PNNL-24856

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

Evaluation of Adult Steelhead Passage with TSW Spill during the Winter of 2014–2015 at McNary Dam

Final Report

October 2015

KD Ham
PS Titzler
RP Mueller

US Army Corps of Engineers®

Prepared for the **U.S. Army Corps of Engineers, Walla Walla District**, under a Government Order with the U.S. Department of Energy
Contract DE-AC05-76RL01830

U.S. DEPARTMENT OF ENERGY

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.
(8/2010)

PNNL-24856

Evaluation of Adult Steelhead Passage with TSW Spill during the Winter of 2014–2015 at McNary Dam

Final Report

KD Ham
PS Titzler
RP Mueller

October 2015

Prepared for the
U.S. Army Corps of Engineers, Walla Walla District,
under a Government Order with the U.S. Department of Energy
Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Efforts to provide safe downstream passage for salmon migrating past dams is not restricted to juvenile life stages. Steelhead kelt are post-spawn adults that return downstream to the sea prior to returning in following years for additional rounds of spawning. Adult salmon that overshoot their natal stream also must pass downstream through dams to return to their spawning grounds. At McNary Dam, the structures and operations designed to improve juvenile survival, such as guidance screens, spill, and the use of surface weirs, might also benefit adults passing downstream, but those operations and specialized routes may not be available outside the typical juvenile passage times.

The hydroacoustic study of temporary spillway weir (TSW) passage for adult steelhead reported herein was funded by the Walla Walla District of the U.S. Army Corps of Engineers and conducted at McNary Dam on the Columbia River from November 2014 to April 2015 by a team of researchers from Pacific Northwest National Laboratory. The study included a comparison of passage during TSW_Spill and No_Spill treatments in a randomized block design. Fish guidance screens were installed in the turbine units during the first experimental period (Screens_In) from 15 November 2014 to 14 December 2014. Fish guidance screens were not installed during the second experimental period (Screens_Out) from 15 February 2015 to 16 March 2015. Both experimental periods focused on the passage distributions of adult steelhead during TSW_Spill or No_Spill treatment conditions.

During the Screens_In experimental period, a statistically significant difference was found among treatments for fish passage efficiency (the proportion of fish passing non-turbine routes) and for total passage. TSW operation resulted in fewer adults passing via turbines and more fish passing the dam overall. Other passage trends were suggestive of fish being drawn away from guided passage by TSW operation, though none of those trends led to a statistically significant difference among treatments. The increase in downstream passage by adults during TSW_Spill treatments suggests that a number of fish upstream of McNary Dam were not actively passing the dam during No_Spill treatments.

Flows exceeding the powerhouse capacity required spill through non-TSW spillbays. Spill discharge exceeding the capacity of the TSW prevented the implementation of treatment conditions during the Screens_Out experimental period. In the absence of controlled treatments, we pursued an ad hoc analysis of data from all days with screens removed to identify relationships among passage and operations. Turbine passage increased significantly with increasing total flow and nearly significantly with total spill. Because spill passage routes were not monitored, it was only possible to speculate what changes to passage efficiency or total passage might be.

The proportion of total individuals that passed through turbines was found to decrease during the TSW_Spill treatment in the Screens_In experimental period although the absolute rate of turbine passage increased. Monitoring results during the Screens_In experimental period and a combination of monitoring results and speculation for the remaining sampling period both suggest that more adult steelhead passed via the powerhouse as flows increased, in spite of TSW or conventional spill.

Acknowledgments

This work was supported by the U.S. Army Corps of Engineers, Walla Walla District. We sincerely acknowledge the cooperation, assistance, and hard work of the following U.S. Army Corps of Engineers staff:

- Brad Trumbo, Walla Walla District, for overall project oversight and direction
- Carl Dugger, Bill Gersbach, Bobby Johnson, Tim Roberts, and the riggers at McNary Dam for help with equipment installation and coordination
- Richard Benoit and Craig Newcomb for dive support
- The McNary Dam operators for research coordination activities at the dam including safety clearances and outages and maintaining the scheduled study conditions.

We acknowledge Associated Underwater Services, Inc., which provided the dive team that installed and removed the underwater sampling equipment.

We thank Dr. Daniel Deng and his team at Pacific Northwest National Laboratory (PNNL) for performance testing the hydroacoustic equipment in their accredited acoustic laboratory.

Finally, we acknowledge the cooperation, assistance, and hard work of the following PNNL staff: Ethan Green, John Stephenson, Kate Deters, Ryan Harnish, and Nikki Fuller.

Acronyms and Abbreviations

ANCOVA	analysis of covariance
ANOVA	analysis of variance
dB	decibel(s)
ESA	Endangered Species Act of 1973
ESBS	extended-length submersible bar screen
FCRPS	Federal Columbia River Power System
FGE	fish guidance efficiency
FPE	fish passage efficiency
ft	foot(feet)
JBS	juvenile bypass system
kHz	kilohertz
m	meter(s)
ms	millisecond(s)
MSL	mean sea level
MW	megawatt(s)
PAS	Precision Acoustic Systems, Inc.
pps	pings per second
RPA	Reasonable and Prudent Alternative
TSW	temporary spill weir
USACE	U.S. Army Corps of Engineers

Contents

Figures

Tables

1.0 Introduction

This report presents the results of a hydroacoustic study of temporary spillway weir (TSW) passage for adult salmonids funded by the Walla Walla District of the U.S. Army Corps of Engineers (USACE) and conducted at McNary Dam on the Columbia River from November 2014 to April 2015 by a team of researchers from Pacific Northwest National Laboratory (PNNL). This study estimated the number of steelhead adults, including kelts, passing downstream through the powerhouse and TSW at McNary Dam and evaluated how passage was distributed vertically in the water column and horizontally across the powerhouse. The study compared passage during TSW_Spill and No_Spill treatments in a randomized block design. Fish guidance screens were installed in the turbine units during the first experimental period from 15 November 2014 to 14 December 2014. Fish guidance screens were not installed during the second experimental period from 15 February 2015 to 16 March 2015.

1.1 Background

The USACE is committed to improving fish passage and increasing survival rates for fish passing its hydroelectric projects on the Snake and Columbia Rivers. As a strategy for improving steelhead survival through the Federal Columbia River Power System (FCRPS), the National Oceanic and Atmospheric Administration Fisheries identified actions in the 2008 FCRPS Biological Opinion to improve the productivity and abundance of steelhead in Reasonable and Prudent Alternatives (RPAs). RPA 54.14 includes the investigation of surface passage routes to provide safer fallback opportunity for overwintering adult steelhead. One expected benefit is a higher conversion rate between McNary and Bonneville Dams (target is 84.5% for upper Columbia River steelhead). Increasing the survival of overwintering pre-spawn adults and post-spawn kelts is important for improving the abundance and productivity of Endangered Species Act-listed steelhead populations in the Snake River and upper and middle Columbia River. In addition, approximately 50% of adult steelhead returning to the John Day River overshoot their destination and pass upstream over McNary Dam, and winter TSW operations may provide a survival benefit as they return downstream.

At McNary Dam, fish passage and survival strategies have included the use of voluntary spill, spillway weirs, barge transportation, and extended-length submerged bar screens (ESBSs) as part of a juvenile bypass system. Surface passage routes such as removable spillway weirs, sluiceways, and the Bonneville Dam corner collector have proven to be effective at passing juvenile fish while providing relatively safe passage conditions (Anglea et al. 2003; Axel et al. 2007; Ham et al. 2007; Johnson et al. 2007; Moursund et al. 2007; Ogden et al. 2007; Ploskey et al. 2006; Plumb et al. 2003, 2004; and Evans et al. 2005). Surface routes have also proven effective at passing adults while being operated for juveniles (Harnish et al. 2015). The ice and trash sluiceway at The Dalles Dam is a surface route that has proven effective at passing adults during the winter (Khan et al. 2013). Its operation is now called for during both juvenile and adult passage seasons and whenever spill occurs during the winter (USACE 2015). The TSWs at McNary Dam were designed to provide the benefits of a surface passage route with reduced structural complexity. At present, however, neither spill nor surface spill are called for during the winter period. This study evaluates whether operating those passage routes during winter would alter passage routing and therefore have some potential for modifying survival rates.

1.2 Objectives

The study reported herein was conducted to determine the proportion of adult size steelhead targets passing through the TSW versus the total that passed via the powerhouse. The secondary goal of this study was to determine the proportion of adult size steelhead targets that were guided into the juvenile bypass system (JBS) compared to the total number that passed though the powerhouse. Finally, we sought to determine if TSW spill increases fallback through the dam versus powerhouse passage with no spill. The specific objectives were as follows:

1. Estimate TSW and powerhouse passage efficiency (including bypass) for adult steelhead at McNary Dam using hydroacoustics during the fall and winter of 2014–2015 (September–March).
    a. Operate one TSW at 10 kcfs in a block design to spill 10 kcfs approximately 50% of the time during the experimental periods.
    b. No specific turbine unit operations.
2. Compare passage efficiency with TSW on versus TSW off ($\alpha = 0.05$).
3. Compare powerhouse fallback to total fallback when the TSW is in operation (powerhouse vs. powerhouse +TSW) to determine if TSW spill increases fallback. Test for statistical ($\alpha = 0.05$) and biological significance.

1.3 Study Site Description

McNary Dam is located at Columbia River mile 292 and it includes a navigation lock, a spillway, and a powerhouse. The dam structure is 7365 ft long. The structure consists of 14 turbine units, 22 spillbays, a navigation lock, two fish ladders for adult fish traveling upstream, and an earth-filled section (Figure 1.1). The McNary Dam powerhouse is 1422 ft long and contains fourteen 70 MW turbine units. All turbines are Kaplan, six-blade units that operate at 85.7 revolutions per minute. Turbine units are numbered 1 through 14 starting from the Oregon shore. Each turbine has three intakes designated A, B, and C. Two small station service units are located south of Main Unit 1 and have a capacity of 3 MW each.

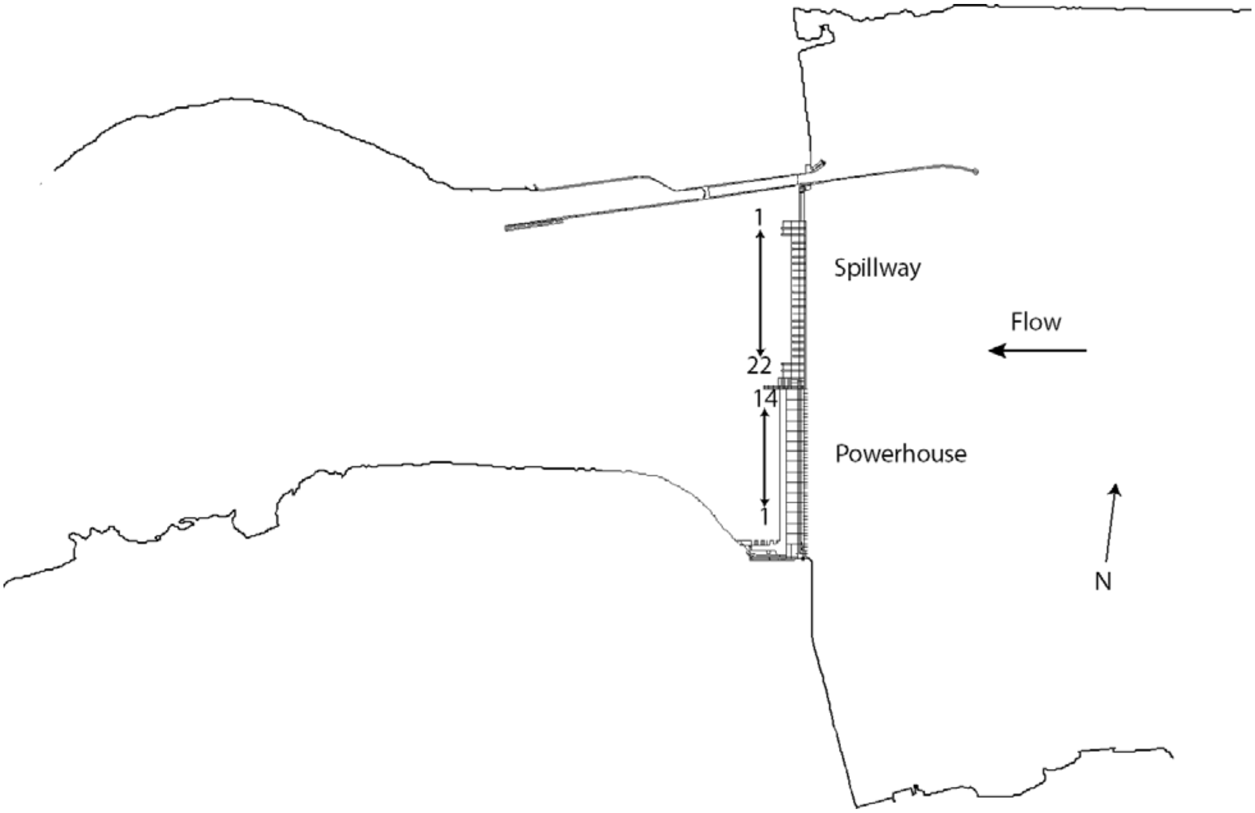

Figure 1.1. Plan View of McNary Dam Illustrating the Location of the Spillway and Powerhouse

Turbine unit intakes are fitted with ESBSs during the juvenile fish passage season (April–August), and through the fall for adult passage. The ice and trash sluiceway has been permanently walled off for use as the collection channel of the JBS. Transportation facilities consist of a separator (to sort juvenile fish by size and to separate them from adult fish), sampling facilities, raceways, office and sampling building, truck- and barge-loading facilities, and passive integrated transponder-tag detection and deflector systems. The current JBS at McNary Dam became operational in 1994. While some fish transportation has occurred at McNary Dam historically, it has been limited to transportation from mid and late summer since 2002. As of the 2013 migration year the USACE has ended transport from McNary Dam and discussions are ongoing as to whether to remove or mothball the facilities.

The 1130 ft spillway is composed of 22 vertical lift gates, which are numbered sequentially starting from the Washington shore—the spillbay closest to the powerhouse is 22 (Figure 1.1). Spill gates are of split-leaf, vertical lift design. During the spring juvenile fish passage season, TSWs are operated in bays 19 and 20. TSWs differ from traditional spill gates in that they allow water to pass over the top of an engineered weir structure, rather than under a spill gate. In this way, TSWs provide a surface passage route for fish. The TSWs at McNary Dam consist of a shaped weir crest installed atop a lower spill gate leaf in the downstream slot, typically occupied by a spill gate consisting of an upper and lower leaf (Figure 1.2). Discharge of water through a TSW spillbay was turned off by lowering the upper spill gate leaf onto the crest of the TSW. During operation, the upper spill gate leaf was raised above the water surface and the discharge over the TSW was controlled by the forebay water surface elevation. An additional lower spill gate leaf was also present in the stoplog slot upstream of the TSW structure. That leaf did not control discharge, but it did affect how water approached the TSW structure. Under the current fish passage plan, the TSWs are removed for the summer juvenile fish passage season and they remain out of operation until they are reinstalled in the spring. In the current study, the TSW was installed and operated in Spillbay 20 during specified treatment periods in the winter and during periods of unplanned spill that were not part of a specified treatment period.

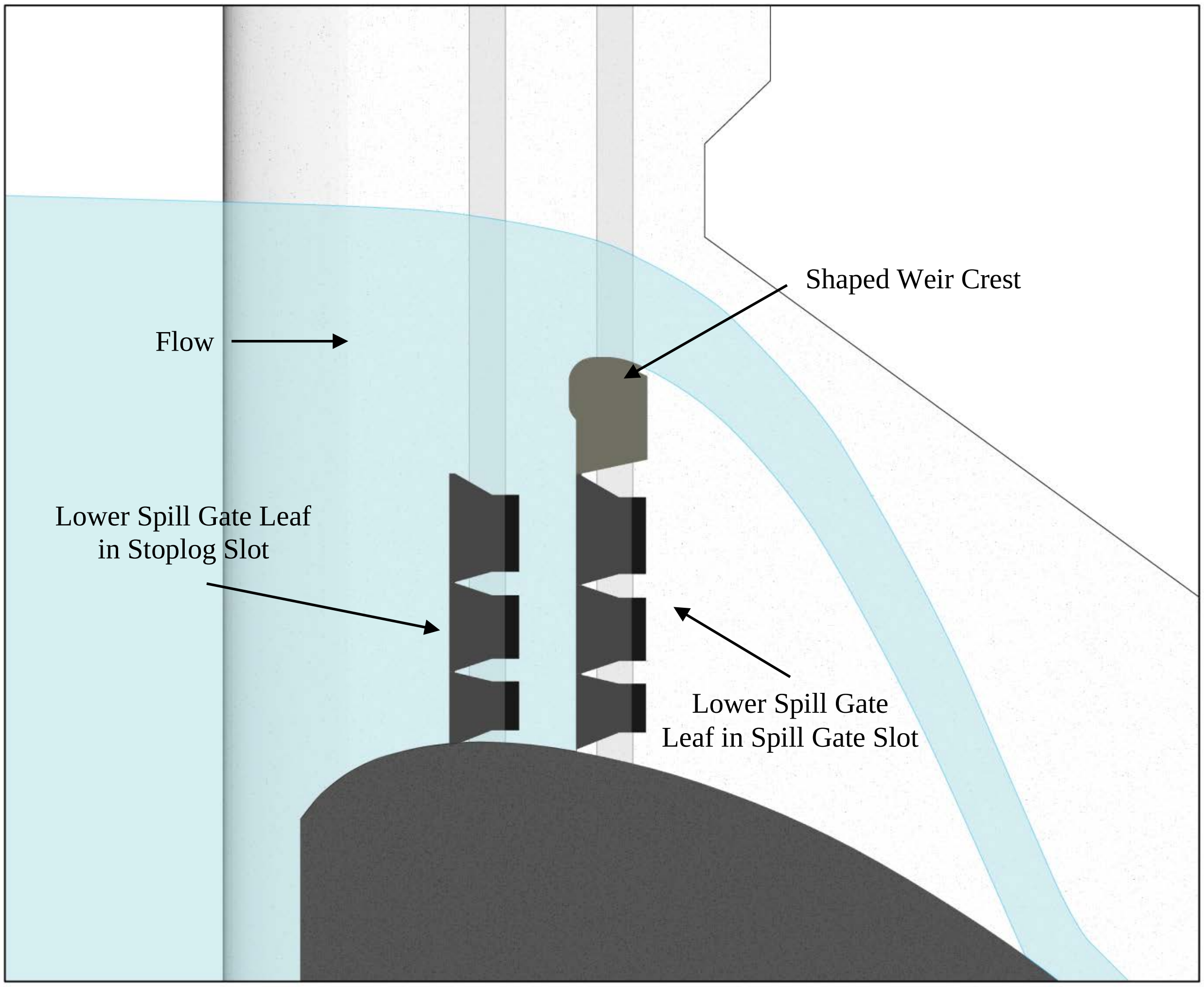

Figure 1.2. Structural Diagram of TSW

The gravity-flow auxiliary water-supply system that supplies water to the Washington shore fish ladder has a 10 MW hydropower turbine unit installed on it, and this unit is operated by the Northern Wasco County Public Utility District. The south fish ladder includes downstream entrances at the north and south ends of the powerhouse and is fed by gravity and pumped auxiliary water-supply systems. The thalweg of the river intersects the dam upstream of the powerhouse, but curves north in the tailrace and continues downstream of the spillway (Figure 1.3)

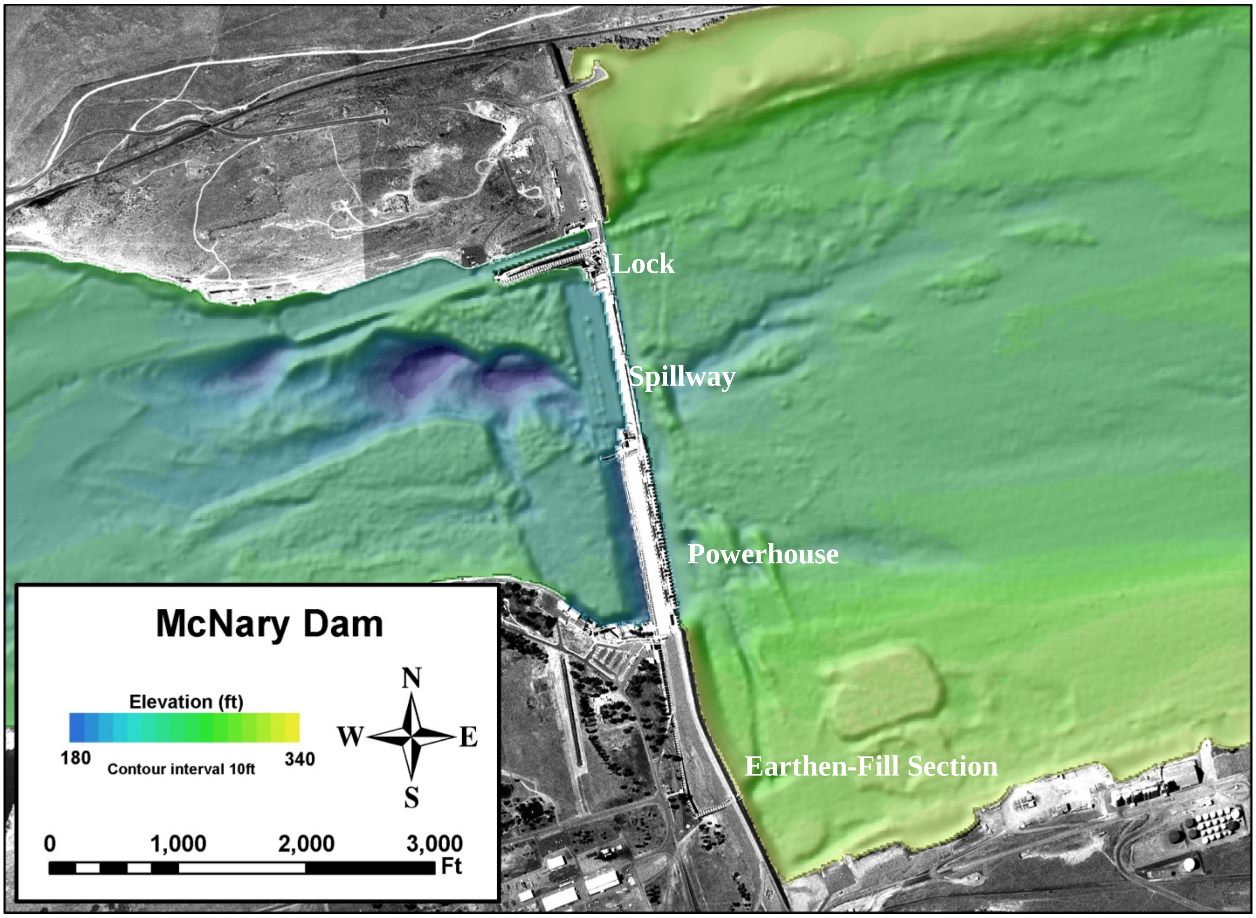

Figure 1.3. Plan View of McNary Dam Major Structural Features Showing River Bathymetry

1.4 Report Contents and Organization

The ensuing sections of this report present the results of the study of adult steelhead passage efficiency of a spillway weir in the winter of 2014–2015. Chapter 2.0 contains a description of methods used, including the study design, sampling equipment, data analysis, and data processing. Chapter 3.0 provides results and discussion, including site conditions during the study, overall fish passage, and comparisons of TSW spill treatments and turbine unit operations on passage distributions. Chapter 4.0 provides our conclusions. Appendices contain supplemental information, as follows: Appendix A, Equipment Configuration and Settings; Appendix B, Raw Hourly Passage and Dam Operations Data; Appendix C, Effective Beam Widths; and Appendix D, Statistical Methods.

2.0 Methods

Fixed-aspect hydroacoustic techniques were used to quantify the number of adult steelhead-sized acoustic targets passing over the TSW, through turbine units, or into the JBS at McNary Dam during the winter of 2014/2015. Two multibeam imaging sonars (“acoustic cameras”) monitored fish at selected locations upstream of the powerhouse and TSW to identify times when the abundance of non-salmonids might influence target counts. The study plan called for monitoring passage through the winter season, with two experimental periods including alternating TSW_Spill and No_Spill treatments in a randomized block-treatment schedule.

2.1 Study Design

A randomized block study design was used with TSW_Spill and No_Spill treatments randomly assigned to the first or last 3 days of each 6-day block. Two 30-day experimental periods were sampled. The first experimental period (Screens_In) was from 15 November–14 December, 2014, while juvenile fish guidance screens were still in place to allow fish guidance efficiency (FGE) to be compared among treatments. The second experimental period (Screens_Out) occurred 15 February to 16 March, 2015, after the screens were removed and before they were reinstalled for juvenile passage operations in spring. Each experimental period was considered a separate blocked study. Passage monitoring with hydroacoustics and imaging sonar continued between experimental periods to assess passage trends, but TSW_Spill and No_Spill treatment conditions were implemented only during the two experimental periods. No spill was planned for the days between the experimental period or when the No_Spill treatment was in effect.

2.1.1 Experimental Treatment and Schedule

Three-day treatment periods (TSW_Spill or No_Spill) were arranged within 6-day blocks. Treatments were randomly assigned to the first or last half of each block within two experimental periods. The first period began 15 November 2014 and ended 14 December 2014 when fish guidance screens were in place and a period that began 16 February 2015 and ended 16 March 2015 with fish guidance screens removed (Table 2.1). Target spill discharge during each TSW_Spill block was 10 kcfs (TSW only) and no discharge through the TSW for each No_Spill block. No spill through conventional spillbays was planned. During the Screens_In experimental period, TSW block treatments and discharge were followed as designed. Forced spill, when water must be discharged over the spillway because total flows exceed powerhouse capacity, occurred frequently throughout the Screens_Out experimental period and the experimental treatments could not be implemented as designed. When forced spill occurred, the TSW was used as the primary spillbay to enable data to be collected on TSW passage during this study, followed by discharge through conventional spillbays according to the fish passage plan (USACE 2014).

Table 2.1. Study Design for TSW Operation during Two Experimental Periods

Winter 2014 (Screens_In)			Early Spring 2015 (Screens_Out)		
Date	Block	Treatment	Date	Block	Treatment
11/15/2014	1	TSW_Spill	2/15/2015	1	TSW_Spill
11/16/2014		TSW_Spill	2/16/2015		TSW_Spill
11/17/2014		TSW_Spill	2/17/2015		TSW_Spill
11/18/2014		No_Spill	2/18/2015		No_Spill
11/19/2014		No_Spill	2/19/2015		No_Spill
11/20/2014		No_Spill	2/20/2015		No_Spill
11/21/2014	2	No_Spill	2/21/2015	2	TSW_Spill
11/22/2014		No_Spill	2/22/2015		TSW_Spill
11/23/2014		No_Spill	2/23/2015		TSW_Spill
11/24/2014		TSW_Spill	2/24/2015		No_Spill
11/25/2014		TSW_Spill	2/25/2015		No_Spill
11/26/2014		TSW_Spill	2/26/2015		No_Spill
11/27/2014	3	No_Spill	2/27/2015	3	No_Spill
11/28/2014		No_Spill	2/28/2015		No_Spill
11/29/2014		No_Spill	3/1/2015		No_Spill
11/30/2014		TSW_Spill	3/2/2015		TSW_Spill
12/1/2014		TSW_Spill	3/3/2015		TSW_Spill
12/2/2014		TSW_Spill	3/4/2015		TSW_Spill
12/3/2014	4	TSW_Spill	3/5/2015	4	No_Spill
12/4/2014		TSW_Spill	3/6/2015		No_Spill
12/5/2014		TSW_Spill	3/7/2015		No_Spill
12/6/2014		No_Spill	3/8/2015		TSW_Spill
12/7/2014		No_Spill	3/9/2015		TSW_Spill
12/8/2014		No_Spill	3/10/2015		TSW_Spill
12/9/2014	5	No_Spill	3/11/2015	5	No_Spill
12/10/2014		No_Spill	3/12/2015		No_Spill
12/11/2014		No_Spill	3/13/2015		No_Spill
12/12/2014		TSW_Spill	3/14/2015		TSW_Spill
12/13/2014		TSW_Spill	3/15/2015		TSW_Spill
12/14/2014		TSW_Spill	3/16/2015		TSW_Spill

2.2 Hydroacoustic Sampling System

Hydroacoustic transducers were used to detect fish passing into the turbines, being guided into the JBS, or passing through the spillway TSW. The details of hydroacoustic equipment installations are described in this section. Data collection relied on nine split-beam hydroacoustic sounder systems to monitor adult steelhead-size targets entering the powerhouse and one split-beam hydroacoustic sounder system for targets entering the TSW. All systems operated at a frequency of 420 kHz. Split-beam data collection was accomplished using Precision Acoustic Systems, Inc. (PAS) Harp–SB Split-Beam Data Acquisition/Signal Processing Software—a DOS-based application that controlled each PAS-103 Split-Beam Multi-Mode Scientific Sounder. Each PAS-103 Split-Beam Sounder controlled a PAS-203 Split-Beam 4-Channel Transducer Remote Multiplexer that multiplexed up to three PAS 420-kHz Split-Beam Transducers (see Appendix A for system configurations). The sounder controlled the pulses (pings) emitted through the transducers and processed the signals received. When a fish passed through the sample volume of the beam, pings were reflected and received as an echo at the transducer. Ping rates of around 25 pings per second (pps) are typically used during juvenile or adult fish studies, where conditions permit. Due to high levels of reverberation within the turbine intakes, ping rates were reduced to 21 pps and 16 pps in the TSW spillbay to eliminate specific reverberation noise within the sample ranges. Pings were transmitted with a pulse width of 100 ms for wideband sounders or 200 ms for narrowband sounders. Each transducer was sampled in sequence 10 times per hour for 118- or 177-second intervals. Echo data were captured using the Harp–SB data-acquisition and signal processing software that controls the sounder and stores the data. Hydroacoustic sampling was conducted at the dam 24 hours per day, 7 days a week. The sounder and the data-acquisition equipment were housed in two equipment shacks on the forebay deck for the duration of the study.

For this study, PAS 420-kHz Split-Beam Transducers (Figure 2.1) with a nominal beam angle of six (6) degrees were used to sample fish passing into turbines or being guided into the JBS through one randomized slot (A, B, or C) of Units 1, 2, 3, 5, 6, 7, 8, 10, 13, and 14 (Figure 2.2). Each split-beam sounder sampled either two or three intake transducers (Appendix A). One sounder sampled the TSW that included three transducers with a nominal beam angle of 10 degrees, so that each transducer was sampled approximately one-third of the time. Other transducers on the same sounder were idle during the sampling time of a given transducer. For the winter (Screens_In) experimental period, two transducers per unit were used to sample both guided and unguided passage. The unguided transducer was removed when the ESBS was removed from each slot at the end of the winter (Screens_In) period, leaving a single transducer to capture passage into the turbine for the remainder of the study. The TSW transducers were sampled during both periods. Estimates of passage within the sampled time were expanded by approximately 2 or 3 times to account for the amount of time at each location that the transducer was idle. Passage within the sample beam was also expanded from the width of the beam at the distance where the fish was detected to the entire width of the passage route (the turbine unit slot) being sampled. That expansion varies from many times to a few times the actual count as the width of the beam increases with range, and is also corrected for how detectable a fish passing through that range would be. These expansions produced estimates that represent the total passage through a route.

Figure 2.1. Transducer Installed in an Adjustable Mount and Prepared for Installation

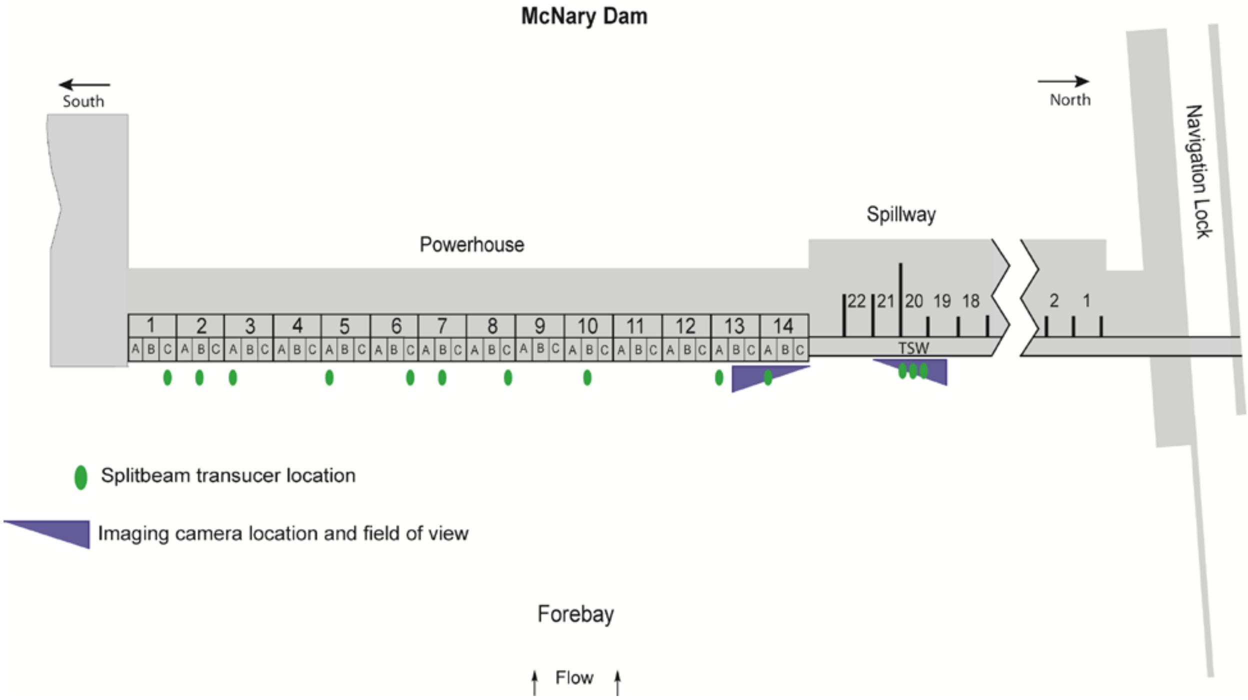

Figure 2.2. Sampling Locations along McNary Dam

Transducers sampling guided fish were attached to the trashrack horizontal member at an elevation of 239 ft above mean sea level (MSL) near the center of the intake, oriented to look up toward the intake ceiling and aimed 31 degrees downstream of the trashrack plane (Figure 2.3). To protect the transducer cables from debris and trash raking, cables were routed through conduit secured to the downstream side of the trashrack as they were routed up to the intake road deck. Transducers sampling unguided fish were attached to a horizontal cross member of the ESBS frame downstream of the screen and at an elevation of 270 ft above MSL oriented to look down toward the intake floor and angled 24 degrees upstream of the frame structure (Figure 2.3). At the end of the winter experimental period, the ESBS and unguided transducer were removed from each study intake slot, leaving only the previously guided transducer to sample the entire slot (Figure 2.4) for the remainder of the study including the early spring experimental period. The transducers sampling fish passing through the TSW were mounted near the top of the vertical upstream face of the spillbay ogee at an approximate elevation of 282 ft above MSL oriented to look up toward the water surface and angled 17.5 degrees downstream (Figure 2.5).

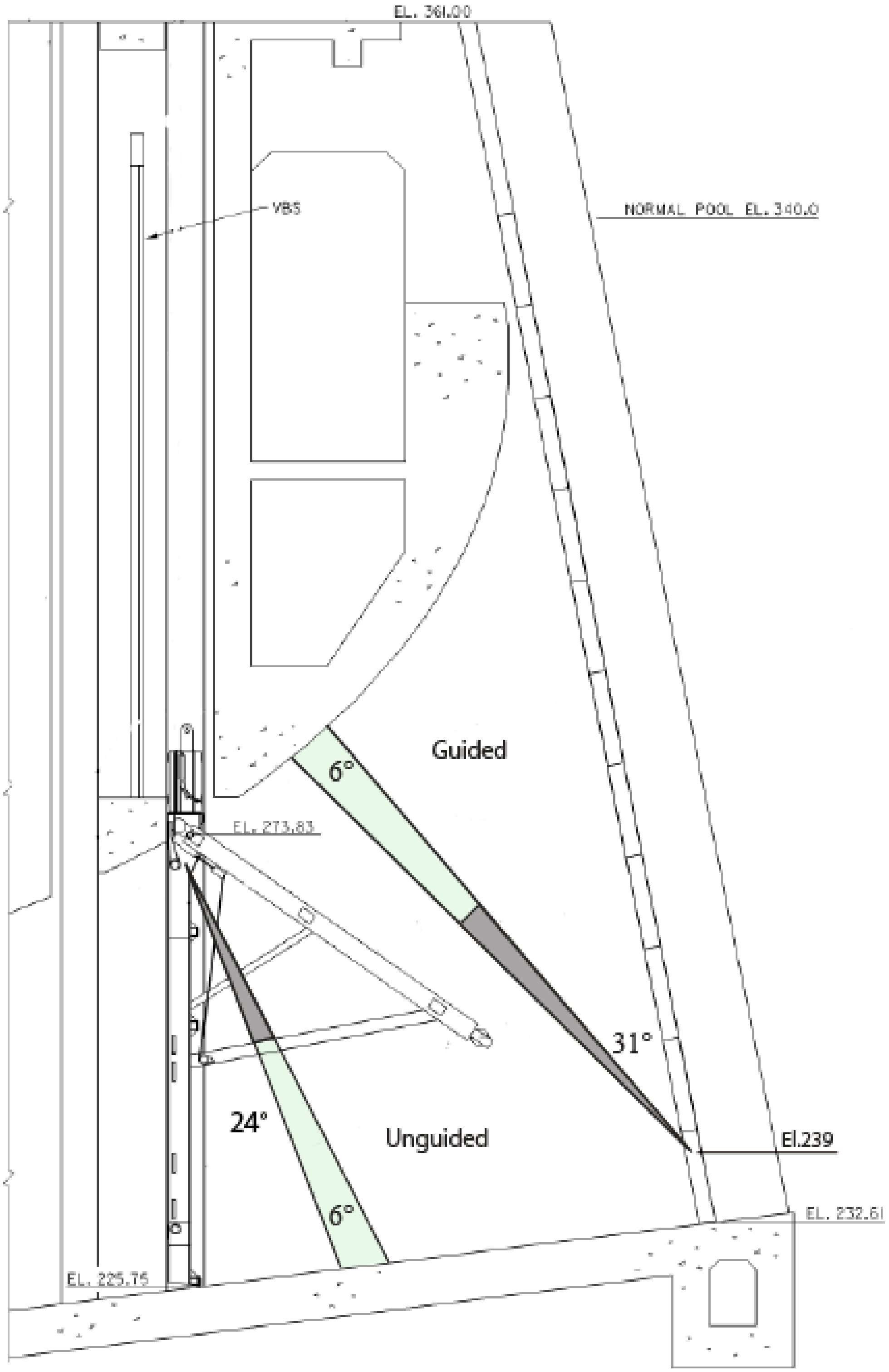

Figure 2.3. Guided and Unguided Transducer Sample Volumes Showing Passage Ranges of Interest for Screens_In sampling conditions

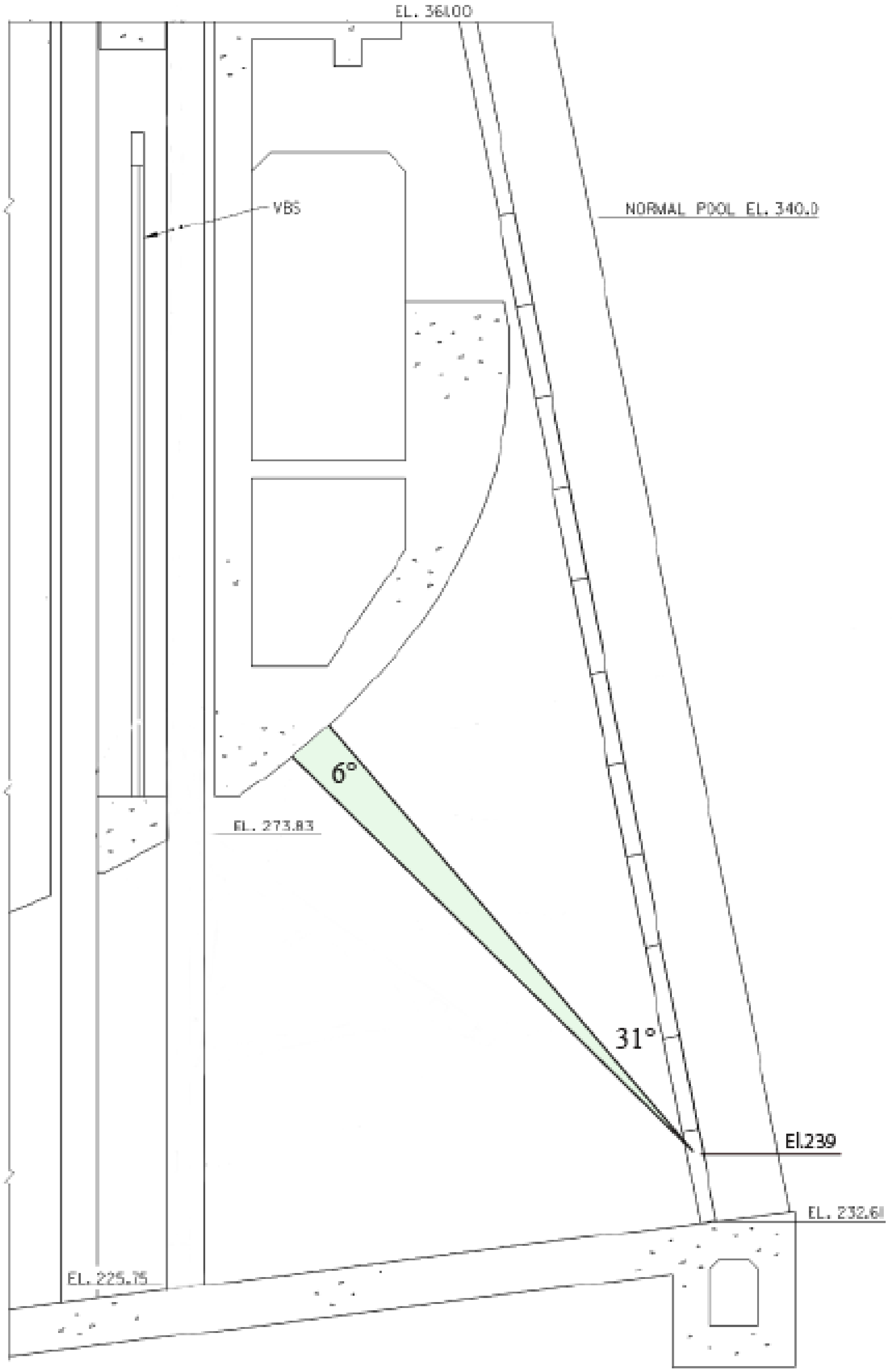

Figure 2.4. Intake Transducer Sample Volume Showing Passage Ranges of Interest for Screens_Out Sampling Conditions

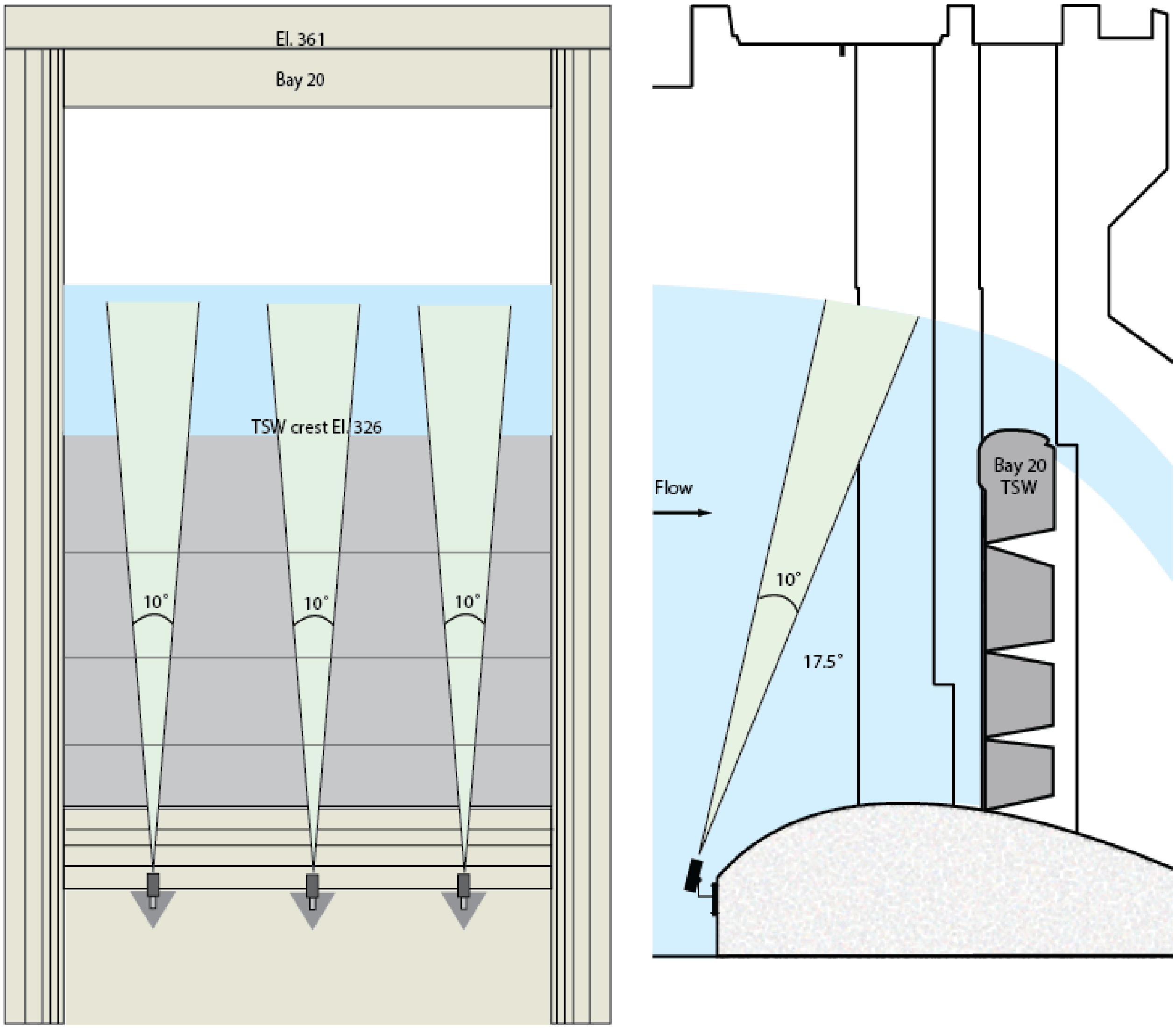

Figure 2.5. Diagram of Mounting Locations, and Sample Volumes of Transducers Sampling TSW Passage

2.3 Imaging Sonar

Two BlueView multibeam imaging sonar systems were deployed during the experimental period. One imaging sonar device was deployed upstream of the TSW on 15 November 2014 and operated until 31 March 2015. The second imaging sonar device was deployed upstream of the powerhouse on 19 November and was operated until 15 April 2015. A P900-45 high-resolution multibeam sonar system was deployed using a modified bracket trolley at the spillway main Pier Nose 21/22 using an existing trolley pipe to monitor fish upstream of the TSW. The imaging sonar was deployed to an elevation of 333.1 ft approximately 7.7 ft below the forebay water surface. The second BlueView (P900-2250-45) was deployed at the existing trolley pipe on the north side of Turbine Unit 14 Slot C (Figure 2.6). This imaging sonar was deployed to an elevation of 325.7 ft above MSL and positioned to look to the south to view intake Slots C and B. Both systems sampled a 45° wide by 20° deep water volume (Figure 2.7 and Figure 2.8). Both imaging sonars used an ultrasonic frequency of 900 kHz. Imaging sonar provided a way to visualize fish shapes and behavior under conditions where optical cameras would be severely limited by turbidity or the absence of light. They provided a way to differentiate among species groups and monitor the apparent relative abundance of those groups just upstream of TSW and turbine intakes. In addition, it was possible to monitor fish behavior within the sampled region to determine whether fish near the intakes were milling around for extended periods or being entrained into the TSW when in operation. A similar imaging sonar system was used at McNary Dam in the 2011–2012 study to estimate the relative abundance and behavior of adult steelhead and adult shad upstream of the trashracks (Ham et al. 2012).

Figure 2.6. BlueView Imaging Sonar Attached to Trolley and Ready for Deployment

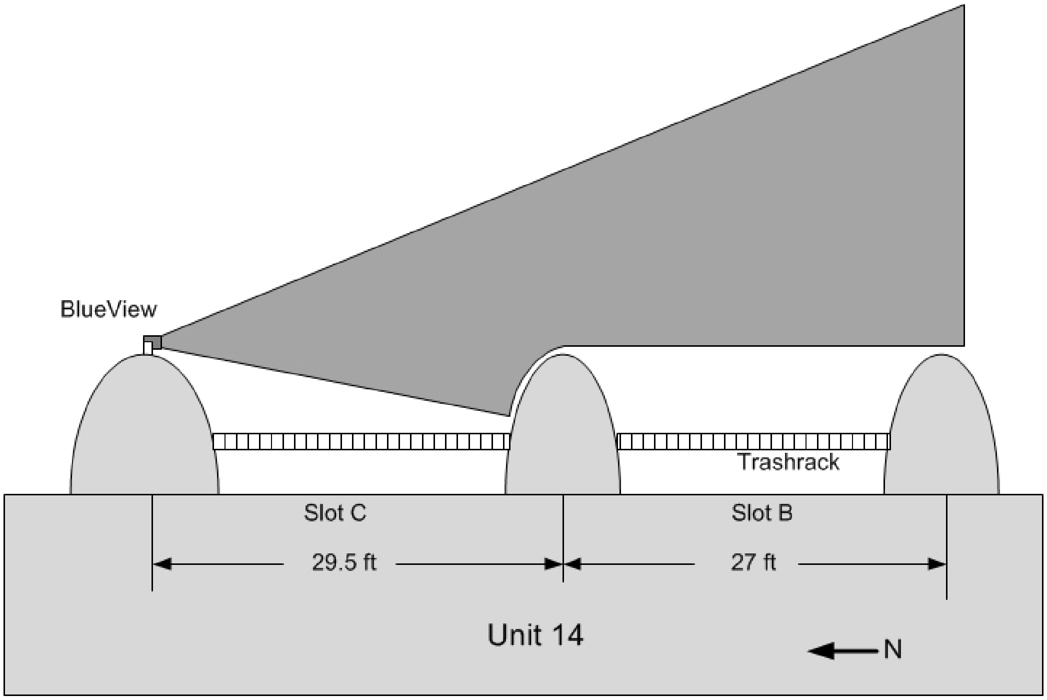

Figure 2.7. Imaging Sonar Sampling Area at Powerhouse Unit 14

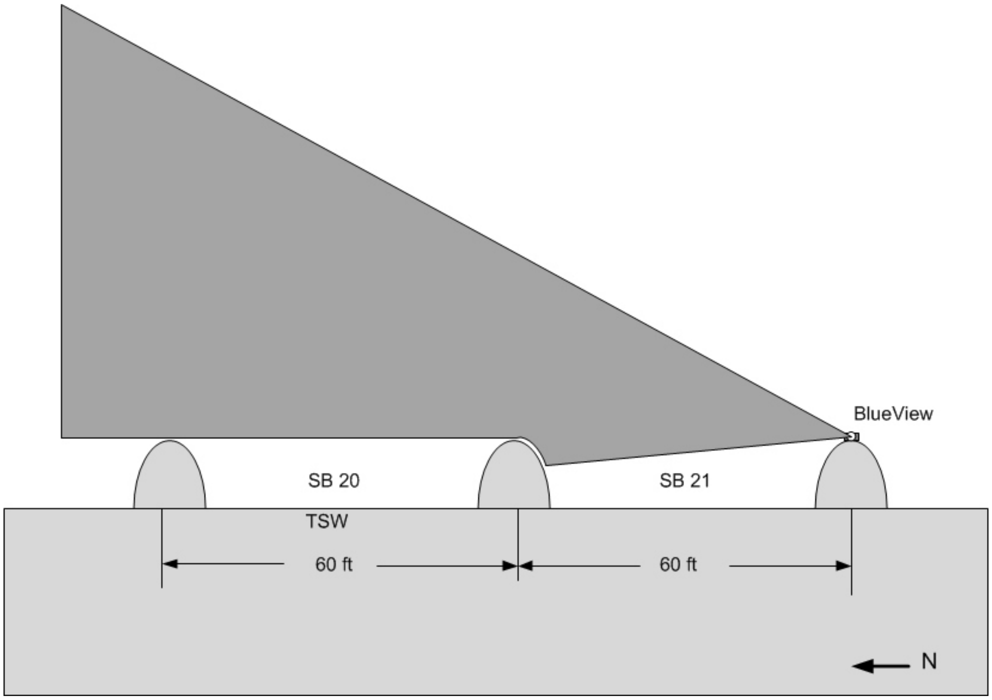

Figure 2.8. Imaging Sonar Sampling Area at the TSW in Spillbay 20

2.4 Data Processing

To estimate adult steelhead passage and evaluate it in the context of the experimental treatments, data collected from hydroacoustic systems were processed to identify tracks of echoes created by individual fish. Counts of fish tracks in the sample volumes were subsequently expanded to estimate fish passage for the entire volume of the turbine intakes and the entire sampling time. Passage estimates were integrated with treatments to evaluate correlations among study or treatment conditions and FGE. This section describes the process of deriving the estimates of fish passage from the raw data. Imaging sonar data were processed to estimate the presence of fish of various species groups near the entrance of the turbine intake and upstream of the TSW and the behavior of those fish.

2.4.1 Dam Operations

Dam operations data, which were provided by the USACE Walla Walla District, included the flows through each passage route on a 5-minute basis as collected by the USACE's Generic Data Acquisition and Control System for McNary Dam. These data were combined with the fish passage data for analysis of relationships between fish passage and treatments. The dam operations data are included with the raw hourly passage data in Appendix B.

2.4.2 Autotracking to Identify Fish Tracks

The data produced by split-beam transducers were processed by autotracking software, which was initially developed by the USACE Portland District and underwent a major revision by PNNL in 2001. The autotracker identifies linear features in echograms, which exhibit characteristics consistent with a fish committed to passage by the monitored route, and the characteristics of the included series of echoes are subsequently summarized and saved as tracks. Each track represents a potential fish target passing through the transducer beam. Further processing removed tracks whose characteristics were inconsistent with a fish passing through a turbine or whose target strengths were lower or higher than expected for an adult steelhead-size fish.

The autotracker software identified any series of echoes that might be a fish track, but many of them can be the result of noise. To focus on juvenile fish passing the routes of interest, rather than noise, the post-processing filters eliminated any tracks that:

- had fewer than 8 (noise) or more than 120 echoes (static objects or wandering fish), or fewer than 4 echoes with no gaps between (noise),
- were in or very near an acoustically noisy location and time (noise),
- were too consistent (static objects) or too variable (noise) in their movement,
- had target strengths greater than -25 dB or less than -33 dB, to include fish of the desired size for this study,
- appeared to be moving upstream (not passing into turbines) or at an unlikely angle (wandering),
- or were outside the sample ranges of interest (i.e., too deep within the guided transducer sample volume to encounter the screen and be guided into the gatewell).

2.4.3 Detectability and Effective Beam Widths

The movement characteristics (e.g., speed and direction) of fish targets passing through the transducer beam were used as inputs to a detectability model. The detectability model simulated individual echoes for fish passing through a transducer beam. The fish movement and echo characteristics were simulated to match those measured by split-beam transducers. A simulated fish was tabulated as detected if enough echoes in a series exceeded a minimum number of consecutive echoes and minimum echo strength. The proportion of fish detected in the beam was used to compute an effective beam width. The nominal beam widths of 6 degrees assigned to a transducer do not accurately reflect the shape of the detection area for a transducer. The effective beam width is a measure that more accurately represents the cross-sectional area across which a transducer is able to detect adult steelhead-sized fish moving at the speed and in the direction that are characteristic of each deployment type. Effective beam widths were computed for each meter of range from the transducer, because track characteristics such as angle and speed are not constant throughout the passage route. To avoid misinterpreting changes in detectability due to treatment levels as changes in passage, we estimated detectability for each treatment level combination. To ensure that inputs were sufficient to model each treatment level combination, fish size and movement characteristics were averaged across all transducers of each deployment type (guided, unguided, or TSW). Appendix C contains plots that illustrate effective beam widths by range for each treatment level combination for each season and diel period.

2.4.4 Spatial and Temporal Expansion of Track Counts

Under the acoustic screen model, the number of tracks detected within the beam is expanded spatially and temporally to estimate total passage through a single passage route. The number of detected fish is expanded from the effective beam widths to the entire widths of the passage opening and to account for sample intervals when the sounder is sampling other transducers. Hourly passage was estimated by expanding the number of adult steelhead-size fish that passed through the beam for the cross-sectional area sampled (Equation 2.1) and the sampled fraction per hour (Equation 2.2):

$$W_{ij} = \frac{I_j}{2R_i \tan\left(\frac{\theta_j}{2}\right)} \tag{2.1}$$

where W_{ij} = the *i*th weighted fish at the *j*th location

I_j = the width (m) at the *j*th location

R_i = the mid-range (m) of the *i*th fish

θ_j = the effective beam width of the transducer at the *j*th location; and

$$\mathrm{X}_{jh} = \left(\frac{K}{k}\right)\sum_{i=1}^{n_{jh}} W_{ijh} \tag{2.2}$$

where X_{jh} = the fish passage at the *j*th location in the *h*th hour

W_{ijh} = the *i*th weighted fish at the *j*th location in the *h*th hour

n_{jh} = the number of fish at the *j*th location in the *h*th hour

K = the total number of sampling intervals in the hour

k = the number of intervals sampled in the hour.

All remaining analyses and response variables are based on these fundamental data. Because the sampling area of a transducer beam covers only a fraction of the intake width and because sounders must each cycle through three or more transducers, each fish detected within the sample area is expanded several fold to estimate how many fish passed the entire intake. Raw hourly passage data are provided in Appendix B.

2.4.5 Imaging Sonar Data Processing

Both imaging sonars were programmed to collect 15-minute samples at 1-hour intervals. Recorded samples were subsampled by reviewing 120 minutes of footage every other day. Each day was segregated into two 12-hour blocks with the day period starting at 0500 hr and ending at 1600 hr and the nighttime period 1700 to 0400 hr. A stratified random subsampling table was generated in which four day periods were selected followed by four nighttime periods. These periods were then reviewed using BlueView ProViewer software. A count was made of targets of each adult steelhead-size species of fish (e.g., adult shad, adult steelhead) for each sample. Individual fish cannot be reliably differentiated once they exit and then re-enter the field of view, so these fish were re-counted when they re-entered the field of view during the same sample period. Additional behaviors were noted that included, milling, movement direction (i.e., north, south or east), and schooling. Other unidentified fish were noted, as were periods of significant entrained air resulting from windy conditions, and drifting debris.

2.4.6 Sampling Outages

While fixed-aspect hydroacoustic systems are relatively reliable, sampling at field locations adds to the uncertainty of vital needs such as electrical power and makes monitoring system operation more challenging. For that reason, a system is in place to send status emails each hour that indicate the hydroacoustic equipment is still operational. Rapid notification of issues allowed technicians to quickly address them either through a remote connection or by driving to the dam when needed to correct a problem or reinitiate sampling. Software lock-ups sometimes occurred, as did a small number of temporary and permanent equipment failures. Sampling was restored in 4 hours or less for most outages. For these short outages, data were interpolated from adjacent hours. Data for outages longer than 4 hours were interpolated from the nearest operational turbine units.

Several outages occurred for the imaging sonar systems (i.e., not recording due to power outages or other computer-related issues). For the majority of the sampling period, files were collected without any significant issues. Both sonars were networked to a main computer at the office trailer and system updates were emailed to PNNL at 4-hr intervals for the duration of the experimental period. If the software program stopped operating for any reason it could be remotely started again from PNNL in Richland by logging into the system server via a remote connection.

2.5 Data Analysis

Data analysis for fixed-aspect hydroacoustics consisted of estimating fish passage numbers and integrating them with flow and other conditions within specific time periods and passage routes. Because spill was not planned and passage at the conventional spillbays was not monitored, it was not possible to estimate or compare passage through spill. These general analysis results were then summarized to address specific questions of interest, such as how fish passage differed among operational and treatment conditions. Both spatial and temporal variations in the sampling were taken into account. The variances were calculated and carried through to the final estimates. Estimates for block and treatment combinations were used to compare passage among treatments using ANOVA (Statistica 12.5, Statsoft, Inc.). The detailed statistical methods are described in Appendix D.

Counts of fish in each species group in imaging sonar sample data were expanded to represent a 24-hour day. Imaging sonar counts are not intended to represent numbers of fish passing through the dam, because the great majority of fish within the view of the imaging sonar did not appear to be passing the dam.

3.0 Results and Discussion

The operation of the TSW is only one aspect of the operation of McNary Dam that might influence passage rates and distributions during the experimental period. Before presenting the results of the treatment comparisons, it is useful to examine how river conditions varied throughout the experimental period to provide context for passage trends. In the following sections, we present information about river conditions, the fish upstream of the dam available for passage, general trends in passage and, finally, the treatment tests.

3.1 Study Conditions

The environmental conditions and the dam operations during the 2014–2015 study provide context for understanding and evaluating the number and distribution of adult salmonids passing downstream through McNary Dam. River flows were near average during the early experimental period in November and December 2014, but were well above average during the latter portion of the experimental period in February and March 2015. As a result, treatments were rarely implemented as planned during the second experimental period, requiring an ad hoc approach to evaluating the influence of TSW and spill discharge in the absence of guidance screens.

3.1.1 River Discharge, Spill, and Temperature

This study monitored passage of adult salmonids through 10 of 14 turbine units at the powerhouse of McNary Dam from 15 November 2014 to 16 March 2015. River discharge was near average in the early portion of the experimental period, but was well above average during the middle and late portions of the experimental period (Figure 3.1). When discharge exceeded powerhouse capacity, it was not possible to maintain planned treatment conditions due to a forced spill condition. Spill through non-TSW spillbays was often required from early January through mid-March (Figure 3.1). The frequency with which discharge exceeded powerhouse capacity during the Screens_Out experimental period, made it impossible to impose the treatment conditions to evaluate the influence of TSW operation.

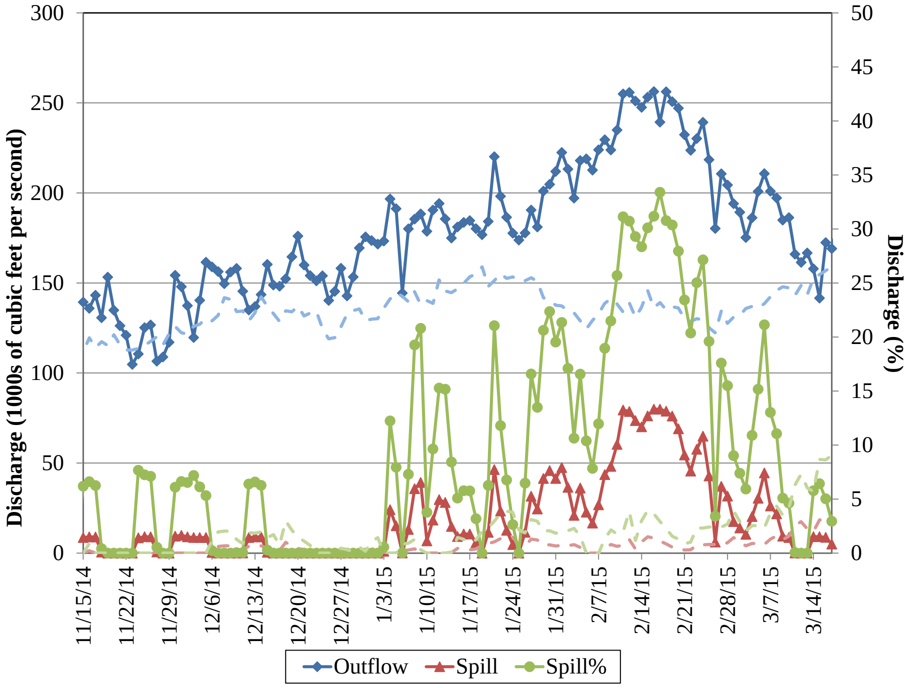

Figure 3.1. Daily Total Discharge, Spill Discharge, and Spill % (solid lines) and 10-Year Averages (dashed lines) for McNary Dam. (Source: www.cbr.washington.edu/dart/river.html)

3.1.2 Species Composition and Run Timing

Adult counts in the fish ladder counting windows at McNary Dam end at the end of October and begin at the start of April, so there were no adult counts during the experimental period. Trends in fish detections in the imaging sonar sample areas give us some indication of what fish were near the dam. The counts of fish in imaging sonar samples were used to estimate the apparent abundance of fish in the forebay upstream of Turbine Unit 14 and in the region just upstream of the TSW (Spillbay 20). Because downstream passage is not assured for fish observed within the sampling area of the imaging sonar, fish can be counted more than once, especially within multiple samples throughout the day. Individuals of schooling species such as adult American shad, which have a tendency to move through the sample area often, are typically observed many times. As a result, apparent counts of shad upstream of the powerhouse were much higher than apparent steelhead counts until about 15 January (Figure 3.2). Adult steelhead were more often observed holding in place or milling, so the chance of multiple counts was reduced. Trends in adult steelhead counts suggest that they were most abundant at the powerhouse through mid-January. Peaks in apparent counts upstream of the TSW differed from those at the powerhouse; a peak occurred in late October and in early February (Figure 3.3).

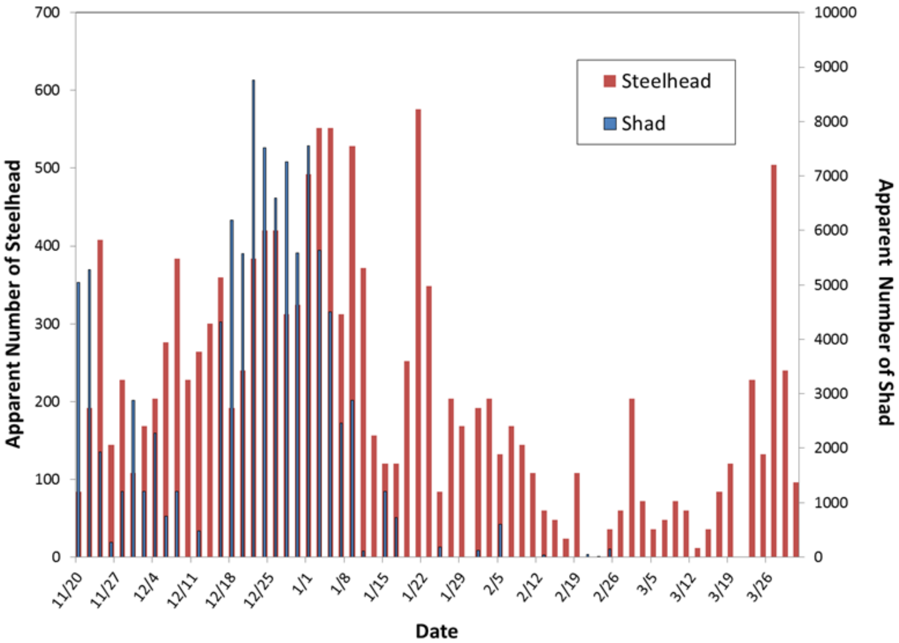

Figure 3.2. Apparent Counts of Fish Observed on Imaging Sonar in the Forebay near Turbine Unit 14, Intake C

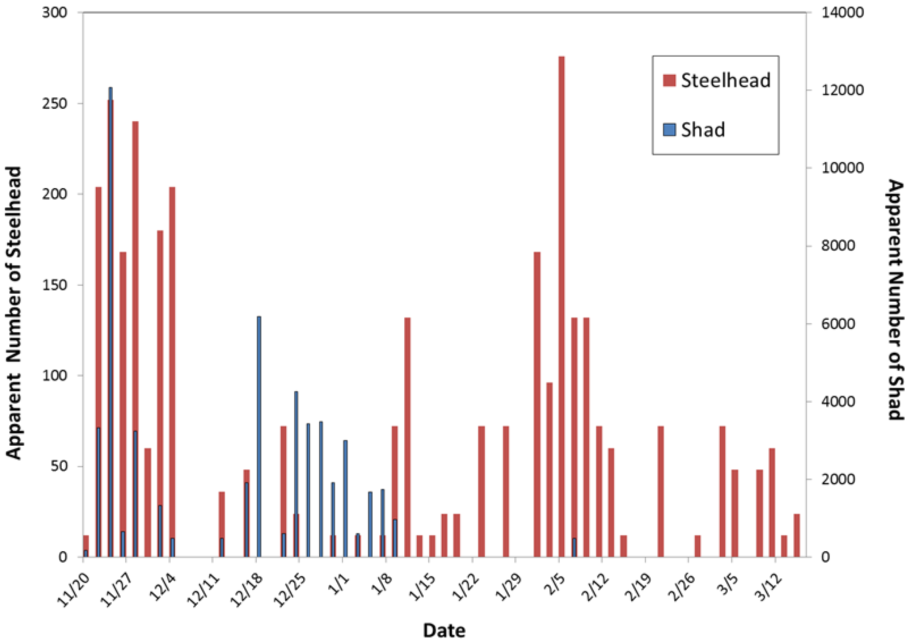

Figure 3.3. Apparent Counts of Fish Observed on Imaging Sonar in the Forebay near the TSW (Spillbay 20)

3.1.3 Dam Operations

The mean hourly discharge of each turbine unit or spillbay was calculated from 5-minute interval dam operations data supplied by the USACE. The mean flow for the experimental period is shown for each route in Figure 3.4. Discharge at all spillbays except 20 (the TSW) would be zero except that forced spill occurred. Turbine Units 4, 9, and 11 were out of service for some or all of the experimental period.

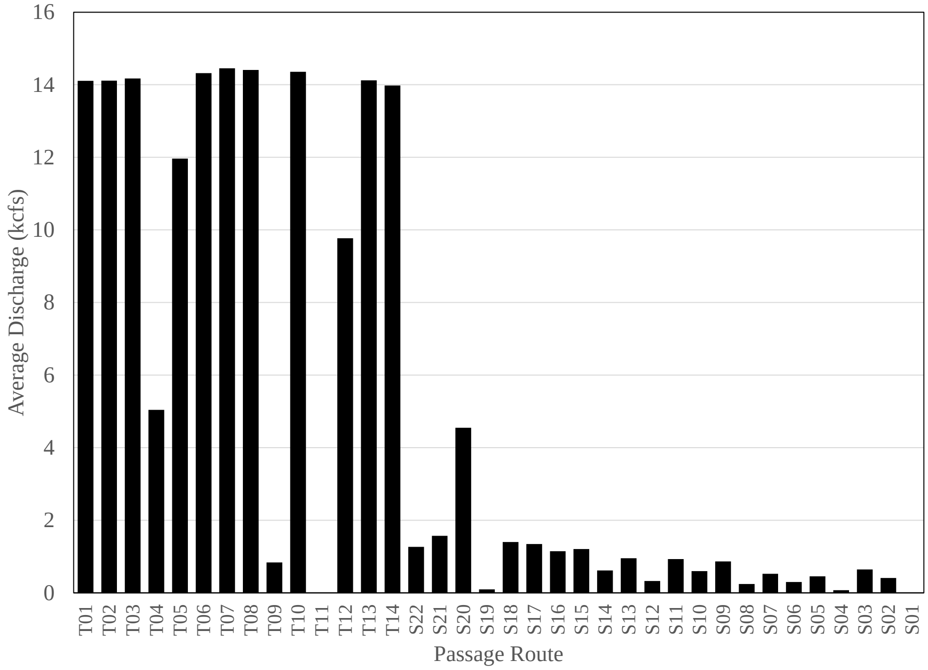

Figure 3.4. Mean Discharge by Location. The TSW is located in spillbay S20.

3.2 Overall Passage

This section describes fish observations, behavior, and adult steelhead passage at the powerhouse and TSW of McNary Dam for the entire study period, without differentiating experimental periods. The intent is to illustrate the rate of adult passage overall. All study days are included.

3.2.1 Imaging Sonar Observations of Fish Behavior and Abundance in the Forebay near Unit 14 and TSW

Adult shad were not observed entering turbine intakes, and their movement patterns suggested they were unlikely to do so. Adult shad were observed near and possibly passing into the TSW when it was in operation. Shad numbers peaked in late November 2014 to early January 2015, but there were no observations starting in mid-January (Figure 3.2 and Figure 3.3).

At Turbine Unit 14, adult steelhead were observed during the entire sample period but peaked from mid-December 2014 through mid-January 2015. Most were observed milling near the pier nose region between intake Slots C and B. Behavioral observations from both the imaging sonar and visual observations from the intake deck suggest that adult steelhead were holding in the forebay for long periods of time (Figure 3.5). It is worth noting that the video from imaging sonar provides a much more compelling differentiation of species because it includes the swimming motions and behaviors that are not captured by the still images as presented in this report. Adult shad were observed from mid-December 2014 through the early part of January 2015. Apparent adult shad numbers were high, in part, because they traveled in large schools in the forebay, and they were counted each time the school passed the imaging sonar while a sample was collected (Figure 3.6). The potential for counting the same individuals multiple times most likely resulted in overestimates of adult shad abundance (Ham et al. 2012). Because adult shad are smaller than adult steelhead of interest, their acoustic target strength is smaller (this is apparent in both their relative size and intensity within the imaging sonar recordings). Post-processing of the fixed-aspect hydroacoustic data removes detections with target strengths smaller than expected for adult steelhead, thereby filtering shad and other fish smaller than adult steelhead from the passage data. A trend of movement to the north (toward the TSW) was not observed at the powerhouse sampling location when the TSW was in operation.

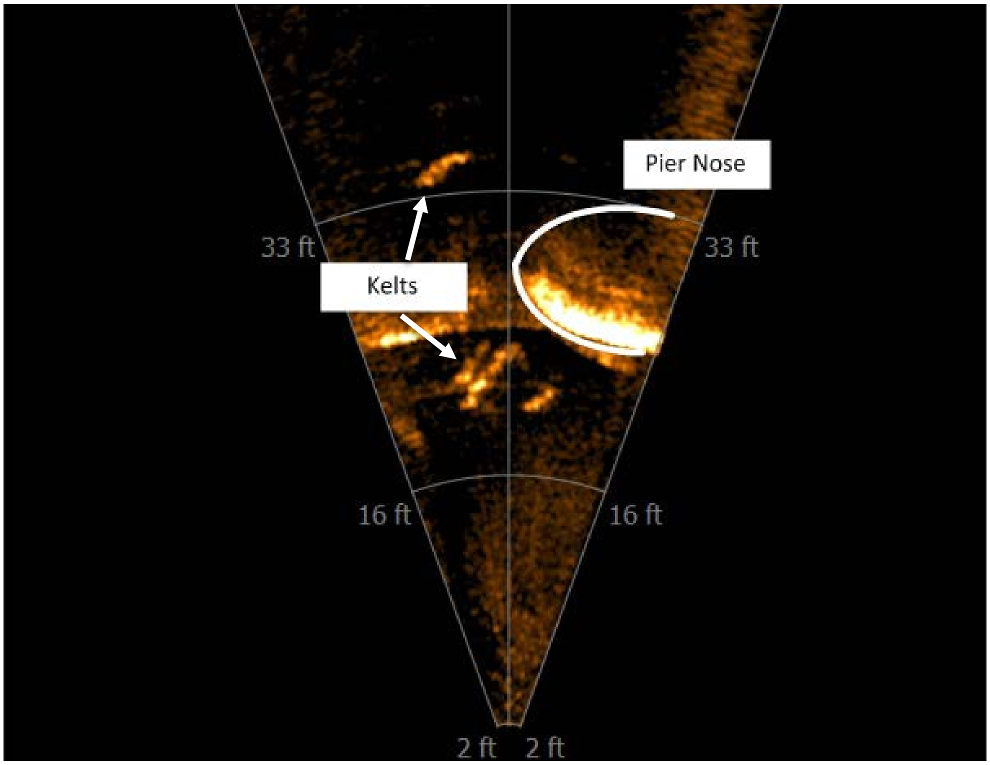

Figure 3.5. Imaging Sonar Field of View Showing Steelhead Milling just Upstream of Turbine Unit 14, Slot C

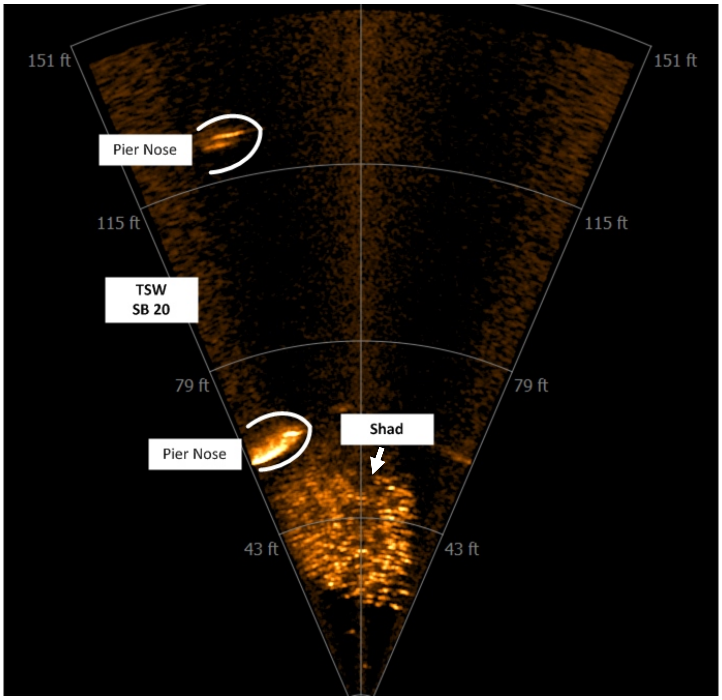

Figure 3.6. Imaging Sonar Field of View Showing Adult Shad Schooling near Spillbay 21 while TSW Was Closed

In contrast to adult shad, adult steelhead were much larger targets and were observed moving much less across the upstream face of the powerhouse; they were usually observed milling or slowly swimming just upstream of the intake and trashracks and near the TSW pier nose between Spillbays 20/21 (Figure 3.7). It was not possible to determine whether individuals were entrained into the TSW due to the position of the sonar in relation to main Pier Nose 20/21, which blocked the imaging sonar's field of view just upstream of the sill of the TSW. During the TSW operation periods we noted that adult steelhead (e.g., in schools of 2–3) were more likely to be observed milling just south of Pier Nose 20/21 (Figure 3.8). When the TSW was not in operation, we observed very little of this behavior.

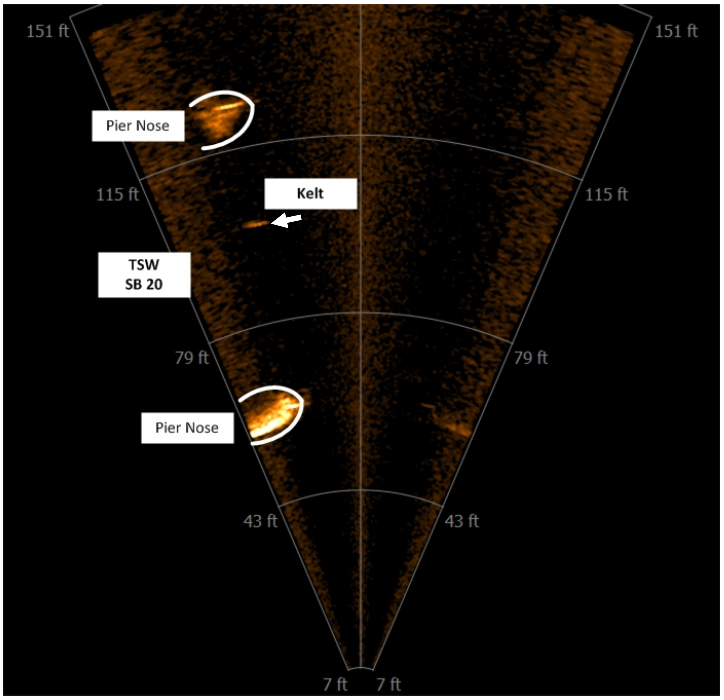

Figure 3.7. Imaging Sonar Field of View Showing Adult Steelhead Prior to Passing Downstream During TSW Operation

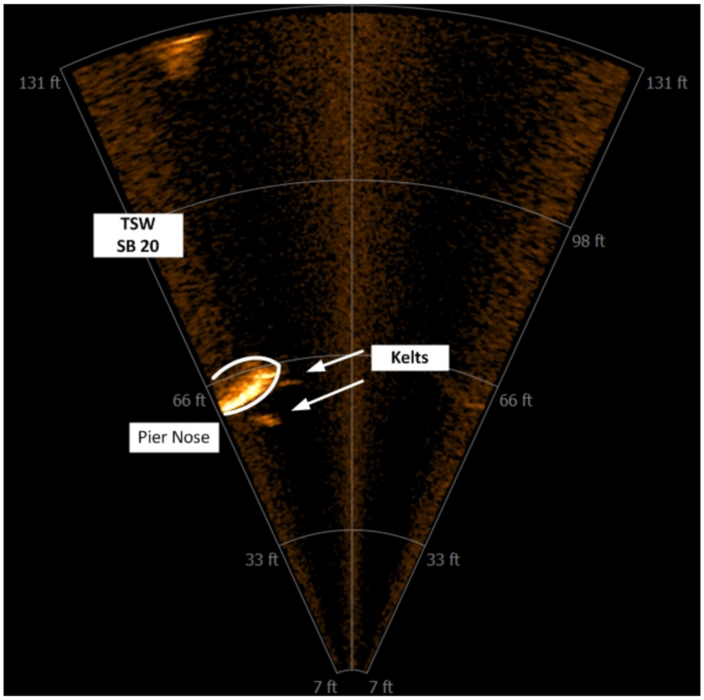

Figure 3.8. Imaging Sonar Field of View Showing Steelhead Milling Behavior near the Pier Nose during TSW Operation

Expanded adult steelhead counts were highest during the winter (Screens_In) experimental period (15 November 2014 through 14 December 2014) for the TSW imaging sonar system with 104.3 per day compared to 24 per day (Table 3.1) for the early spring (Screens_Out) experimental period (15 February

2015–15 March 2015). Average steelhead counts were also high during the winter TSW_Spill blocks compared to No_Spill periods. Average expanded winter counts were over 4 times greater than counts in the spring period at both sampling locations. In both seasons, counts near turbine unit 14 were slightly more than double the counts near the TSW.

Table 3.1. Imaging Sonar Expanded Steelhead Counts for Screens_In and Screens_Out Experimental Periods at the TSW and Turbine Unit 14

	TSW			Turbine Unit 14		
	TSW_Spill	No_Spill	Total	TSW_Spill	No_Spill	Total
Screens_In Total	900	456	1356	1596	1392	2988
Average (#/day)	128.6	88.8	104.3	228.0	232.0	229.8
Sample Days	7	6	13	7	6	13
Screens_Out Total			360			816
Average (#/day)			24			54.4
Sample Days			15			15

3.2.2 Hydroacoustic Estimates of Adult Fish Passage at the Powerhouse and TSW

The typical trend of adult passage at McNary Dam during winter is not well known because most routine sampling programs are suspended during that period. The seasonal trend in hydroacoustic estimates of passage over the TSW during the present study revealed a peak during late November and early December with a patchy distribution of smaller peaks throughout the remainder of the experimental period (Figure 3.9). Powerhouse passage did not exhibit a peak of similar magnitude, but smaller peaks were also distributed throughout the experimental period. Unplanned spill occurred through spillbays other than the TSW beginning in early January, so additional adult passage likely occurred through those unmonitored spill routes that is not represented in the plotted passage estimates.

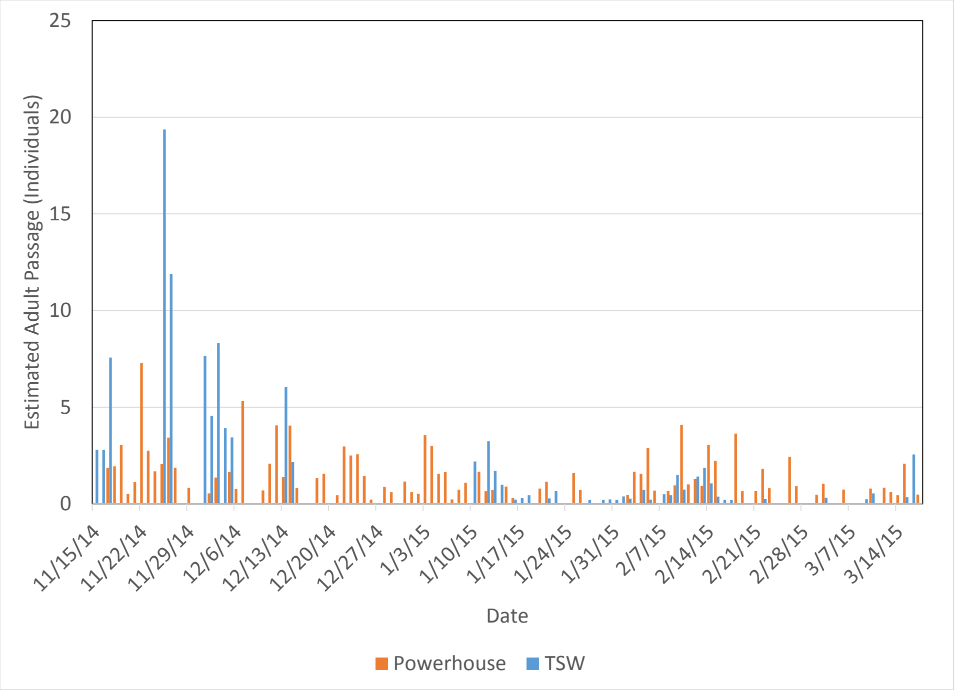

Figure 3.9. Daily Passage at the McNary Dam Powerhouse and TSW. Passage at spillbays other than the TSW spillbay was not monitored.

3.3 TSW Spill Treatment Effects

In the study design, TSW spill (TSW_Spill) was contrasted with no-spill (No_Spill) operations in two distinct experimental periods. Spill through non-TSW spillbays was not included in either treatment. The first experimental period (15 November 2014–14 December 2014) was conducted while the fish guidance screens were in place (Screens_In) to guide adults into the JBS. The second experimental period (15 February 2015–16 March 2014) was conducted after screens were removed and all powerhouse passage was through turbines. Figure 3.10 illustrates that treatment conditions were followed closely during the Screens_In experimental period. During the Screens_Out experimental period, however, high river discharge levels often exceeded powerhouse capacity, forcing the dam to discharge water through non-TSW spillbays. As a result, treatments were rarely implemented as planned during the Screens_Out experimental period and a comparison of the planned treatments was not possible (Figure 3.11).

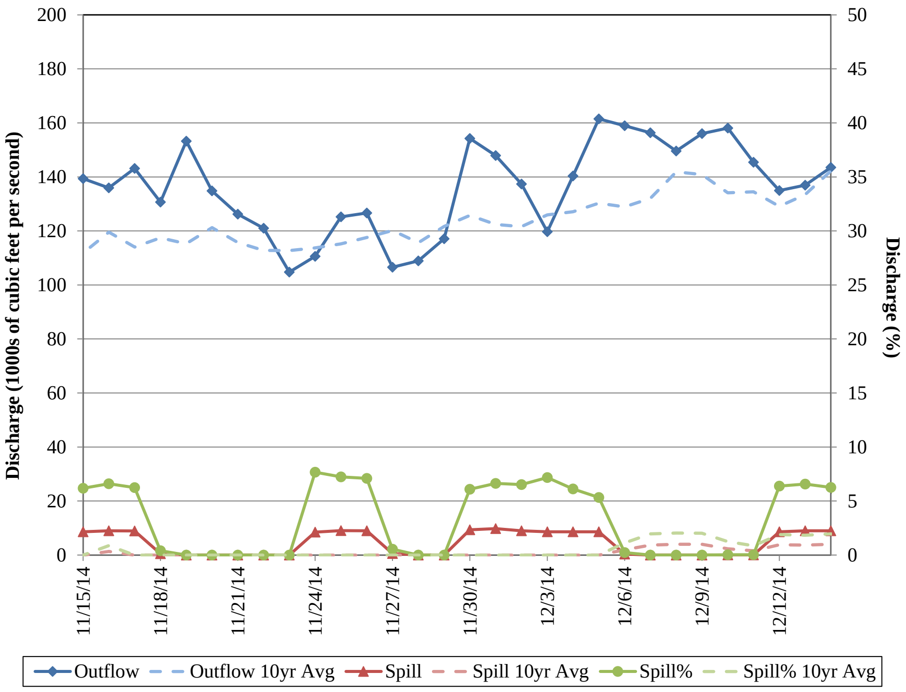

Figure 3.10. Daily Total Discharge and Spill Discharge for the Screens-In Experimental Period (solid lines) and 10-Year Averages (dashed lines). (Source: www.cbr.washington.edu/dart/river.html)

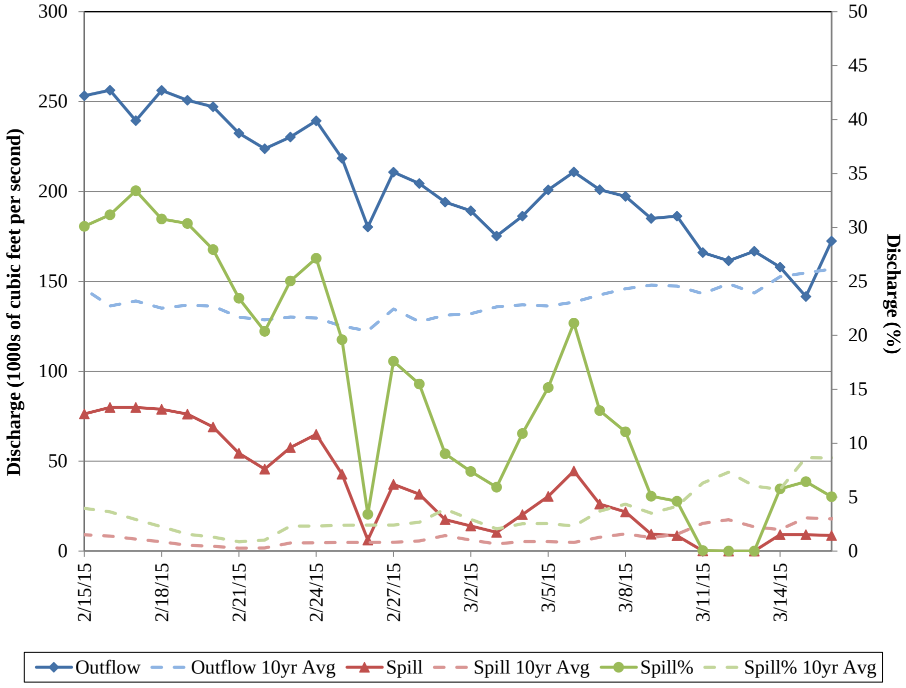

Figure 3.11. Daily Total Discharge and Spill Discharge for the Screens-Out Experimental Period (solid lines) and 10-Year Averages (dashed lines). (Source: www.cbr.washington.edu/dart/river.html)

3.3.1 Among Day Variation in Fish Passage during the Screens_In Experimental Period

Daily variation in fish passage was not the focus of the treatment comparison, but it may be relevant to the operation of TSW spill for adult passage. Figure 3.12 illustrates the daily trends in passage. In spite of considerable variation among days, the trends suggest that TSW passage is low or absent on the first day following opening. This result suggests that fish take some time to pass the TSW once the route opens. The imaging sonar data indicated that adult steelhead were found in the area near the TSW, though they were less frequently observed during the last block (Figure 3.3). Beyond the first day, passage continues throughout the open period (maximum of 6 days continuously open due to randomized treatment scheduling within blocks). During this experimental period, the other, non-TSW, spillbays remained closed, such that no downstream flow was occurring in the vicinity of the TSW unless it was in operation.

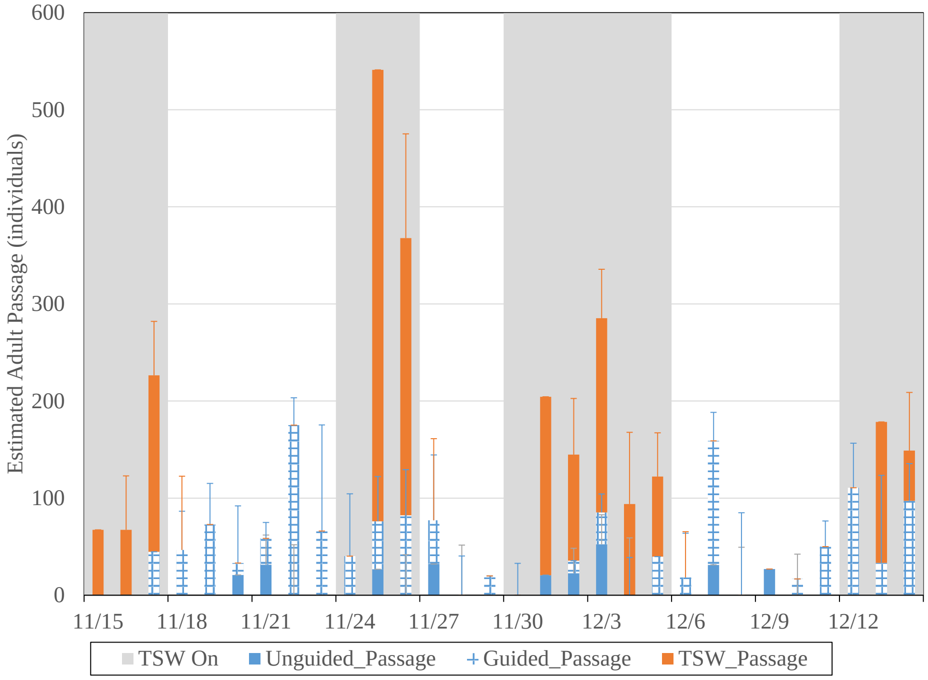

Figure 3.12. Estimated Daily Fish Passage by Route during the Screens-In Experimental Period. Error bars indicate 95% confidence intervals.

3.3.2 Diel Variation in Fish Passage during the Screens_In Experimental Period

Diel variation in passage is also of interest to guide the operations of the TSW for adult passage during the winter. During the Screens_In experimental period, TSW_Spill and No_Spill treatments were tested. Figure 3.13 illustrates the diel trends by route and by treatment (no TSW passage during No_Spill treatment). Passage trends through the 24-hour daily cycle were noisy, in that adjacent hours were often quite different. Powerhouse passage trends throughout the day appeared to be similar among treatments, with the largest peak occurring around dawn. When the TSW was in operation, TSW passage trends also exhibited a peak near dawn, though it was not as obvious because of a high level of variation from hour to hour throughout the day.

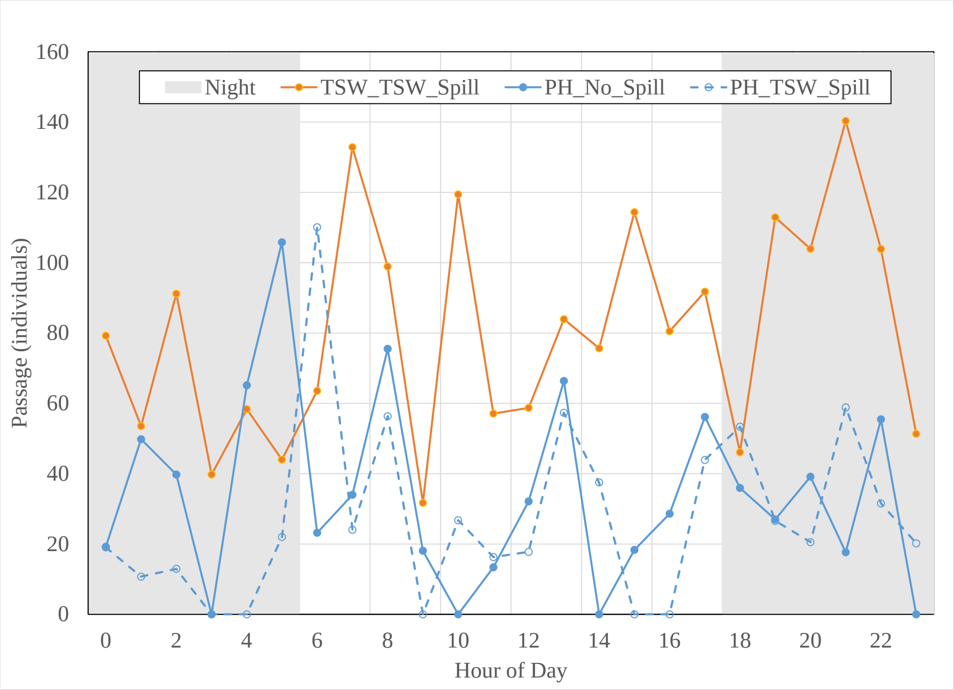

Figure 3.13. Diel Trends in Passage by Treatment during Screens_In Experimental Period. Series represents TSW and powerhouse (PH) passage and treatment (TSW_Spill vs No_Spill) differences.

3.3.3 Among Block Variation in Fish Passage during the Screens_In Experimental Period

Per block estimates of fish passage efficiency (FPE), the proportion of fish passing through non-turbine routes, were consistently higher during TSW_Spill versus No_Spill periods (Figure 3.14). Likewise, powerhouse passage was lower during TSW_Spill for 4 of 5 blocks (Figure 3.15). This trend suggests that individuals that would have passed via the powerhouse are passing via the TSW instead. Trends across blocks in Unguided passage did not reveal a clear treatment difference (Figure 3.16). FGE was often lower during TSW_Spill treatments, but low unguided fish counts in general result in wide confidence bounds (Figure 3.17). The trend in FGE suggests that fish that are likely to pass the TSW would have been more likely to have been guided by guidance screens.

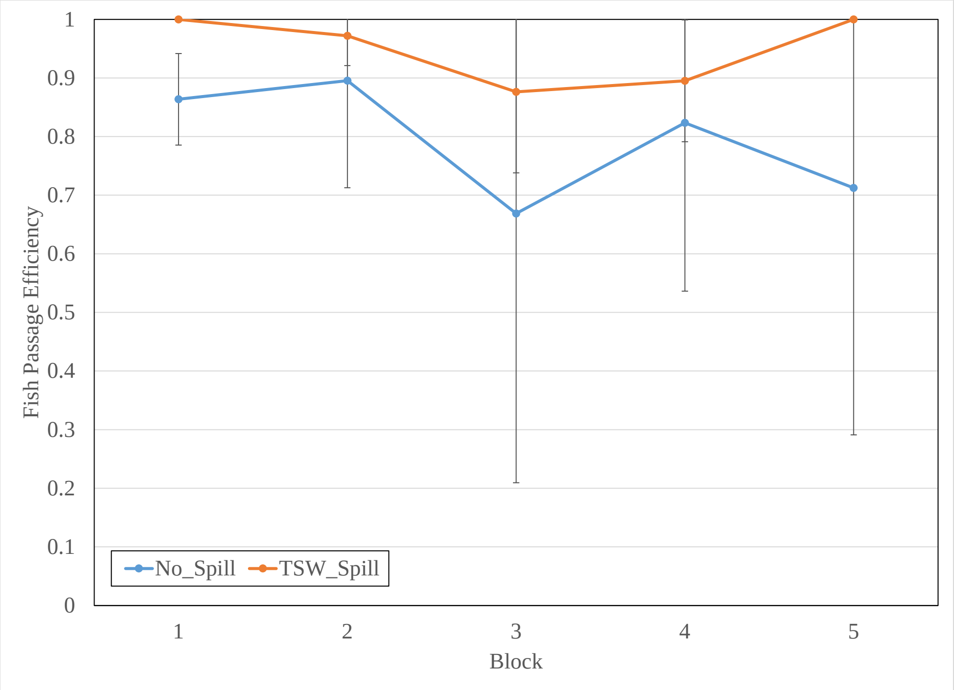

Figure 3.14. Mean Fish Passage Efficiency by Experimental Block. Error bars indicate 95% confidence intervals.

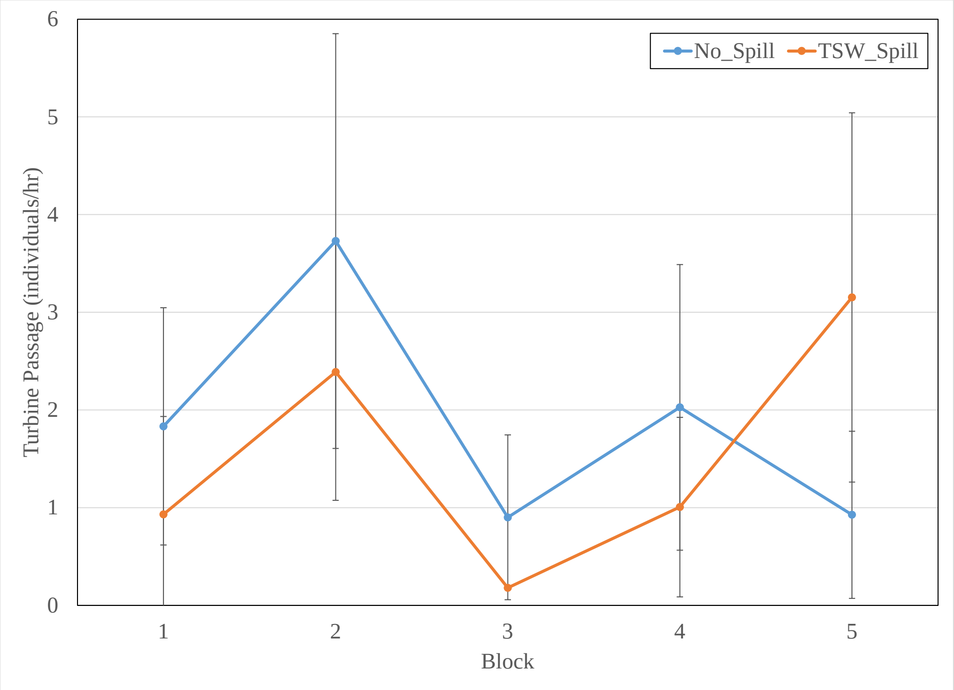

Figure 3.15. Mean Powerhouse Passage by Experimental Block. Error bars indicate 95% confidence intervals.

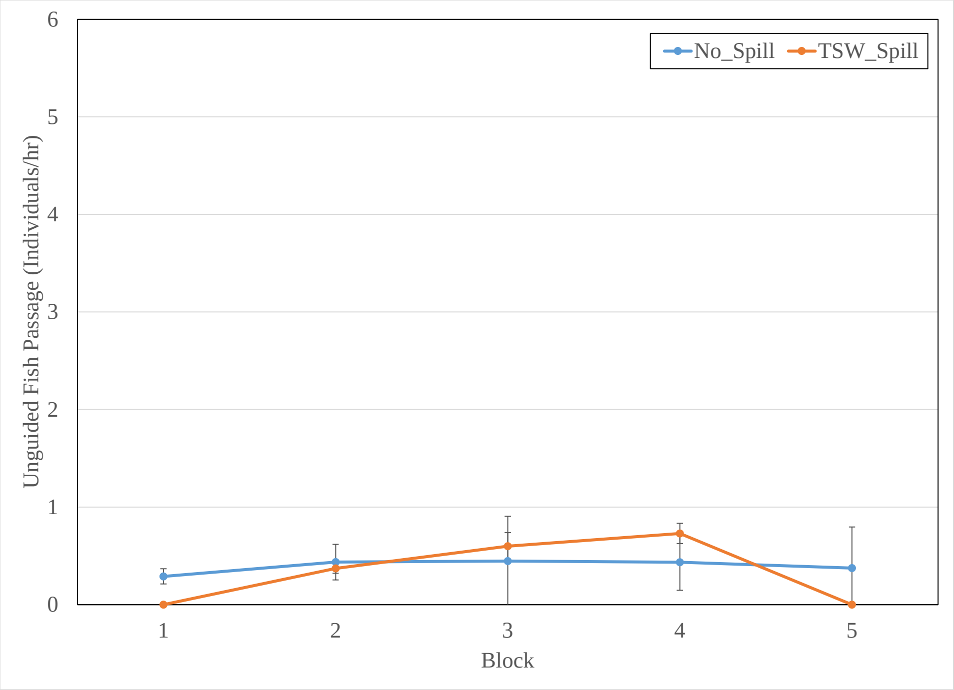

Figure 3.16. Mean Unguided Fish Passage by Experimental Block. Error bars indicate 95% confidence intervals.

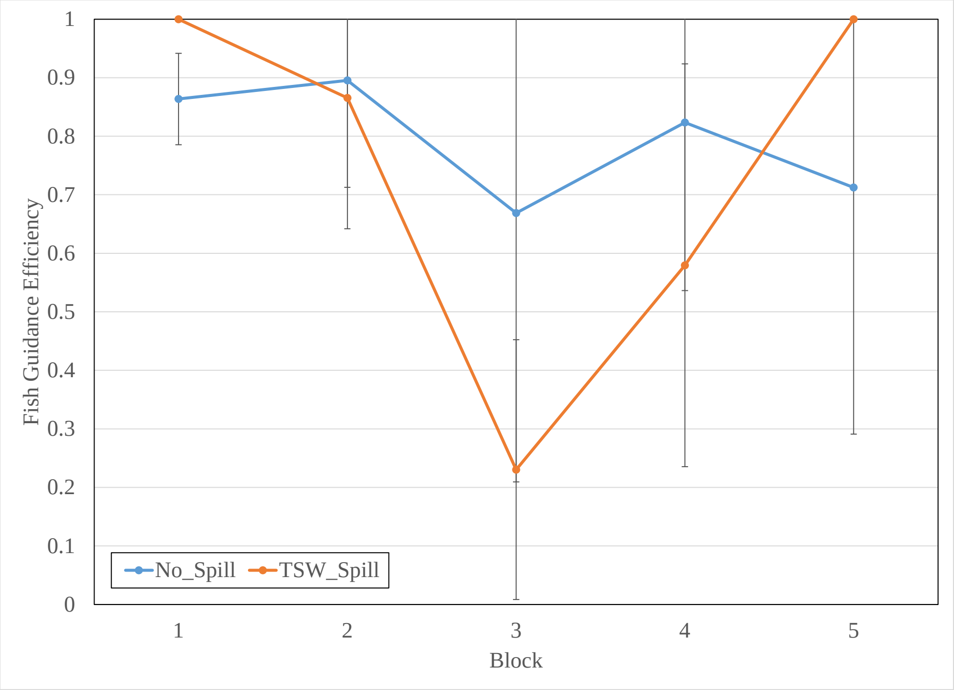

Figure 3.17. Mean Fish Guidance Efficiency by Experimental Block. Error bars indicate 95% confidence intervals.

3.3.4 Comparison of TSW Spill Treatments for the Screens_In Experimental Period

Of the five measures evaluated, only FPE and total passage differed significantly among treatments during the Screens_In experimental period (Table 3.2). During TSW_Spill treatments, only about 5% of fish passing the dam passed through turbines (which is computed by subtracting FPE from 1 and converting to a percentage value) compared to about 20% during No_Spill treatments (Figure 3.18). Guided passage, unguided passage, and FGE were lower during TSW_Spill treatments, but differences were not statistically significant (Figure 3.19, Figure 3.20, and Figure 3.21). Decreasing FGE would normally be seen as a negative for fish survival, but in this case the evidence suggests fish are being drawn away from the powerhouse rather than changing from the guided to the unguided route. Total passage was significantly higher ($p < 0.05$) during TSW_Spill than during No_Spill treatments (Figure 3.22). This suggests that TSW operation increases downstream passage, relative to operating the powerhouse alone.

Table 3.2. ANOVA Results for TSW Treatment Comparisons. Significant P values (<0.05) highlighted in bold.

		df	SS	MS	F	p
Fish Passage Efficiency	Intercept	1	7.580982	7.580982	1792.805	**0.000002**
	Block	4	0.035333	0.008833	2.088952	0.246555
	TSW_Trtmt	1	0.060806	0.060806	14.37985	**0.019234**
	Error	4	0.016914	0.004229		
	Total	9	0.113053			
Fish Guidance Efficiency	Intercept	1	5.835	5.835	138.3907	**0.000299**
	Block	4	0.306006	0.076502	1.814415	0.289028
	TSW_Trtmt	1	0.008317	0.008317	0.197246	0.679922
	Error	4	0.168653	0.042163		
	Total	9	0.482976			
Unguided Passage	Intercept	1	1.355881	1.355881	33.52775	**0.004422**
	Block	4	0.307468	0.076867	1.900737	0.274595
	TSW_Trtmt	1	0.007792	0.007792	0.192679	0.683365
	Error	4	0.161762	0.040441		
	Total	9	0.477022			
Guided Passage	Intercept	1	28.77067	28.77067	23.04543	**0.008645**
	Block	4	7.281905	1.820476	1.45821	0.361819
	TSW_Trtmt	1	0.35094	0.35094	0.281105	0.624045
	Error	4	4.99373	1.248432		
	Total	9	12.62658			
Total Passage	Intercept	1	225.555	225.555	78.11364	**0.000905**
	Block	4	41.27279	10.3182	3.573372	0.122524
	TSW_Trtmt	1	60.98927	60.98927	21.12165	**0.010062**
	Error	4	11.5501	2.887524		
	Total	9	113.8122			

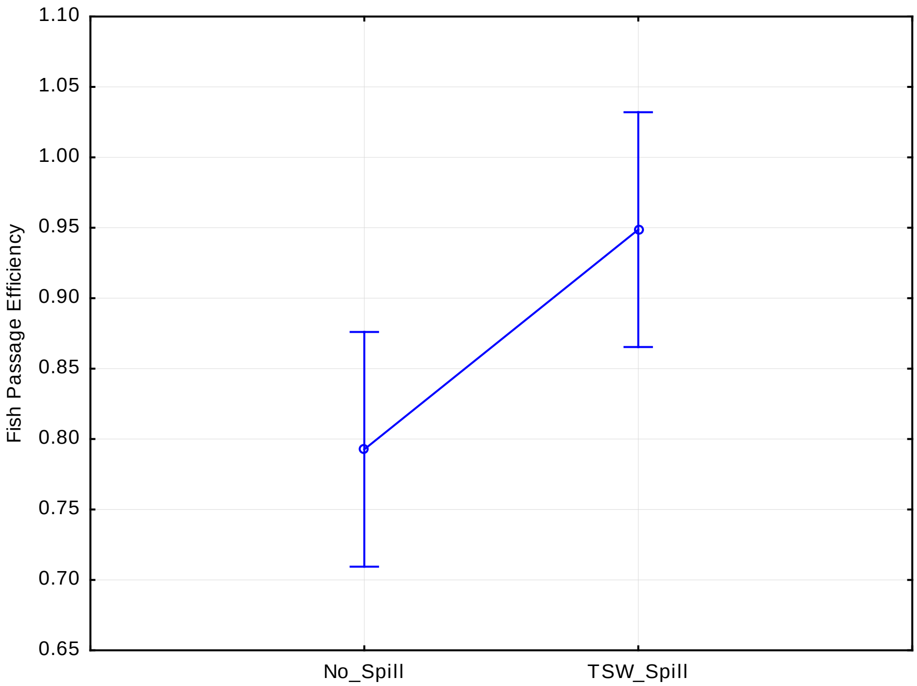

Figure 3.18. Least-Squares Means of Fish Passage Efficiency for the Screens_In Experimental Period

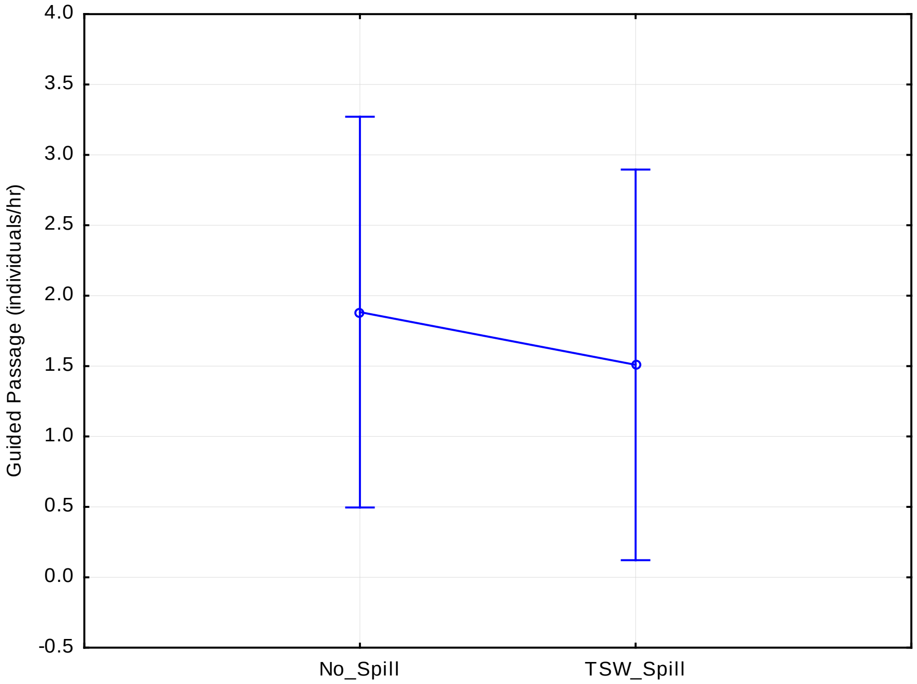

Figure 3.19. Least-Squares Means of Guided Passage for the Screens_In Experimental Period

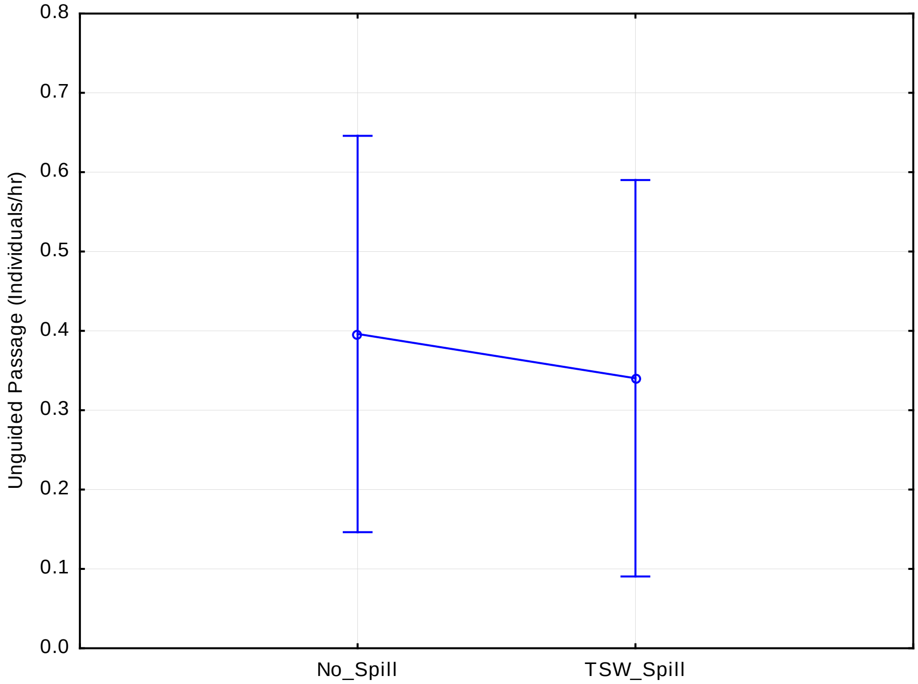

Figure 3.20. Least-Squares Means of Unguided Passage for the Screens_In Experimental Period

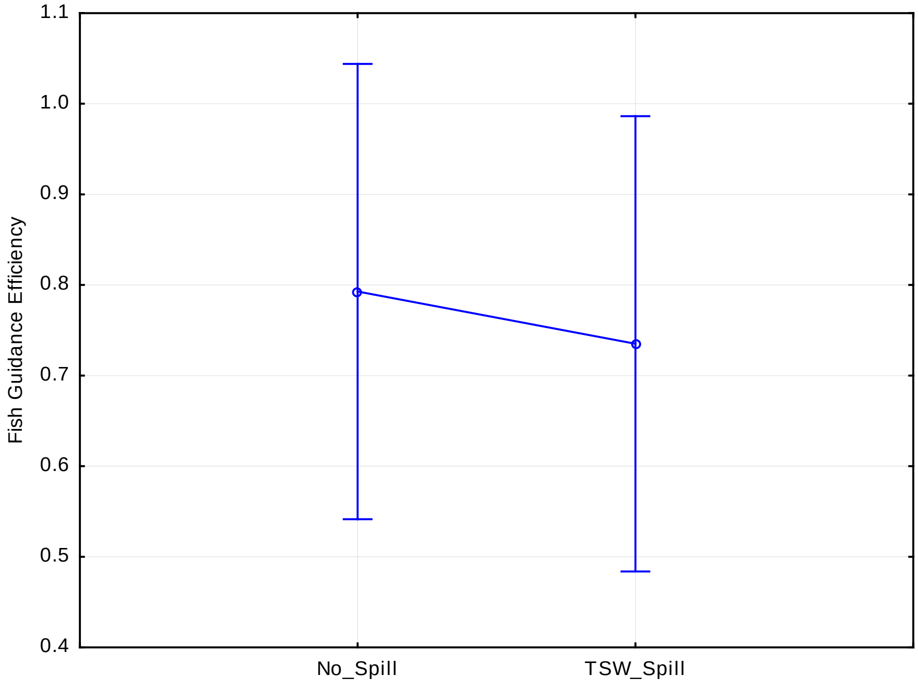

Figure 3.21. Least-Squares Means of Fish Guidance Efficiency for the Screens_In Experimental Period

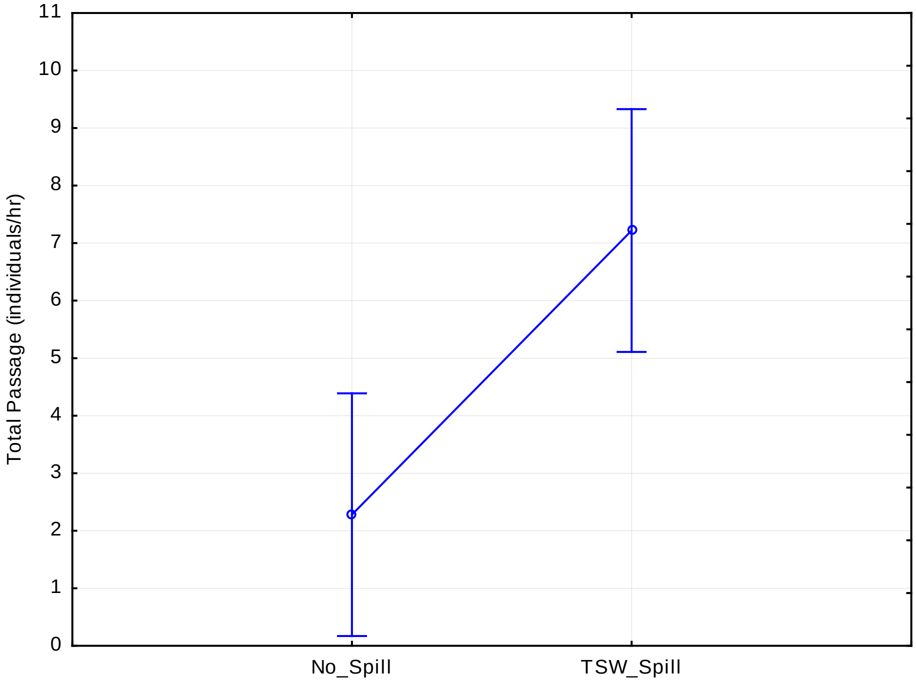

Figure 3.22. Least-Squares Means of Total Passage for the Screens_In Experimental Period

3.3.5 Ad Hoc Evaluation of Adult Passage during TSW and Conventional Spill without Powerhouse Guidance Screens

High river flows during the latter portion of the study prevented TSW treatment operations from being implemented as intended during the Screens_Out experimental period. The TSW was operated during that experimental period as well as during unplanned occurences of spill outside of the experimental period. Additional spill through unmodified bays was common, and passage through those routes was not sampled. To take advantage of the data collected when screens were not in place, but treatment conditions could not be maintained, we pursued an ad hoc analysis approach. To begin, we examined correlations among discharge and passage while the TSW was in operation (Table 3.3). Turbine passage was significantly correlated ($p < 0.05$) with total flow, and nearly so ($0.05 < p < 0.10$) with spill proportion, but not with TSW proportion. The positive slope indicates that turbine passage increased with total flow (and also with spill proportion, which is closely related to total flow when forced spill conditions arise). No significant or nearly significant correlations were found between TSW passage and any of these flow measures. Turbine passage and TSW passage were not significantly correlated.

Table 3.3. Correlations among Passage and Flow Metrics with the TSW Operating. Significant P values (<0.05) are highlighted in bold.

X	Y	r^2	t	p	N	Constant	Slope
Total Flow	Turbine Passage	0.098897	2.197504	**0.033293**	46	-32.4597	0.252
	TSW Passage	0.000198	0.093358	0.926043	46	11.0258	0.009
Spill Proportion	Turbine Passage	0.063016	1.720220	0.092419	46	8.8469	62.298
	TSW Passage	0.001756	0.278173	0.782183	46	11.5412	8.241
TSW Proportion	Turbine Passage	0.010223	-0.674133	0.503753	46	34.2616	-356.071
	TSW Passage	0.003881	0.414028	0.680865	46	5.2177	173.882
TSW Passage	Turbine Passage	0.000691	0.174462	0.862303	46	18.2294	0.033

Figure 3.23 illustrates the correlation between turbine passage and total flow. In spite of the statistical significance of the correlation, the r^2 value is quite low at 0.099, reflecting a great deal of scatter around the linear trend. Although there is much scatter, the suggestion that increasing total flow is associated with increasing turbine passage is not unreasonable. The relationship of turbine passage and spill proportion was even less significant, with a similar level of scatter around the trend (Figure 3.24). In studies that monitored all passage routes, increasing spill proportions have been associated with reduced powerhouse passage proportions (Harnish et al. 2015). The present study did not sample spillway passage (other than at the TSW), but if increasing spill proportion tends to decrease the proportion of fish passing through a powerhouse, and increasing total flows (in this instance highly correlated with spill proportion) result in greater turbine passage, we would speculate that higher total flow and spill would be associated with an increase in total passage (spill + TSW + powerhouse).

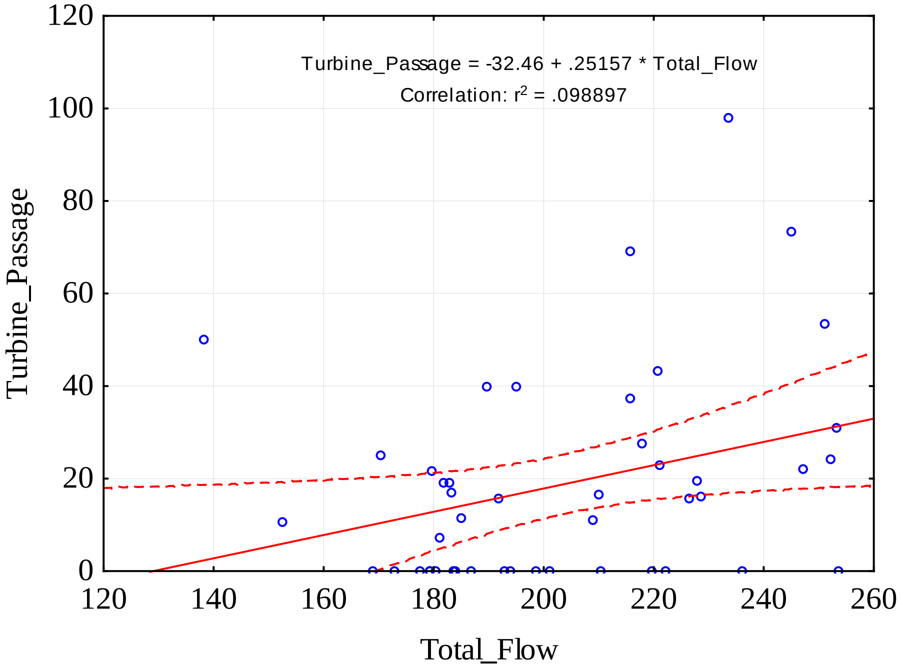

Figure 3.23. Linear Trend in Daily Turbine Passage Estimates across the Range of Total Flow with the TSW in Operation. 95% confidence bounds are illustrated with dashed lines.

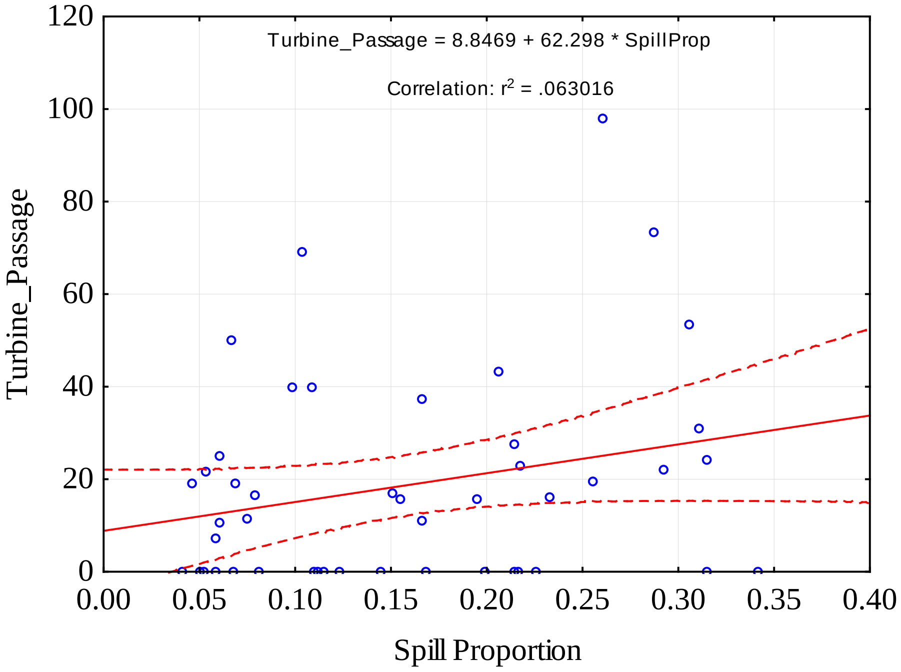

Figure 3.24. Linear Trend in Daily Turbine Passage Estimates across the Range of Spill Proportion with the TSW in Operation. 95% confidence bounds are illustrated with dashed lines.

4.0 Conclusions

During the Screens_In experimental period, a statistically significant difference was found among treatments for FPE (the proportion of fish passing non-turbine routes) and for total passage. TSW operation resulted in fewer adults passing via turbines and more fish passing the dam overall. Other passage trends were suggestive of fish being drawn away from guided passage by TSW operation, though none of those trends led to a statistically significant difference among treatments. The increase in downstream passage during TSW_Spill treatments suggests that a number of fish upstream of McNary Dam were not passing the dam during No_Spill treatments.

The ad hoc analysis of trends when guidance screens were not in place revealed only limited information about the relationship between operations and passage. Turbine passage increased significantly with increasing total flow and nearly significantly with total spill. Although there was much scatter around those trends, it is interesting to speculate about the implications for total passage. The present study did not sample spillway passage (other than at the TSW), but if increasing spill proportion tends to decrease the proportion of fish passing through a powerhouse (Harnish et al. 2015), and because increasing total flows (in this instance highly correlated with spill proportion) resulted in greater turbine passage in the present study, extrapolating both trends would result in an increase in total passage (spill + TSW + powerhouse) as flow and spill increased. The information supporting that speculation is limited, but is consistent with the increase in downstream passage with increasing flow and spill that was found during the Screens_In experimental period, during which all available routes were monitored for passage and treatment conditions were well controlled.

Monitoring results during the Screens_In experimental period and a combination of monitoring results and speculation for the remaining sampling period both suggest that more adult steelhead passed the powerhouse as flows increased, in spite of TSW or conventional spill. The proportion of total individuals that passed through turbines was found to decrease during the TSW_Spill treatment in the Screens_In experimental period, although the absolute rate of turbine passage increased.

Hydroacoustic monitoring does not identify individuals, so it is not possible to link passage with the expected destination of those fish. If they have overshot their intended spawning grounds, or are kelts returning to the ocean after spawning, then downstream passage is a beneficial step in that journey. If an individual heading to spawning grounds upstream of McNary Dam passes downstream, then it could prove to be a disadvantage by increasing the energetic cost of migration or the opportunity for injury. Evaluating those possibilities by tagging individuals is an attractive possibility, but the logistics of such a study and its potential to affect the fish under study are obstacles that have yet to be overcome.

5.0 References

Anglea SM, MA Simmons, CS Simmons, KD Ham, GE Johnson, EA Kudera, and JR Skalski. 2003. *Hydroacoustic Evaluation of the Removable Spillway Weir at Lower Granite Dam in 2002*. PNWD-3219, prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington (under Contract DACW68-02-D-0001), by Battelle, Pacific Northwest Division Richland, Washington,

Axel GA, EE Hockersmith, DA Ogden, BJ Burke, KE Frick, and BP Sandford. 2007. *Passage Behavior and Survival for Radio-Tagged Yearling Chinook Salmon and Steelhead at Ice Harbor Dam, 2005*. Prepared by National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington, for the U.S. Army Corps of Engineers Walla Walla District, Walla Walla, Washington (under Contract W68SBV92844866).

Endangered Species Act of 1973. 16 USC 1531 et seq.

Evans, SD, LS Wright, RE Reagan, NS Adams, and DW Rondorf. 2005. *Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam, 2004*. Report of U.S. Geological Survey (Contract W66QKZ40238289) to U.S. Army Corps of Engineers, Portland, Oregon.

Ham KD, PS Titzler, SP Reese, and RA Moursund. 2007. *Hydroacoustic Evaluation of Fish Passage Distribution at the Ice Harbor Removable Spillway Weir, 2006*. PNWD-3862, prepared for for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington (Contract DACW68-020D-0001), by Battelle—Pacific Northwest Division, Richland, Washington,

Ham KD, PS Titzler, RP Mueller, and DM Trott. 2012. *Hydroacoustic Evaluation of Adult Steelhead Fallback and Kelt Passage at McNary Dam, Winter 2010-2011*. PNWD-4154, final report submitted to the U.S. Army Corps of Engineers, Walla Walla District, by Pacific Northwest National Laboratory, Richland, Washington.

Harnish RA, AH Colotelo, X Li, T Fu, KD Ham, ZD Deng, and E Green. 2015. *Factors Affecting Route Selection and Survival of Steelhead Kelts at Snake River Dams in 2012 and 2013*. PNNL-24207, final report submitted to the U.S. Army Corps of Engineers, Walla Walla District, by Pacific Northwest National Laboratory, Richland, Washington.

Johnson GE, F Khan, JR Skalski, CI Rakowski, MC Richmond, and JA Serkowski. 2007. *Hydroacoustic Evaluation of Juvenile Salmonid Passage at the Dalles Dam Spillway, 2006*. Prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Khan F, IM. Royer , GE. Johnson and SC Tackley. 2013. *Sluiceway Operations for Adult Steelhead Downstream Passage at The Dalles Dam, Columbia River, USA*. North American Journal of Fisheries Management, 33:5, 1013-1023, DOI: 10.1080/02755947.2013.793629

Moursund RA, KD Ham, and PS Titzler. 2007. *Effects of Turbine Loading on Fish Guidance Efficiency, Gap Loss, and Debris Performance of Prototype Vertical Barrier Screens at McNary Dam in 2005*. PNWD-3704, Battelle—Pacific Northwest Division, Richland, Washington.

Ogden DA, EE Hockersmith, GA Axel, BJ Burke, K Frick, and BP Sandford. 2007. *Passage Behavior and Survival for River-Run Subyearling Chinook Salmon at Ice Harbor Dam, 2005*. Prepared by National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington, for the U.S. Army Corps of Engineers Walla Walla District, Walla Walla, Washington (Contract W68SBV92844866).

Ploskey GR, MA Weiland, SA Zimmerman, JS Hughes, K Bouchard, ES Fisher, CR Schilt, ME Hanks, J Kim, JR Skalski, J Hedgepeth, and WT Nagy. 2006. *Hydroacoustic Evaluation of Fish Passage through Bonneville Dam in 2005*. Prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington (under Contract DE-AC05-76RLO1830), by Pacific Northwest National Laboratory, Richland, Washington.

Plumb JM, AC Braatz, JN Lucchesi, SD Fielding, AD Cochran, TK Nation, JM Sprando, JL Schei, RW Perry, NS Adams, and DW Rondorf. 2004. *Behavior and Survival of Radio-Tagged Juvenile Salmon and Steelhead Relative to the Performance of a Removable Spillway Weir at Lower Granite Dam, 2003*. Prepared by the U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington (under Contract W68SBV00104592).

Plumb JM, AC Braatz, JN Lucchesi, SD Fielding, JM Sprando, GT George, NS Adams, and D Rondorf. 2003. *Behavior of Radio-Tagged Juvenile Chinook Salmon and Steelhead and Performance of a Removable Spillway Weir at Lower Granite Dam, Washington, 2002*. Prepared by the U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington (under Contract W68SBV00104592).

USACE (U.S. Army Corps of Engineers). 2014. *2014 Fish Passage Plan: Corps of Engineers Projects. U.S. Army Corps of Engineers Northwest Division, Portland, Oregon*. Available from U.S. Army Corps of Engineers Northwest Division, Columbia Basin Water Management Division, Portland, Oregon (http://www.nwd-wc.usace.army.mil/tmt/documents/fpp/2014/final/FPP14_Complete.pdf).

USACE (U.S. Army Corps of Engineers). 2015. *2015 Fish Passage Plan: Corps of Engineers Projects. U.S. Army Corps of Engineers Northwest Division, Portland, Oregon*. Available from U.S. Army Corps of Engineers Northwest Division, Columbia Basin Water Management Division, Portland, Oregon (http://www.nwd-wc.usace.army.mil/tmt/documents/fpp/2015/final/FPP15_Final_081315.pdf).

Appendix A

Equipment Configuration and Settings

Appendix A

Equipment Configuration and Settings

Tables A.1 and A.2, respectively, list configurations and settings for the sampling equipment.

Table A.1. Configurations of Sounder Systems Including Multiplexers, Transducers, and Cables, Including Locations and Sampling Rates

Description		S/N	Beam Width	System Channel	Location	Cable Length_S/N	Aiming Angle	Xducer El. (ft)	Pings/ Second
System A	SPB Sounder	26							21
	Remote Multiplexer	11				470_133			
	SPB Xducer 1	485	6°	0	1C_Guided	300_141	31° d/s of vertical	239	
	SPB Xducer 2	486	6°	1	2B_Guided	268_154	31° d/s of vertical	239	
	SPB Xducer 3	453	6°	2	3A_Guided	313_137	31° d/s of vertical	239	
System B	SPB Sounder	25							21
	Remote Multiplexer	28				470_104			
	SPB Xducer 1	466	6°	0	10B_Guided	243_182	31° d/s of vertical	239	
	SPB Xducer 2	461	6°	2	10B_Unguided	313_158	24° u/s of vertical	270	
System C	SPB Sounder	12							21
	Remote Multiplexer	22				235_184			
	SPB Xducer 1	470	6°	0	5A_Guided	285_155	31° d/s of vertical	239	
	SPB Xducer 2	462	6°	2	6C_Guided	313_138	31° d/s of vertical	239	
System D	SPB Sounder	19							21
	Remote Multiplexer	29				470_140			
	SPB Xducer 1	492	6°	0	1C_Unguided	313_197	24° u/s of vertical	270	
	SPB Xducer 2	493	6°	1	2B_Unguided	313_205	24° u/s of vertical	270	
	SPB Xducer 3	460	6°	2	3A_Unguided	313_196	24° u/s of vertical	270	
System E	SPB Sounder	18							21
	Remote Multiplexer	15				235_156			
	SPB Xducer 1	423	6°	0	7B_Guided	235_198	31° d/s of vertical	239	
	SPB Xducer 2	452	6°	1	8C_Guided	313_179	31° d/s of vertical	239	
System F	SPB Sounder	13							21
	Remote Multiplexer	25				235_177			
	SPB Xducer 1	411	6°	2	5A_Unguided	235_56	24° u/s of vertical	270	
	SPB Xducer 2	442	6°	3	6C_Unguided	235_204	24° u/s of vertical	270	
System H	SPB Sounder	11							16
	Remote Multiplexer	24				470_89			
	SPB Xducer 1	472	10°	0	TSW_North	220_111	10° d/s of vertical		
	SPB Xducer 2	477	10°	1	TSW_Mid	215_41	10° d/s of vertical		
	SPB Xducer 3	404	10°	2	TSW_South	157_86	10° d/s of vertical		

Table A.1. (contd)

Description		S/N	Beam Width	System Channel	Location	Cable Length_S/N	Aiming Angle	Xducer El. (ft)	Pings/ Second
System I	SPB Sounder	20							21
	Remote Multiplexer	23				235_139			
	SPB Xducer 1	494	6°	0	14A_Unguided	203_163	24° u/s of vertical	270	
	SPB Xducer 2	434	6°	1	13A_Unguided	235_76	24° u/s of vertical	270	
System J	SPB Sounder	50							21
	Remote Multiplexer	12				235_132			
	SPB Xducer 1	438	6°	0	13A_Guided	280_148	31° d/s of vertical	239	
	SPB Xducer 2	475	6°	2	14A_Guided	313_171	31° d/s of vertical	239	
System K	SPB Sounder	53							21
	Remote Multiplexer	14				470_146			
	SPB Xducer 1	491	6°	0	7B_Unguided	250_199	24° u/s of vertical	270	
	SPB Xducer 2	467	6°	1	8C_Unguided	210_78	24° u/s of vertical	270	

Table A.2. Operating Settings for Sounder Systems by Transducer

Static Transmit Power	Installed System	Channel	Location	Sounder Number	Transducer Serial No.	Receiver Gain (L) (db)	Source Level (SL) (db)	Receiver Sensitivity (db)	Target Strength of Smallest On-Axis Target (db)	Voltage of Smallest On-Axis Target at 20 db per Volt (V)	Target Strength of Largest On-axis Target of Interest (db)	Voltage of Largest On-Axis Target at 20 db per Volt (V)
-4	A	0	1C	26	485	6.75	215.06	-105.81	-56	3.0	-26	-4.5
-4	A	1	2B	26	486	6.50	214.62	-105.12	-56	3.0	-26	-4.5
-4	A	2	3A	26	453	7.00	214.68	-105.68	-56	3.0	-26	-4.5
-4	B	0	10B	25	466	6.00	215.02	-105.02	-56	3.0	-26	-4.5
-4	B	1	10B	25	463	8.50	214.59	-107.09	-56	3.0	-26	-4.5
-4	C	0	5A	12	470	6.75	215.56	-106.31	-56	3.0	-26	-4.5
-4	C	1	6C	12	471	6.50	216.07	-106.57	-56	3.0	-26	-4.5
-4	D	0	1C	19	492	8.00	215.61	-107.61	-56	3.0	-26	-4.5
-4	D	1	2B	19	493	8.00	215.34	-107.34	-56	3.0	-26	-4.5
-4	D	2	3A	19	460	7.50	215.88	-107.38	-56	3.0	-26	-4.5
-4	E	0	7B	18	423	5.50	216.29	-105.79	-56	3.0	-26	-4.5
-4	E	1	8C	18	452	5.75	216.34	-106.09	-56	3.0	-26	-4.5
-4	F	2	5A	13	411	8.25	214.69	-106.94	-56	3.0	-26	-4.5
-4	F	3	6C	13	442	5.00	216.38	-105.38	-56	3.0	-26	-4.5
-4	H	0	TSW	11	472	4.76	212.73	-111.49	-56	3.0	-26	-4.5
-4	H	1	TSW	11	477	4.25	212.72	-110.97	-56	3.0	-26	-4.5
-4	H	2	TSW	11	404	5.25	212.88	-112.13	-56	3.0	-26	-4.5
-4	I	0	14A	20	494	5.25	215.49	-104.74	-56	3.0	-26	-4.5
-4	I	1	13A	20	434	5.75	215.01	-104.76	-56	3.0	-26	-4.5
-4	J	1	13A	50	447	3.75	216.89	-104.64	-56	3.0	-26	-4.5
-4	J	2	14A	50	475	3.00	216.96	-103.96	-56	3.0	-26	-4.5
-4	K	0	7B	53	491	3.25	217.31	-104.56	-56	3.0	-26	-4.5
-4	K	1	8C	53	467	2.75	217.07	-103.82	-56	3.0	-26	-4.5

Appendix B

Raw Data

Appendix B

Raw Data

Raw data for passage, dam operations, and covariates are included in the attached file, “PNNL_24856_MCN_Winter_TSW_Passage_2014_2015_Appendix_B_Raw_Data.csv.” The attached file, “PNNL_24856_MCN_Winter_TSW_Passage_2014_2015_Appendix_B_Raw_Data.csv,” contains metadata describing the data fields in the raw data file.

Appendix C

Effective Beam Widths

Appendix C

Effective Beam Widths

The effective beam width is estimated with a detectability model. Inputs to this model include fish speeds and trajectories as well as the sensitivity and beam pattern of each transducer. These inputs come from split-beam data of actual fish paths and from the equipment performance testing process, respectively. The output forms the basis for expanding the fish counts. Nominal beamwidths were 6 degrees for guided and unguided deployments and 10 degrees for TSW deployments. As shown below, the effective beam width varies by range and among deployment types. Because this study focuses on adult salmon, which are fewer in number than is typical for a juvenile study, we chose to combine detectability inputs across all transducers within a deployment to ensure we could reliably model the differences. Figure C.1 shows the mean effective beam widths by deployment type.

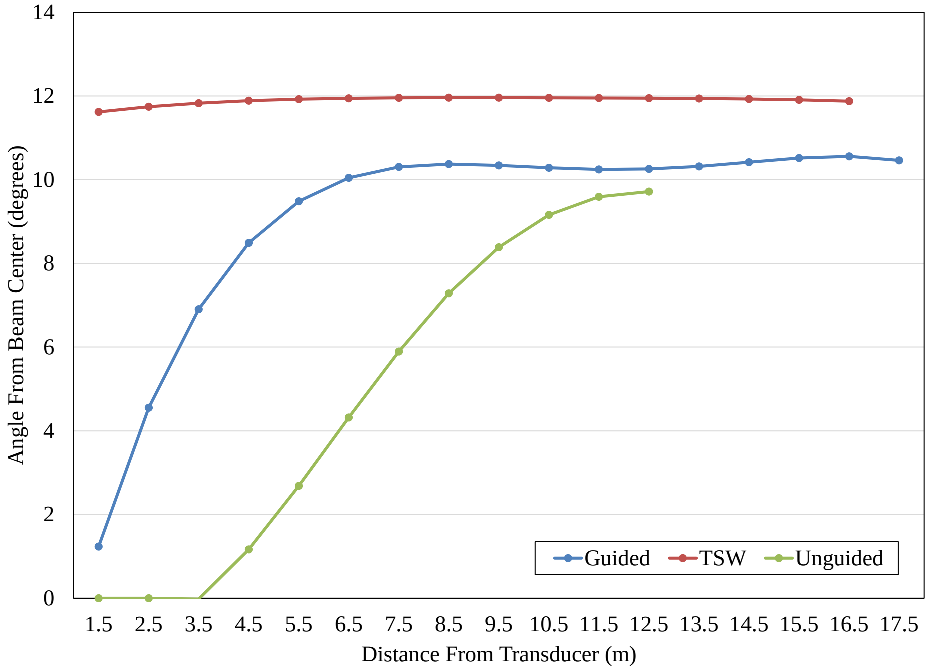

Figure C.1. Mean Effective Beam Widths for Guided Deployments by Operational Treatment, Season, and Diel Period

Appendix D

Statistical Methods

Appendix D

Statistical Methods

The purpose of this synopsis is to describe the statistical methods used in the analysis of the 2014–2015 hydroacoustic study of adult steelhead passage during winter operation of the temporary spillway weir (TSW). The study estimated passage through the powerhouse and TSW (Spillbay 20), including fish guidance efficiency during a portion of the study when guidance screens were in place.

D.1 Estimating Fish Passage

When a fish passes through the beam of a hydroacoustic sensor, echoes are recorded to indicate when and where the fish passed through the beam. The echoes are processed into tracks that are processed to quantify the number of fish passing through a given route. Tracks are filtered to include only tracks consistent with juvenile fish passing via the route of interest. The following sections describe the processing steps required to convert filtered track counts into estimates of smolt passage.

D.1.1 Estimating Unguided Passage

The estimator of unguided passage at the single turbine unit is as follows:

$$\hat{U} = \sum_{i=1}^{3}\sum_{j=1}^{D}\sum_{k=1}^{24}\left[\frac{B_{ijk}}{b_{ijk}}\sum_{g=1}^{b_{ijk}} z_{ijkg}\right], \qquad (.1)$$

where

z_{ijkg} = expanded fish count in the *g*th sampling unit $(g = 1, \ldots, b_{jkl})$ in the *k*th hour $(k = 1, \ldots, 24)$ of the *j*th day $(j = 1, \ldots, D)$ at the *i*th intake slot $(i = 1, \ldots, 3)$;

b_{ijk} = number of sampling units monitored in the *k*th hour $(k = 1, \ldots, 24)$ of the *j*th day $(j = 1, \ldots, D)$ at the *i*th intake slot $(i = 1, \ldots, 3)$;

B_{ijk} = total number of possible sampling intervals in the *k*th hour $(k = 1, \ldots, 24)$ of the *j*th day $(j = 1, \ldots, D)$ at the *i*th intake slot $(i = 1, \ldots, 3)$.

The variance of $\hat{U}$ can be estimated by

$$\widehat{\text{Var}}\left(\hat{U}\right) = \sum_{i=1}^{3}\sum_{j=1}^{D}\sum_{k=1}^{24}\left[\frac{B_{ijk}^{2}\left(1-\dfrac{b_{ijk}}{B_{ijk}}\right)s_{z_{ijk}}^{2}}{b_{ijk}}\right], \qquad (.2)$$

where

$$s_{z_{ijk}}^2 = \frac{\sum_{g=1}^{b_{ijk}} \left(z_{ijkl} - \overline{z}_{ijk} \right)^2}{\left(b_{ijk} - 1 \right)},$$

$$\overline{z}_{ijk} = \frac{1}{b_{ijk}} \sum_{g=1}^{b_{ijk}} z_{ijkg} \ .$$

Estimates of guided passage by day, slot, or period can be readily derived from Equation (.1) by restricting summation over various subscripts in Equation (.1) and analogously for variance formula (.2).

D.1.2 Estimating Guided Passage

The estimator of guided passage at the single turbine unit is as follows:

$$\hat{G} = \sum_{i=1}^{3} \sum_{j=1}^{D} \sum_{k=1}^{24} \left[\frac{B_{ijk}}{b_{ijk}} \sum_{g=1}^{b_{ijk}} y_{ijkg} \right], \qquad (.3)$$

where y_{ijkg} is the expanded fish passage at the *g*th sampling unit $(g = 1, \ldots, b_{jkl})$ in the *k*th hour $(k = 1, \ldots, 24)$ of the *j*th day $(j = 1, \ldots, D)$ at the *i*th intake slot $(i = 1, \ldots, 3)$. The variance of $\hat{G}$ can be estimated by

$$\mathrm{Var}\left(\hat{G}\right) = \sum_{i=1}^{3} \sum_{j=1}^{D} \sum_{k=1}^{24} \left[\frac{B_{ijk}^2 \left(1 - \frac{b_{ijk}}{B_{ijk}} \right) s_{y_{ijk}}^2}{b_{ijk}} \right], \qquad (.4)$$

where

$$s_{y_{ijk}}^2 = \frac{\sum_{g=1}^{b_{ijk}} \left(y_{ijkg} - \overline{y}_{ijk} \right)^2}{\left(b_{ijk} - 1 \right)},$$

$$\overline{y}_{ijk} = \frac{\sum_{g=1}^{b_{ijk}} y_{ijkg}}{b_{ijk}}.$$

Estimates of guided passage by day, slot, or period can be readily derived from Equation (.3) by restricting summation over various subscripts in Equation (.3) and analogously for variance formula (.4).

D.1.3 Fish Passing through a Turbine

The breadth of a turbine can be envisioned as being subdivided into three strata. Within each stratum, fish passage is independently monitored over time. Total turbine fish passage can then be estimated as

$$\hat{T} = \sum_{i=1}^{D} \sum_{j=1}^{24} \frac{C_{ij}}{c_{ij}} \sum_{k=1}^{c_{ij}} t_{ijk} \, , \tag{ .5}$$

where t_{ijkl} = expanded fish count in the *k*th sampling unit $\left(l = 1,\ldots,c_{ijk}\right)$ in the *j*th hour $\left(j = 1,\ldots,24\right)$ of the *i*th day $\left(i = 1,\ldots,D\right)$;

c_{ij} = number of sampling units actually observed in the *j*th hour $\left(j = 1,\ldots,24\right)$ of the *i*th day $\left(i = 1,\ldots,D\right)$;

C_{ij} = total number of sampling units within the *j*th hour $\left(j = 1,\ldots,24\right)$ of the *i*th day $\left(i = 1,\ldots,D\right)$.

Nominally, C_{ijk} = 30 and $c_{ij} = 10 \;\; \forall ij$. Based on the assumptions of simple random sampling within the hour, then

$$\widehat{\text{Var}}\left(\hat{T}\right) = \sum_{i=1}^{D} \sum_{j=1}^{24} \left[\frac{C_{ij}^{2} \left(1 - \frac{c_{ij}}{C_{ij}}\right) s_{t_{ij}}^{2}}{c_{ij}} \right] , \tag{ .6}$$

where: $s_{t_{ij}}^{2} = \dfrac{\sum_{l=1}^{c_{ij}} \left(t_{ijk} - \overline{t}_{ij}\right)^{2}}{\left(c_{ij} - 1\right)}$

and where: $\overline{t}_{ij} = \dfrac{\sum_{l=1}^{c_{ij}} t_{ijk}}{c_{ij}}$.

D.2 Confidence Interval Estimation

For all estimated passage and performance parameters (e.g., θ), confidence interval estimates were based on the assumption of asymptotic normality. Interval estimates were calculated according to the formula

$$\text{CI}\left(\hat{\theta} - Z_{1-\frac{\alpha}{2}} \sqrt{\widehat{\text{Var}}\left(\hat{\theta}\right)} < \theta < \hat{\theta} + Z_{1-\frac{\alpha}{2}} \sqrt{\widehat{\text{Var}}\left(\hat{\theta}\right)}\right) = 1 - \alpha \tag{ .7}$$

where $Z_{1-\frac{\alpha}{2}}$ = standard normal deviate corresponding to the probability $P\left(\left|Z\right| < Z_{1-\frac{\alpha}{2}}\right) = 1 - \alpha$.

For example, a Z-value of 1.96 is used to construct a 95% confidence interval. The interval estimate, using Equation (.7), characterizes the statistical uncertainty associated with the measurement of a fish passage or performance parameter.

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

US Army Corps
of Engineers®

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)
www.pnl.gov