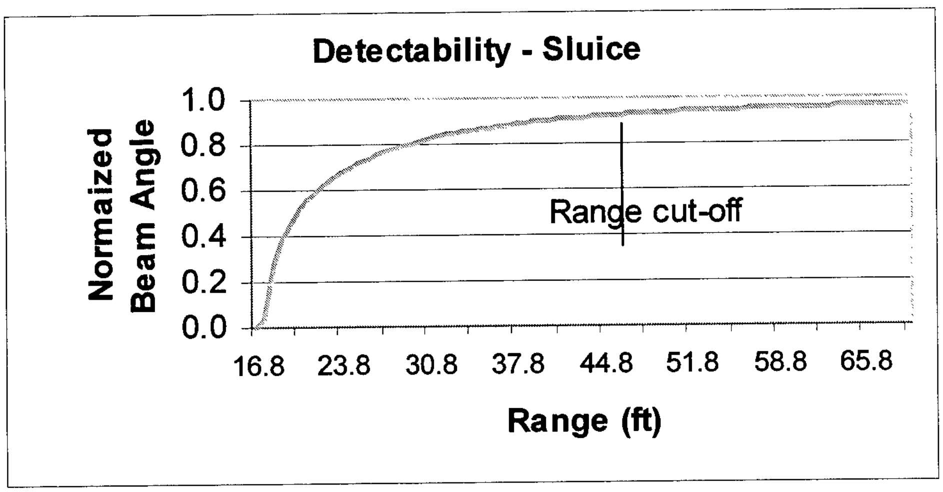


Figure B4. Detectability at the sluiceway at TDA in 1999

Detectability in turbines also increased as distance from the transducer increased (Figure B5). Relatively low detectability near the transducer was not a problem because most fish were detected at far ranges (see vertical distribution data from Ploskey et al. 1999). The detectability assumption was met for in-turbine samples at TDA in 1999.

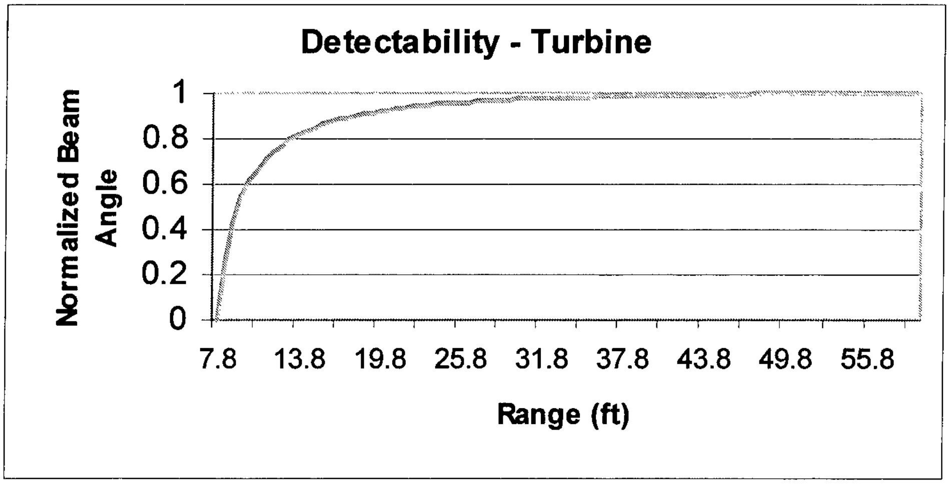


Figure B5. Detectability at main turbine units at TDA in 1999

Effective beam angle

Effective beam angle, the most important parameter of the acoustic screen model, has been estimated in many ways in fish passage studies at dams. The following methods were described in section on "Methods," nominal, half power, individual target strength, population target strength, detectability, Rayleigh, and detectability/Rayleigh combined. The nominal method provided this study a reference level. The half power method was widely used by investigators at Corps and PUD dams on the Columbia and Snake rivers in the 1980s (e.g., Sullivan et al. 1988 at Wells, Raemhild et al. 1984 at Rocky Reach, Carlson et al. 1983 at Priest Rapids, Magne et al. 1983 at John Day, Steig and Johnson 1986 at The Dalles, Stansell et al. 1990 at Bonneville, Kuehl 1986 at Lower Granite, McFadden 1988 at Lower Monumental, and Johnson et al. 1982 at Ice Harbor). The half power method has also been used for the past 4 years during surface bypass studies at Lower Granite (e.g., Johnson et al. 1997). The individual and population target strength methods have been rarely used. One example of the individual target strength approach is by Dawson (1991) at the Park Mill Plant in Wisconsin. The detectability method was used recently by Ploskey et al. (1998) for a fish passage study at Bonneville Dam. The Rayleigh scheme described by Ehrenberg (1985, reproduced in final section, this appendix) has not been applied, to my knowledge. The procedure combining the detectability and Rayleigh methods was applied for the first time by Ploskey et al. (1999) at The Dalles Dam in 1999. Other methods not included in the analyses for this study have also been applied (e.g., Thorne and Kuehl (1989) used duration-in-beam at Bonneville). Methods to determine effective beam angle as accurately as possible are becoming more prevalent as the importance of the data to regional decision-makers increases.

Beam angles using the seven methods (paragraph "Effective beam angle") were 0 to 35 percent higher or lower than the nominal angle at TDA in spring (Figure B6) and summer (Figure B7) 1999. Patterns between spring and summer were the same. Beam angles for the individual and population target strength methods were larger than the nominal. The detectability, Rayleigh, and

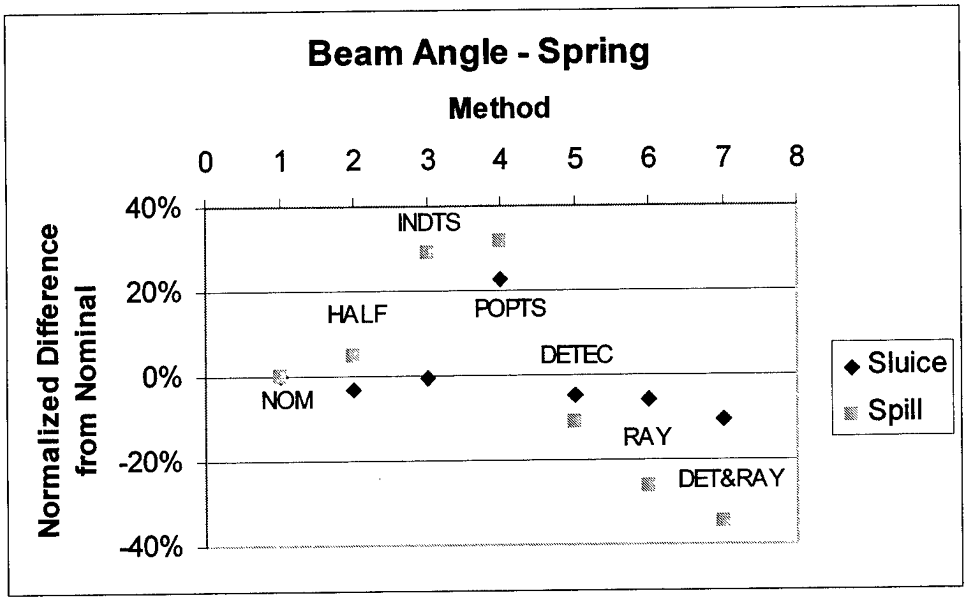


Figure B6. Analysis of effective beam angles using seven different methods for data from sluice and spill split-beam transducers at TDA in spring 1999. Results expressed as normalized difference from nominal (X_ANGLE minus N_ANGLE quantity divided by N_ANGLE). Descriptions of the beam angle methods are presented in this appendix

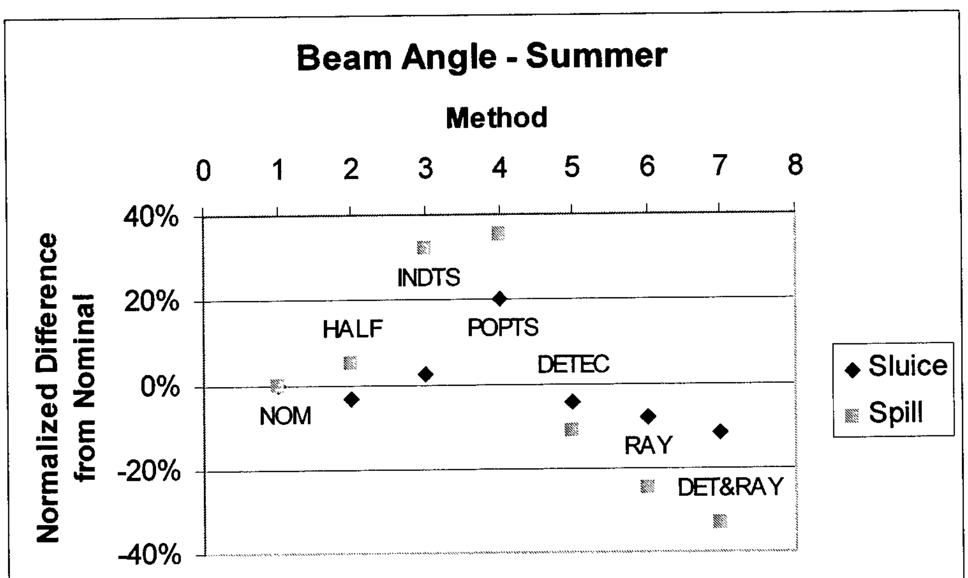


Figure B7. Analysis of effective beam angles using seven different methods for data from sluice and spill split-beam transducers at TDA in summer 1999. See Figure B6 for a description

detectability/Rayleigh combined methods had smaller beam angle compared to the nominal. The combined method resulted in the smallest beam angle in this analysis. Beam angles for the spillway showed greater differences from the nominal than those for the sluiceway. Beam angle differences affected the corresponding weighted fish estimates.

Weighted fish estimates using the six beam angles were 0 to 48 percent higher or lower than the estimate from the nominal angle at TDA in spring (Figure B8) and summer (Figure B9) 1999. Patterns between spring and summer were the same. Weighted fish estimates for the individual and population target strength methods were about 20 percent smaller than the nominal. The detectability, Rayleigh, and detectability/Rayleigh combined methods had larger weighted fish estimates compared to the nominal. The combined method resulted in the largest weighted fish estimate in this analysis (48 percent larger than nominal). Weighted fish estimates for the spillway showed greater differences from the nominal than those for the sluiceway. This analysis showed that the beam angle method used can have a large impact on the passage estimate derived from the weighting process.

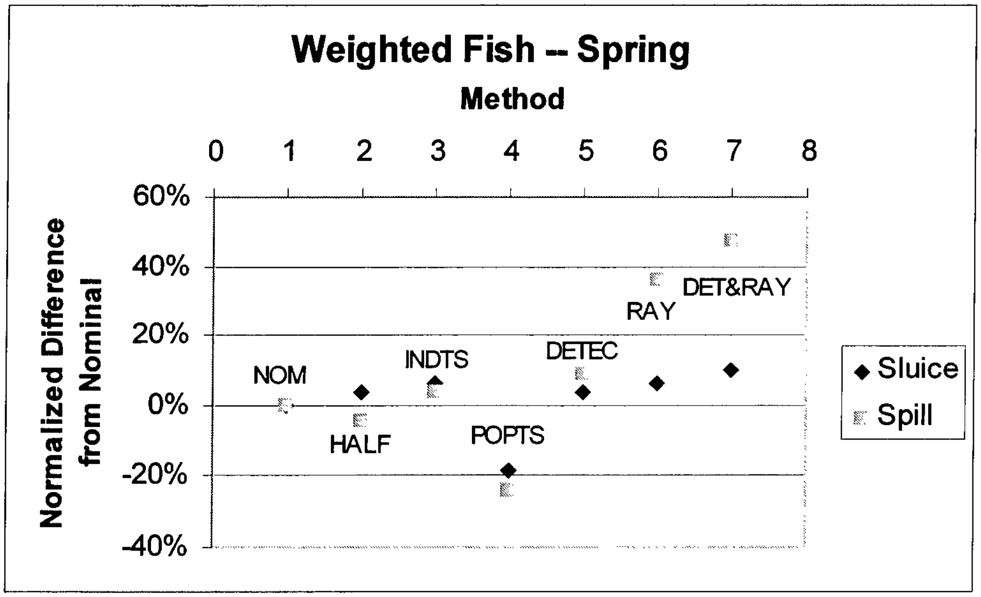


Figure B8. Analysis of weighted fish using seven different methods for data from sluice and spill split-beam transducers at TDA in spring 1999. Results expressed as the normalized difference between the weighted fish estimates from the subject and nominal methods (WT_XXXX minus WT_NOM quantity divided by WT_NOM). Descriptions of the beam angle and associated weighting methods are presented in this appendix

Target strength

Target strength varied between locations (Figures B10 and B11). During spring, mean target strength was 5.07 dB lower at the turbines than the sluiceway (Figure B10). Target strength was similar between spring and summer. Weekly target strength was fairly uniform during spring and summer at the spillway (Figure B11). On the other hand, weekly target strength at the sluiceway increased (smaller negative number) during spring and decreased during summer. The weekly target strength values, however, should be viewed with caution because of relatively few fish (<30) during some weeks. In conclusion, the target strength assumption was probably not valid at TDA in 1999.

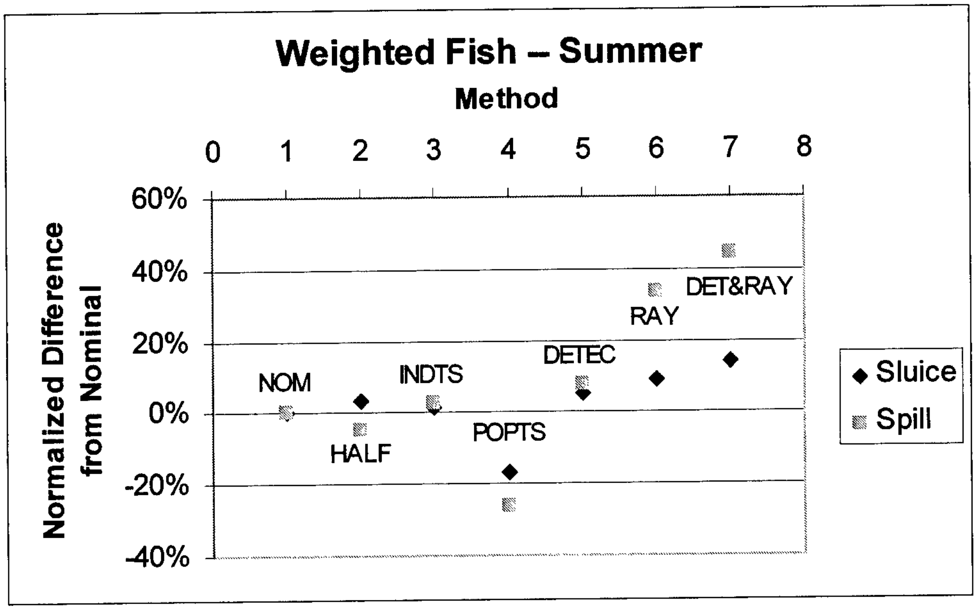
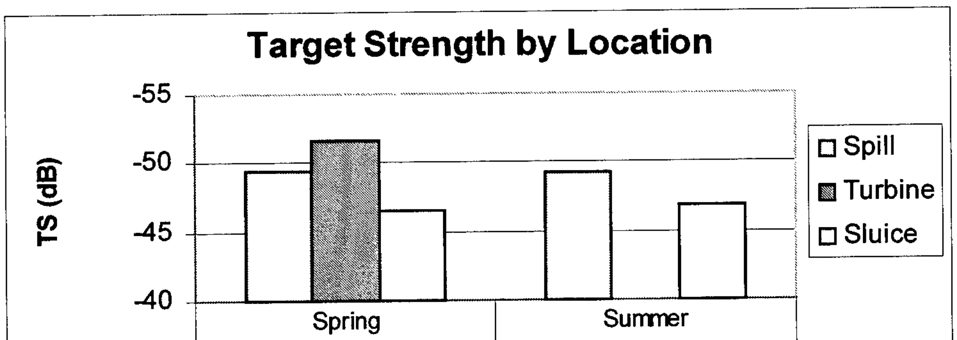


Figure B9. Analysis of weighted fish using seven different methods for data from sluice and spill split-beam transducers at TDA in summer 1999. See Figure B8 for a description



	Spring	Summer
Spill	-49.44	-49.25
Turbine	-51.59	0.00
Sluice	-46.52	-46.87

Figure B10. Mean back-scattering cross sections expressed as target strength (dB) for spring and summer from split-beam systems at spillway, sluiceway, and turbine sample locations at TDA in 1999

The impact of this difference in target strength between sample locations depends where we are on the directivity pattern. A 3 dB difference near the acoustic axis is much more important than a 3 dB difference where the pattern drops off. Given that the on-axis threshold was set at -56 dB for TDA in 1999, the impact was probably not severe. This conclusion is supported by Thorne and Kuehl (1989) who reported that fish passage estimates by echo counting were relatively “insensitive” to error associated with target strength.

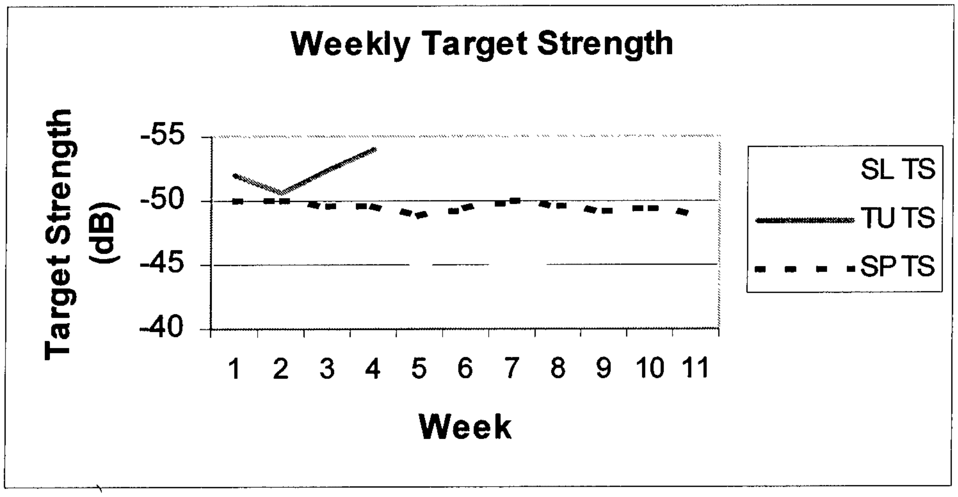


Figure B11. Weekly mean back-scattering cross sections expressed as target strength (dB) from split-beam systems at spillway, sluiceway, and turbine sample locations at TDA in 1999

A possible cause for the difference in mean target strength between sample locations at TDA in 1999 may be differences in aspect. Aspect is the orientation of the fish relative to the acoustic beam. For example, a fish oriented head-on to the acoustic beam will reflect less acoustic energy than one oriented with its ventral side to the beam. At TDA in 1999, recall sluiceway and turbine sample locations had primarily ventral aspect while the spillway was more head-on. McFadden and Hedgepeth (1990) also observed differences in target strength between spill and turbine sample locations, although their target strength estimates were higher for the spillway than the turbines. The effect of aspect on target strength and, hence, effective beam angle is important to consider.

Another possible reason for target strengths differences between spill and turbine sample locations may be temperature and depth effects on transducer performance. That is, temperature and depth may have source levels and receiving sensitivities of the transducers. In situ target strength estimates would account for this effect, if any.

Horizontal distribution

The horizontal distribution of fish in fyke net samples from turbine intakes or in hydroacoustic samples from spill bays at TDA was generally not uniform (Tables B4, B5, and B6). Comparing the proportion of fish in the center to 1/3, which is a looser assumption than uniformity, showed that at times the null hypothesis (middle proportion = 1/3) was rejected and other times it was retained. For example, in 10 of 23 fyke tests, the proportion of fish captured in the middle row of nets was significantly different than 1/3. At the spillway, fish passage in the center sample location was significantly different than 1/3 ($P<0.055$) at Bay 13 but not at Bay 3 (Table B4). Thus, the horizontal assumption of the acoustic screen model is not consistently valid.

Table B4
T- Test of the Significance of the Difference between 1/3 and the Proportion of Fish Passage in the Middle Hydroacoustic Sample Location at Bays 3 and 13 in Spring and Summer 1999 at TDA

Season	Bay	N	Mean	T	Prob>|T|
Spring	Thirteen	72	0.302	1.96	0.054
	Three	72	0.342	-0.54	0.591
Summer	Thirteen	72	0.251	4.14	0.0001
	Three	72	0.359	-1.57	0.121

Table B5
Fyke Net Data Analysis of Horizontal Distribution Using the Ryan-Einot-Gabriel-Welsch Multiple Range Test for Response Variable MIDPRO. Means with same letter are not significantly different (P>0.05)

Grouping	Mean	N	Level
Dam			
A	0.332	94	TDA
A	0.331	40	JDY
B	0.289	59	LGO
B	0.277	206	MCN
Year			
A	0.331	40	1996
A	0.317	134	1994
B	0.293	142	1993
C	0.255	83	1992
Screen			
A	0.324	114	ESTS
B	0.286	285	ESBS
Species			
A	0.320	176	CH0
A	0.316	53	ST
B	0.271	132	CH1
B	0.254	38	SO

Table B6
Horizontal Distribution Analysis of Hydroacoustic Data Using the Ryan-Einot-Gabriel-Welsch Multiple Range Test for Response Variable Passage Rate. Means with same letter are not significantly different (P>0.05)

Grouping	Mean	N	Level
A	986	288	South
B	553	288	Middle
B	436	288	North

Nonuniform horizontal distribution was noted in other hydroacoustic studies. For example, Ploskey et al. (1998) used a video system at the Bonneville First Powerhouse sluiceway and observed greater numbers of smolts passing into sluice entrances near the edges (pier noses) than in the middle. Johnson et al. (1998) deployed a 360-deg scan-head sonar in a turbine intake at Lower Granite Dam in 1997. They found a nonuniform horizontal distribution. The horizontal distribution pattern, however, was statistically similar between guided and unguided sample areas of the extended-length intake screen, validating the estimation process for fish guidance efficiency. Recommendations on how to address nonuniform horizontal distributions in the acoustic screen model are presented in the following text.

Conclusions and Recommendations

The acoustic screen model is the basis of the fixed-location hydroacoustic method. This method has been widely used to estimate smolt passage rates at Columbia and Snake River dams. Its use will probably continue in the future as mainstem smolt passage research intensifies. The acoustic screen model, however, must be applied carefully so that quality results are produced that decision-makers have confidence in. Careful application means assessing the model's assumptions. This was done in a case study at The Dalles Dam in 1999.

Assessment of assumptions of the acoustic screen model as used at TDA revealed uncertainties that required investigation. The following conclusions about the model's assumptions were reached primarily using monitoring and research data from the split-beam systems at TDA in 1999.

a. Truncation of small echoes was not a problem.

b. Detectability was relatively low at the spillway at ranges near the ogee, especially during gate openings greater than 1.2 m.

c. Effective beam angle methods that I assessed, including the commonly used half-power method, were insufficient, except for the detectability/ Rayleigh procedure. This method was acceptable because it accounted for differences in detectability between locations and ranges and included Rayleigh aspects of the *empirical* target strength distribution by sample location, whereas the other methods did not.

d. Target strength (mean fish) differed by sample location, presumably because of aspect differences. It was important to account for this in the effective beam angle method.

e. Horizontal distribution within a passage route was not consistently uniform. Thus, horizontal randomization of transducer placement was required.

f. Overall, the data showed that Principle of Equivalency was valid at TDA in 1999.

Recommendations for hydroacoustic studies employing the acoustic screen model include:

a. Deploy a spilt-beam transducer at each type of sample location, e.g., spillway, sluiceway, turbine.

b. Measure fish velocity or approximate it using water velocity measurements for various operating conditions, e.g., spill gate openings.

c. Report detectability results and describe how differences between sample locations and ranges, if any, were accounted for.

d. Describe in detail how the effective beam angle was obtained.

e. Consider applying the detectability / Rayleigh method to determine beam angle.

f. Estimate target strength by sample location and by season.

g. Randomize transducer placement horizontally within a sample location.

h. Incorporate within route (horizontal) variability in passage rate variance estimation.

i. Cross check hydroacoustic estimates with independent methods and report the results.

j. Avoid using the acoustic screen model to make absolute estimates of smolt passage.

k. Ensure that the Principle of Equivalency has not been violated.

Further refinement of the acoustic screen model than was reported herein is warranted. For example, it would be appropriate to develop a simulation model of effective beam width that meshes Rayleigh scattering characteristics with acoustic detectability, the "combined" approach. This model, a logical step forward, would be useful to hydroacoustic researchers using the acoustic screen model to estimate fish passage rates.

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Ehrenberg Memorandum[1]

To: All Consulting Staff *[BioSonics, Inc.]*

From: John Ehrenberg

Subject: Use of Dual Beam Data for Obtaining Effective Beam Angles of Transducers

If fish targets were simple scatterers (like ideal ping pong balls), it would be simple to determine the relationship between target strength, threshold setting, and beam width. In particular, if the target strength value of the scatterer is TS *[dB]* and the threshold is set such that the minimum on-axis detected target has a target strength of T dB, then the minimum beam pattern for target detection is

$$B_{\min} = \frac{T - TS}{2}$$

and the maximum beam angle is θ such that $B(\theta) = B_{\min}$. For example, if the system is set up to have a threshold corresponding to an on-axis target of –56 dB and the actual target strength of the scatterers is –46 dB, then

$$B_{\min} = \frac{-56-(-46)}{2} = \frac{-10}{2} = -5 \text{ dB}$$

and the maximum half angle θ would be found from the beam pattern plot such that $B(\theta) = -5$ dB.

Unfortunately, fish are <u>not</u> ideal ping pong balls and their target strength and back scattering cross section *[σ_{bs}]* are randomly distributed. Since the target strength and σ_{bs} are random, the maximum beam angle of the transducer for a given threshold will also be random. Given we know the distribution of σ_{bs} (or target strength) we can find the effective transducer beam angle by averaging the angle as a function of θ_{bs} over the distribution for σ_{bs}. Fortunately, we have a good model for the distribution of σ_{bs}. Peterson et al.[2] have used central limit theorem arguments to show that $\sqrt{\sigma_{bs}}$ is Rayleigh distributed when the size of the fish is big relative to the acoustic wavelength, λ Note, λ at 420 kHz = .36 cm and therefore at 420 kHz the assumption is valid for nearly all fish of interest. The model characterizes the statistical variability about the average value of σ_{bs}. It does not account for the variability produced by variation in the average value of σ_{bs}. The average value of σ_{bs} is a function of the size of the fish.

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[1] This memo was word processed from handwritten copies obtained from G. Johnson's and J. Dawson's files. The memo was not dated but is believed to have been written around 1985.

[2] M. L. Peterson, C. S. Clay, and S. B. Brandt, "Acoustic estimates of fish density and scattering functions," *J. Acoust. Soc. Am.* 60, 618-622 (1976).

I have used the statistical model for σ_{bs} to determine the effective beam angle of transducers relative to the 3 dB beam width as a function of the average value of σ_{bs} and the system threshold. The results are shown in Figure 1.

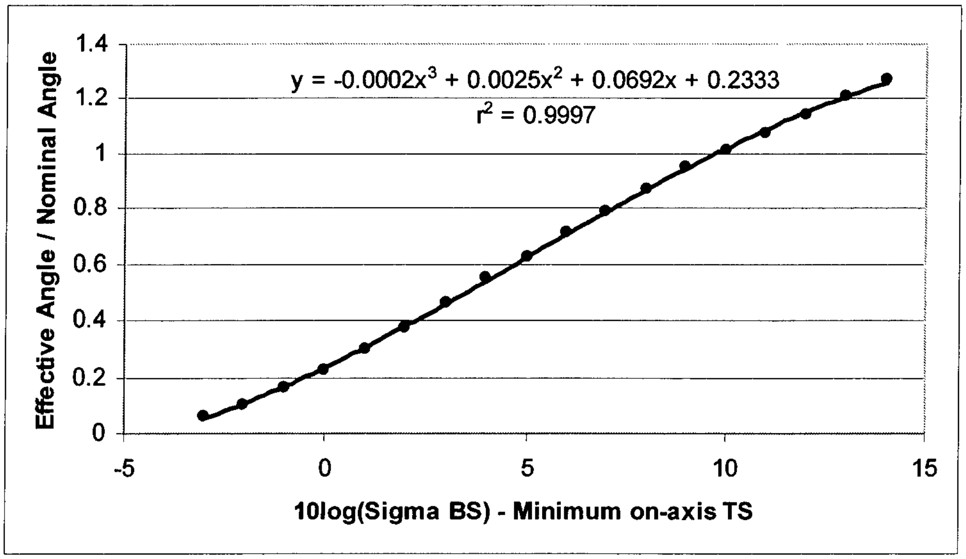

Figure 1.

In those cases where you do not have dual beam results, the length of the fish in the population can be used to estimate the average target strength (see BioSonics dual beam application note). The curve in Figure 2 can then be used to obtain the effective beam angle as a function of average target strength and system threshold. Note that the average target strength and the average back scattering cross section in dB are not the same.

To apply these results to an uniform size fish population, you would first use the dual beam system to find the average backscattering cross section, $\overline{\sigma_{bs}}$. You would then calculate the difference between $\overline{\sigma_{bs}}$ in dB and the minimum on-axis detected target strength. Figure 1 can then be used to find $\frac{\theta_{eff}}{\theta_{3dB}}$.

For example, if the threshold is set to detect a –56 dB target on-axis and $10\log(\overline{\sigma_{bs}})$ (from dual beam results) is –48 dB, then

$$10\log(\overline{\sigma_{bs}}) \text{ - } (\min \ on\text{-}axis \ TS) = +8 \text{ dB}$$

From Figure 1, $\frac{\theta_{eff}}{\theta_{3dB}} = 0.86$

If $\theta_{3dB} = 15.5°$, $\theta_{eff} = 0.86 * 15.3° = 13.2°$

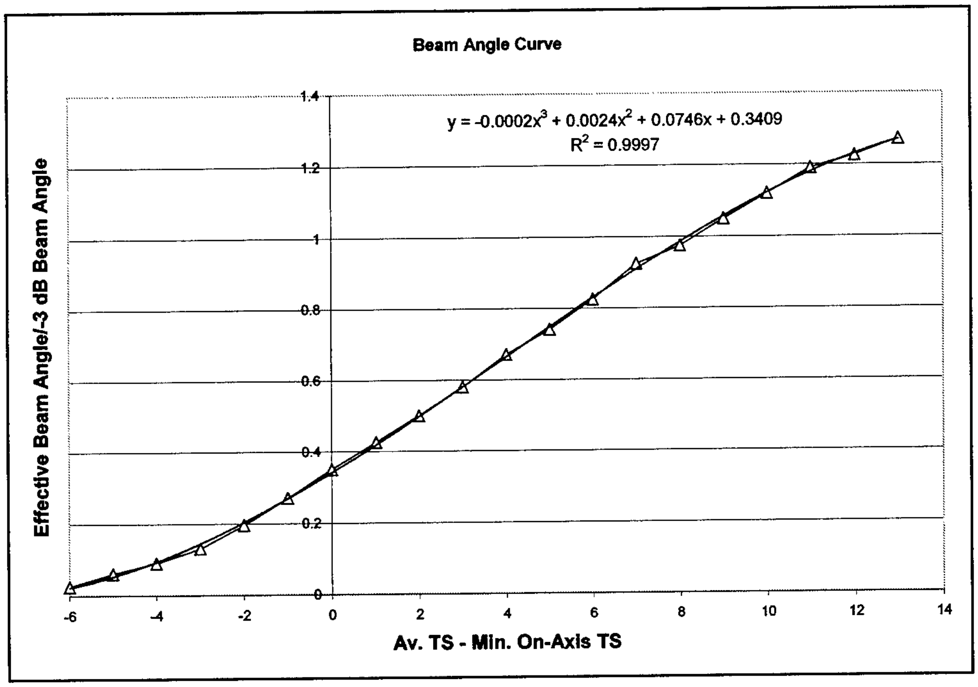

Figure 2.

Analysis

Relationship between threshold, σ_{bs}, and *[beam]* angle:

Output voltage .... $V_o^2 = Kb^2(\theta)\sigma_{bs}$

in dB, ... $V_o(dB) = 10\log K + 2B(\theta) + TS$

where, ... $B(\theta) = 10\log(b(\theta))$

.... $TS = 10\log(\sigma_{bs})$

$$V_o(dB) > T_{dB} \Rightarrow 10\log(k) + 2B(\theta) + TS > T_{dB}$$

Specify T_{db} in term of its on-axis target strength then $10\log K = 0$.

$$V_o(dB) > T_{dB} \Rightarrow 2B(\theta) + TS > T_{dB}$$
$$\Rightarrow B(\theta) > \frac{T_{dB} - TS}{2}$$

For a theoretical piston transducer, angle θ and $B(\theta)$ are related[1] by

$$\theta = k_1 \theta_{3db} \quad |B|^{k_2}$$

$\theta_{3dB} = 3dB$ half angle beam width,

$k_1 \approx 0.5883$
$k_2 \approx 0.4608$

$$\therefore \theta_{\max} = 0.5883\theta_{3dB} \, |B(\theta_{\max})|^{0.4608}$$

$$But, B(\theta_{\max}) = \frac{T_{db} - TS}{2} = \frac{T_{dB} - 10\log(\sigma_{bs})}{2}$$

$$\theta_{\max} = 0.5883\sigma_{3dB} \, \left|\frac{T_{dB} - 10\log(\sigma_{bs})}{2}\right|^{0.4608}$$

$$E[\theta_{\max}] = \int \theta_{\max} p(\sigma_{bs}) d\sigma_{bs}$$

For Rayleigh distributed $a = \sqrt{\sigma_{bs}}$, *[JE edit November 1999]*

$$p(a) = \frac{ae^{-a^2/\overline{\sigma_{bs}}}}{\sigma_{bs}/2},$$ *[JE edit November 1999]*

where, $a = E[\sigma_{bs}]$, the expected value of σ_{bs} *[JE edit November 1999]*

$$\therefore \; E[\theta \max] = \int_{a_{\min}}^{\infty} \theta_{\max}(a) p(a) da .$$

$$\theta_{\max}(a) = 0.5883\theta_{3dB} \, \left|\frac{T_{dB} - 10\log(a^2)}{2}\right|^{0.4608}$$

$$a_{\min} = \min \sqrt{\sigma_{bs}} = \sqrt{t}$$

where, $10\log(t) = T_{dB}$

$$E[\theta_{\max}] = \int_{\sqrt{t}}^{\infty} 0.5883\theta_{3dB} \, \left|\frac{10 * \log(\frac{t}{a^2})}{2}\right|^{0.4608} \frac{ae^{-a2/\overline{\sigma_{bs}}}}{\frac{\sigma_{bs}}{2}} da$$

---

[1] J. E. Ehrenberg, T. J. Carlson, J. J. Traynor, and N. J. Williamson, "Indirect measurement of the mean acoustic scattering cross section of fish," *J. Acoust. Soc. Am.*, Vol. 69, pp. 955-962, 1981. *[JE added November 1999]*

$$z = \frac{a}{\sqrt{\overline{\sigma_{bs}}}} \Rightarrow a = \sqrt{\overline{\sigma_{bs}}}z$$

$$a = \infty \Rightarrow z = \infty$$

Let $a = \sqrt{t} \Rightarrow z = \sqrt{\frac{t}{\overline{\sigma_{bs}}}}$

$$da = \sqrt{\overline{\sigma_{bs}}}dz$$

$$\frac{E[\theta_{\max}]}{\theta_{3dB}} = 2.47\theta_{3dB} \int_{\frac{\sqrt{t}}{\overline{\sigma_{bs}}}}^{\infty} |\log(\frac{t}{\overline{\sigma_{bs}}}\frac{1}{z^2}|^{0.4608} ze^{-z}dz$$

The integral has been evaluated using Simpson's Rule as a function of $\frac{t}{\overline{\sigma_{bs}}}$ or equivalency as a function of $10\log(t) - 10\log(\overline{\sigma_{bs}}) = T - 10\log(\overline{\sigma_{bs}})$ relationship between $\overline{\sigma_{bs}}$ and $\overline{TS}$.

Let $a = \sqrt{\sigma_{bs}}$, then $p_A(a) = \frac{ae^{-a^2/\overline{\sigma_{bs}}}}{\overline{\sigma_{bs}}/2}$

$$TS = 10\log(\sigma_{bs}) = 10\log(a^2)$$

$$\overline{TS} = \int_0^{\infty} 10\log(a^2)p(a)da$$

$$= 10\int_0^{\infty} a\log(a^2)\frac{e^{-a^2/\overline{\sigma_{bs}}}}{\overline{\sigma_{bs}}/2}da$$

Let $y = a^2$, $dy = 2ada$

$$\overline{TS} = \frac{10}{\overline{\sigma_{bs}}}\int_0^{\infty} \log(y)c^{-y/\overline{\sigma_{bs}}}dy$$

$$\log(y) = \frac{\ln(y)}{\ln(10)}$$

$$\overline{TS} = \frac{10}{\overline{\sigma_{bs}}\ln(10)}\underbrace{\int_0^{\infty} \ln(y)e^{-y/\overline{\sigma_{bs}}}dy}_{-\overline{\sigma_{bs}}[c + \ln(\frac{1}{\overline{\sigma_{bs}}})]}$$

From Grooshteyn and Ryznik table of integrals p. 573, c = Euler's constant = 0.577215

$$\overline{TS} = -2.507 - \frac{10}{\ln(10)} \underbrace{\ln(\frac{1}{\overline{\sigma_{bs}}})}_{\frac{\log(\frac{1}{\overline{\sigma_{bs}}})}{\log(e)}}$$

$$\overline{TS} = -2.507 + \frac{10}{\ln(10)\log(e)} \log(\overline{\sigma_{bs}})$$

$$\overline{TS} = -2.507 + \log(\overline{\sigma_{bs}})$$

Appendix C[1] Interpolating Fish-Passage Estimates for Unsampled Spill Bays

Introduction

We evaluated two candidate methods of estimating fish passage at unsampled spill bays: 1) using the amount of water passed or "Q" and 2) using linear interpolation between adjacent spill bays that were sampled. Plotting fish passage estimates from hydroacoustic samples against flow estimates at the sampled bays provided a test of flow-based interpolation. We used the sum of hourly fish-passage estimates and the sum of hourly spill bay "dog" settings multiplied by 1.5 (the conversion factor from "dogs" to kcfs) for each day, night, or total (24 hr) period for the six spill bay blocks established by Skalski in Appendix A. For evaluating linear interpolation from hydroacoustic passage estimates, we summed hourly fish passage for each day, night, or whole season and plotted the estimates for Spill Bay 2 against the average of hydroacoustic estimates at Spill Bays 1 and 3. We also plotted those same fish passage estimates for Spill Bay 2 divided by the summed "dogs" * 1.5 (the sum of estimated Q's) for each sample. For all of these tests the Coefficient of Determination (r^2) and its associated P-value is taken as an indication of the efficacy of that regression for estimating fish passage through unsampled spill bays. All summed estimates, r^2 values, p-values, and slopes were rounded to the nearest thousandth.

Interpolation Based on Flow

For the regressions of flow estimates versus fish passage, we used estimates summed into the six spill bay spatial blocks described by Skalski in Appendix A of this report. Since there were two spill treatments and strong day and night differences in fish-passage statistics, we performed tests on all of those

[1] This appendix was prepared by Carl Schilt, AScI, Inc., P.O. Box 40, North Bonneville, WA 98639.

combinations for the six spill bay blocks and for all 13 sampled spill bays combined. Those results are presented in Tables C1 through C4. Except for spill bay Block 5 on spring nights and on summer nights with 64 percent spill (Tables C2 and C4), low r^2 values and widely varying slopes indicate that flow was a poor predictor of spillway fish passage. Both treatments during spring nights at Block 5 and the 64-percent spill treatment at Block 5 during summer nights produced a much higher r^2 value and a stronger positive slope than did any other regressions. These results may indicate a stronger relationship between flow and fish passage, but they are exceptions to the usually poor relationship between fish-passage estimates and flow estimates.

Linear Interpolation from Nearby Sampled Spill Bays

Linear interpolation between or among nearby sampled spill bays provided somewhat better results. We sampled adjacent spill bays in only two locations in 1999. We sampled Spill Bays 1 through 3 and plotted our sample-based estimates for Spill Bay 2 against the average of those for Spill bays 1 and 3. Those results are presented in Table C5. Although some r^2 values are very low, those from the regressions for "Daily Totals" (which sum day and night values) were significant and reasonably high for the 30-percent spill treatment and when both spill treatments are considered in spring. Daily totals for spring and summer 64-percent spill and summer daily totals for both spill treatments produced low r^2 values.

Table C1
Results of Regressions of Hourly Fish-Passage Estimates on Hourly Estimates of Water Passage (Q) at The Dalles Dam Spillway for Spring Days in 1999. Estimates were summed for 0600–1900 hours, inclusive, for each day. Comparisons are for the six spill bay blocks described in Appendix A, this report, and for all 13 sampled spill bays

Spill Treatment	Block	Coefficient of determination (r^2)	p-value	Slope	Sample Size
64%	1	0.140	0.005	40.617x	54 Spill Bay Days
64%	2	0.275	0.001	-75.771x	36 Spill Bay Days
64%	3	0.002	0.825	0.002x	36 Spill Bay Days
64%	4	0.117	0.041	-13.979x	36 Spill Bay Days
64%	5	0.219	0.001	-36.017x	34 Spill Bay Days
64%	6	0.199	0.007	27.271x	34 Spill Bay Days
64%	13 Bays	0.012	0.099	6.0765x	234 Spill Bay Days
30%	1	0.061	0.072	-39.687x	54 Spill Bay Days
30%	2	0.005	0.686	-13.863x	36 Spill Bay Days
30%	3	0.001	0.850	-6.578x	36 Spill Bay Days
30%	4	0.004	0.719	10.067x	36 Spill Bay Days
30%	5	0.004	0.713	5.806x	36 Spill Bay Days
30%	6	0.150	0.019	58.502x	36 Spill Bay Days
30%	13 Bays	0.004	0.319	10.04x	234 Spill Bay Days

Table C2
Results of Regressions of Hourly Fish-Passage Estimates on Hourly Estimates of Water Discharge (Q) at The Dalles Dam Spillway for Spring Nights in 1999. Estimates were summed for 2000– 0500 hours the next calendar day, inclusive, for each night. Comparisons are for the six spill bay blocks described in Appendix A, this report, and for the 13 sampled spill bays

Spill Treatment	Block	Coefficient of Determination (r^2)	p-value	Slope	Sample Size
64%	1	0.012	0.423	8.014x	54 Spill Bay Nights
64%	2	0.181	0.010	-42.862x	36 Spill Bay Nights
64%	3	0.018	0.434	-13.201x	36 Spill Bay Nights
64%	4	0.037	0.261	-7.610x	36 Spill Bay Nights
64%	5	0.679	0.000	86.499x	36 Spill Bay Nights
64%	6	0.041	0.240	6.180x	36 Spill Bay Nights
64%	13 Bays	0.075	0.000	8.036x	234 Spill Bay Nights
30%	1	0.002	0.762	5.995x	54 Spill Bay Nights
30%	2	0.029	0.980	-34.991x	36 Spill Bay Nights
30%	3	0.000	0.082	0.406x	36 Spill Bay Nights
30%	4	0.086	0.000	16.567x	36 Spill Bay Nights
30%	5	0.612	0.000	95.118x	36 Spill Bay Nights
30%	6	0.000	0.922	0.348x	36 Spill Bay Nights
30%	13 Bays	0.269	0.000	39.573x	234 Spill Bay Nights

Table C3
Results of Regressions of Hourly Fish-Passage Estimates on Hourly Estimates of Water Discharge (Q) at The Dalles Dam for Summer Days in 1999. Estimates were summed for 0600–1900 hours, inclusive, for each day. Comparisons are for the six spill bay blocks described in Appendix A, this report, and for all 13 sampled spill bays. Low r^2 values and widely varying slopes suggest that, in these cases, flow is a poor predictor of fish passage

Spill Treatment	Block	Coefficient of Determination (r^2)	p-value	Slope	Sample Size
64%	1	0.200	0.001	-15.581x	54 Spill Bay Days
64%	2	0.170	0.012	-30.383x	36 Spill Bay Days
64%	3	0.003	0.761	8.941x	36 Spill Bay Days
64%	4	0.042	0.232	-16.367x	36 Spill Bay Days
64%	5	0.107	0.051	-24.298x	36 Spill Bay Days
64%	6	0.287	0.001	34.12x	36 Spill Bay Days
64%	13 Bays	0.003	0.403	2.874x	234 Spill Bay Days
30%	1	0.018	0.339	21.837x	54 Spill Bay Days
30%	2	0.004	0.718	-23.733x	36 Spill Bay Days
30%	3	0.397	0.000	0.831x	36 Spill Bay Days
30%	4	0.076	0.104	65.894x	36 Spill Bay Days
30%	5	0.066	0.132	35.353x	36 Spill Bay Days
30%	6	0.121	0.037	57.606x	36 Spill Bay Days
30%	13 Bays	0.017	0.045	31.761x	234 Spill Bay Days

Table C4
Results of Regressions of Hourly Fish-Passage Estimates on Hourly Estimates of Water Passage (Q) at The Dalles Dam Spillway for Summer Nights in 1999. Estimates were summed for 2000–0500 hours the next calendar day, inclusive, for each night. Comparisons are for the six spill bay blocks described in Appendix A, this report, and for all sampled spill bays

Spill Treatment	Block	Coefficient of Determination (r^2)	p-value	Slope	Sample Size
64%	1	0.073	0.049	-18.197x	54 Spill Bay Nights
64%	2	0.047	0.206	-81.313x	36 Spill Bay Nights
64%	3	0.072	0.114	50.170x	36 Spill Bay Nights
64%	4	0.282	0.001	139.32x	36 Spill Bay Nights
64%	5	0.644	0.000	79.335x	36 Spill Bay Nights
64%	6	0.308	0.000	13.881x	36 Spill Bay Nights
64%	13 Bays	0.038	0.003	10.250x	234 Spill Bay Nights
30%	1	0.061	0.073	-23.339x	54 Spill Bay Nights
30%	2	0.015	0.473	35.607x	36 Spill Bay Nights
30%	3	0.125	0.036	-54.280x	36 Spill Bay Nights
30%	4	0.215	0.004	91.540x	36 Spill Bay Nights
30%	5	0.270	0.001	21.040x	36 Spill Bay Nights
30%	6	0.112	0.047	7.036x	36 Spill Bay Nights
30%	13 Bays	0.202	0.000	34.818x	234 Spill Bay Nights

Table C5
Results of Regressions of Hourly Fish-Passage Estimates for Spill Bay 2 on the Average of Estimates from Spill Bays 1 and 3

Data Set	Coefficient of Determination (r^2)	p-value	Sample Size
Spring Days 64%	0.132	0.139	18 Spill Bay Days
Spring Days 30%	0.574	0.000	18 Spill Bay Days
Spring Nights 64%	0.071	0.284	18 Spill Bay Nights
Spring Nights 30%	0.358	0.009	18 Spill Bay Nights
Spring Days Both Spills	0.266	0.001	36 Spill Bay Days
Spring Nights Both Spills	0.296	0.001	36 Spill Bay Nights
Spring Daily Totals 64%	0.165	0.094	18 Spill Bay Diurnal Cycles
Spring Daily Totals 30%	0.599	0.000	18 Spill Bay Diurnal Cycles
Spring Daily Totals Both Spills	0.445	0.000	36 Spill Bay Diurnal Cycles
Summer Days 64%	0.035	0.467	18 Spill Bay Days
Summer Days 30%	0.328	0.013	18 Spill Bay Days
Summer Nights 64%	0.347	0.010	18 Spill Bay Nights
Summer Nights 30%	0.347	0.010	18 Spill Bay Nights
Summer Days Both Spills	0.227	0.003	36 Spill Bay Days
Summer Nights Both Spills	0.355	0.000	36 Spill Bay Nights
Summer Daily Totals 64%	0.000	0.957	18 Spill Bay Diurnal Cycles
Summer Daily Totals 30%	0.575	0.000	18 Spill Bay Diurnal Cycles
Summer Daily Totals Both Spills	0.111	0.047	36 Spill Bay Diurnal Cycles

The regressions in Table C5 were improved slightly by dividing both variables (Spill Bay 2 hydroacoustic estimates and the averages of Spill Bay 1 and 3 estimates) by that appropriate total Q for each sample. Those results are presented in Table C6. Although normalizing by Q estimates decreased some of the lower r^2 values, the "Daily Total" regressions were improved except for the 64-percent spill in spring. The daily total samples for summer including both spills changed from 0.111 to 0.442.

Table C6
Results of Regressions of Hourly Fish-Passage Estimates for Spill Bay 2 on the Average of Estimates from Spill Bays 1 and 3, Each Divided by the Estimated Flow (Q) for Spill Bay 2

Data Set	Coefficient of Determination (r^2)*	p-value	Sample Size
Spring Days 64%	0.121 -	0.157	18 Spill Bay Days
Spring Days 30%	0.532 -	0.000	18 Spill Bay Days
Spring Nights 64%	0.046 -	0.390	18 Spill Bay Nights
Spring Nights 30%	0.452 +	0.002	18 Spill Bay Nights
Spring Days Both Spills	0.360 +	0.000	36 Spill Bay Days
Spring Nights Both Spills	0.529 ++	0.000	36 Spill Bay Nights
Spring Daily Totals 64%	0.150 -	0.113	18 Spill Bay Diurnal Cycles
Spring Daily Totals 30%	0.618 +	0.000	18 Spill Bay Diurnal Cycles
Spring Daily Totals Both Spills	0.625 +	0.000	36 Spill Bay Diurnal Cycles
Summer Days 64%	0.150 +	0.113	18 Spill Bay Days
Summer Days 30%	0.328 nc	0.013	18 Spill Bay Days
Summer Nights 64%	0.366 +	0.008	18 Spill Bay Nights
Summer Nights 30%	0.410 +	0.004	18 Spill Bay Nights
Summer Days Both Spills	0.482 +	0.000	36 Spill Bay Days
Summer Nights Both Spills	0.529 +	0.000	36 Spill Bay Nights
Summer Daily Totals 64%	0.033 +	0.471	18 Spill Bay Diurnal Cycles
Summer Daily Totals 30%	0.594 +	0.000	18 Spill Bay Diurnal Cycles
Summer Daily Totals Both Spills	0.442 +++	0.000	36 Spill Bay Diurnal Cycles

*change in r^2 (from Table C5) produced by dividing both variables by the appropriate Q. "+" = r^2 improved by , 0.2; "++" = r^2 improved by > 0.2, "+++" = r^2 improved by > 0.3; "-" = r^2 reduced, nc = no change.

Discussion

In all cases except Spill Bay Block 5 at night, flow was a poor predictor of fish passage at The Dalles Dam spillway, at least in the 1999 fish passage seasons (Tables C1 through C4, above). Even for a given spill bay the relationship between flow and hydroacoustic fish passage estimate is very weak. Each spill bay had the same estimated flow on many days or nights, and, even for identical flow estimates for the same spill bay, there were widely varying fish passage estimates. This is not surprising since many other factors besides flow may influence passage by spill, including run timing, flow patterns upstream of the spill bays, conditions elsewhere at the dam, and fish behavioral responses. Why r^2 values for Spill Bay Block 5 for both spills at night in spring and for 64 percent spill at night in summer indicate a much closer relationship between flow and passage is unclear. Although resolving the issue might provide clues to understanding the relationship between flow and passage, it would probably not support using flow alone at the basis for predicting or interpolating passage estimates.

Interpolating passage values for unsampled spill bays based on nearby sampled bays is probably preferable to using flow. In the case of our tests on Spill Bay 2 (Table C5) it appears to be a good option in some cases. There were 18 regression equations, and 13 of the 18 equations had slopes that were significantly different from zero.

Dividing both sampled estimates and interpolated values by the appropriate spill (Q) estimate raised r^2 values in many cases, with the largest increases for spring nights under both spills (an increase in r^2 of 0.233) and for summer daily totals under both spills (an increase in r^2 of 0.331).

In general, using estimates from sampled units is better than interpolating estimates or using flow to make estimates. It also seems that linear interpolation may be better at night, under lower spill operational regimes, and in summer. Normalizing linear interpolation estimates with estimates of Q may improve some estimates. The horizontal distribution of fish passage at TDA spillway in 1999 was quite variable among spill bays and hours, so even using linear interpolation is not as good as sampling all bays.

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14. ABSTRACT

This study compares hydroacoustics-based estimates of fish passage and passage metrics for two spill treatments (30- and 64-percent spills) and concomitant powerhouse operations at The Dalles Dam during the 1000 spring and summer juvenile salmon passage seasons. Data were analyzed for significant differences (Wilcoxen Signed-Rank Tests, $\alpha = 0.05$) in daytime, nighttime, and total daily fish passage and passage metrics over six 3-day treatment blocks in spring and summer. Horizontal distributions of fish passage at spillway and powerhouse and vertical distributions of fish at sluiceway and powerhouse are presented by treatment and time of day for each season. Project fish-passage efficiency (FPE) and spill efficiency were significantly higher with the higher spill and lower powerhouse generation treatment at night but not during days in both seasons. Sluiceway efficiency was higher with the lower spill and higher generation treatment at night in spring and both night and day in summer. Spill passage was not significantly different during day or night in spring but was higher with the higher spill treatment during summer nights (but not days). Sluiceway passage was higher during spring days and nights during the 30-percent spill than during the 64-percent spill but not different during days or nights in summer. Turbine passage was higher

(Continued)

15. SUBJECT TERMS

Acoustic screen model	Fish-guidance efficiency	Fixed-aspect hydroacoustics	Juvenile salmon passage	Spillway passage
Columbia River	Fish passage	Hydroacoustics	Salmon	Surface collection
	Fish-passage efficiency	Hydropower dams	Sluiceway passage	

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U.S. Army Engineer Research and Development Center
Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

AscI Corporation
1365 Beverly Road
McLean, VA 22101

BioAnalysts, Inc.
11807 Northeast 99th Street, Suite 1160
Vancouver, WA 98683

DynTel, Inc.
3530 Manor Drive, Suite 4
Vicksburg, MS 39180

University of Washington
Columbia Basin Branch, School of Fisheries
1325 Fourth Avenue, Suite 1820
Seattle, WA 98101-2509

U.S. Army Engineer District, Portland
P.O. Box 2946
Portland, OR 97208-2946

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with the lower spill treatment at night in both seasons. Results should be considered in light of the confounding effects of higher spill vs. lower generation and the converse, which was inherent in the experimental design.

Statistical methods, a detailed evaluation of the "acoustic screen model," and an evaluation of two methods for estimating passage at unsampled spill bays are presented in the appendixes.