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Evaluation of a Surface Spill Operation to Return Adult Steelhead Overshoots Downstream of McNary Dam

Final Report

January 2021

Kenneth D Ham
P Scott Titzler
Robert P Mueller
Ryan Harnish

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

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Pacific Northwest National Laboratory
Richland, Washington 99354

Summary

This study, funded by the U.S. Army Corps of Engineers (USACE), was conducted by the Pacific Northwest National Laboratory to evaluate the efficacy of operating one temporary spillway weir (TSW) at McNary Dam outside the normal TSW operation dates for juvenile salmon passage. Of interest is whether the TSW is an effective downstream passage route for adult steelhead overshoots. Overshoots are fish which, having passed upstream at McNary Dam, must pass downstream to return to their natal stream to spawn. This report covers fall (2019) and spring (2020) study periods.

The study design arranged the available 24 hours of TSW spill per week into weekly blocks with sub-blocks differentiated into day and night operations. TSW discharge periods of 4- and 8-hour durations within the sub-blocks were evaluated. Hydroacoustic techniques were used to sample adult fish passage at the TSW and at turbine Units 1 and 10. The experimental design contrasted TSW spill periods of differing durations and at different times of the day. The small number of fish detected passing the TSW, and the smaller number of fish detected passing the turbine units, were best suited to an ad hoc, exploratory approach to evaluating the effect of TSW spill.

It is worthwhile to note that the operations data obtained for the fall study period had a greater than expected number of gaps and apparent anomalies that we believe were a result of how the data were aggregated. These problems are not particularly problematic for the present study, because the available data still provide a good indication of whether the TSW was operating at each point in time. TSW flows in both fall and spring data sets were further examined using the established relationship between forebay elevation and TSW discharge rate and corrected whenever TSW flows exceeded that rate. Additional analysis of operations data would be needed, however, if a more quantitative evaluation of dam-wide flow and passage relationships is required.

Spring adult steelhead passage rates estimated using hydroacoustics were less than half of those estimated during the fall study period, consistent with our analysis of fish tagged with passive integrated transponder (PIT) tags that were likely to be in the vicinity during each study period.

Detections of fish in imaging sonar sampling areas upstream of the TSW and powerhouse were not correlated with detections of fish passing hydroacoustic sampling areas, which suggests that fish approaching the face of the dam can move within the forebay before passing. Other fish detected in the forebay in large numbers, such as adult American Shad, were able to be distinguished and removed from adult steelhead passage counts; these detections do not appear to influence hydroacoustic passage rate estimates.

A pulse of passage at the initial TSW opening was not consistent, but trends across 4- and 8-hour operational periods did not show a distinct decline in passage over time as TSW operation continued. Our findings do not indicate a reason to choose one 8-hour period over two 4-hour periods, or vice versa. This suggests that the duration of spill periods can be chosen based on operational or other considerations.

Passage rates were as much as two times higher during the daytime TSW discharge periods than during nighttime TSW discharge periods. The experimental design of the current study used start times near dawn for day periods and near dusk for night periods. Current findings

show that TSW spill periods beginning near dawn should be chosen if the desire is to increase downstream passage of adult steelhead. Further refinement of that recommendation may be possible given further study of diel influences on adult steelhead passage.

Given that the diel timing of TSW discharge appears to have a greater influence on passage rates than duration, future studies might focus on the influence of the diel period on passage. If 4-hour periods were chosen, a 24-hour weekly allocation of spill would provide six TSW discharge periods for developing a study design. That design could compare the best diel periods from the current study with other times of day to find the most effective times of day for passing adult steelhead over the TSW at McNary Dam.

Acknowledgments

We acknowledge the following USACE staff for their help in making this study successful: Martin Ahmann, Ricardo Walker, Joe Norton, Bobby Johnson, Charles Chamberlain, Troy Gilbert, John Oberhelman, Tim Wik, Bill Gersbach, Pete Stewart, Jim Harris, and many fisheries, maintenance, and operations staff at McNary Dam.

Acronyms and Abbreviations

ANOVA	analysis of variance
DOS	Disk Operating System
FGE	fish guidance efficiency
h	hour(s)
JBS	juvenile bypass system
JDA	John Day Dam
kcfs	thousands of cubic feet per second
kHz	kilohertz
ms	millisecond
MSL	mean sea level
PAS	Precision Acoustic Systems, Inc.
PIT	passive integrated transponder
pps	pings per second
SMP	Smolt Monitoring Program
TSW	temporary spillway weir
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

Approximately 50% of adult steelhead (*Oncorhynchus mykiss*) returning to the John Day and Umatilla Rivers annually overshoot their destination and pass upstream of McNary Dam, which results in adult steelhead fallback to return to spawning grounds (Keefer et al. 2008; Richins and Skalski 2017). Monitoring efforts are needed to evaluate whether the added availability of a downstream passage or fallback route other than a turbine route increases fallback events of steelhead overshoots and upriver stock pre-spawner migrants. A management goal is to develop a surface spill operation at McNary Dam that increases spawner return rates of adult steelhead that overshoot their natal tributaries as well as downriver origin adult steelhead that overwinter in the McNary Dam forebay. The goal of this study, funded by the U.S. Army Corps of Engineers (USACE) and conducted by the Pacific Northwest National Laboratory, is to assess the effectiveness of fall and spring surface spill operations through a single temporary spillway weir (TSW) for increasing returns of John Day and Umatilla River (downstream) origin steelhead spawners that overshoot McNary Dam. The fall and spring study designs evaluate the diel timing of TSW spill periods as well as their duration.

1.1 Background

A direct injury and survival study conducted during the early spring of 2014 at McNary Dam evaluated differences in TSW and turbine survival (Normandeau Associates, Inc. 2014). Adult steelhead survival was estimated to be 97.7% over the TSW compared to 90.7% through the turbine. Given the differences in survival, a hydroacoustic passage study in 2014–2015 (Ham et al. 2015) evaluated the proportion of adult steelhead that would pass the McNary Dam TSW if it were operated during fall and winter. Studies at other dams in the Snake and Columbia Rivers using acoustic telemetry found that surface spill routes were very effective for steelhead kelts and were typically one of the routes with higher than average survival at a dam (Colotelo et al. 2013, 2014; Rayamajhi et al. 2013). This document covers a study conducted to estimate the influence of TSW operation during periods after juvenile spill had ended in 2019 and before juvenile spill had commenced in 2020 on adult steelhead use of the TSW as a route of passage.

1.2 Objectives

The objectives of this hydroacoustic evaluation of McNary Dam adult steelhead passage were as follows

1. Estimate the timing and number of adult steelhead passing through TSW spill and selected turbine units using hydroacoustics.
    a. Assess daily, weekly, seasonal, and diel timing and passage distributions.
    b. Correlate passage events to potential influential environmental and biological variables (such as river temperature and discharge) to the extent possible.
2. Compare total downstream adult passage rates among TSW on and TSW off periods.

1.3 Study Site Description

McNary Dam is located on the Columbia River at river mile 292 and includes a navigation lock, a spillway, and a powerhouse. The dam structure is 7,365 ft long and consists of 14 turbine units, 22 spill bays, a navigation lock, two fish ladders for adult fish traveling upstream, and an earth-filled section (Figure 1.1). The McNary Dam powerhouse is 1,422 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 as A, B, and C. Two small station service units are located south of Main Unit 1 and have a capacity of 3 MW each.

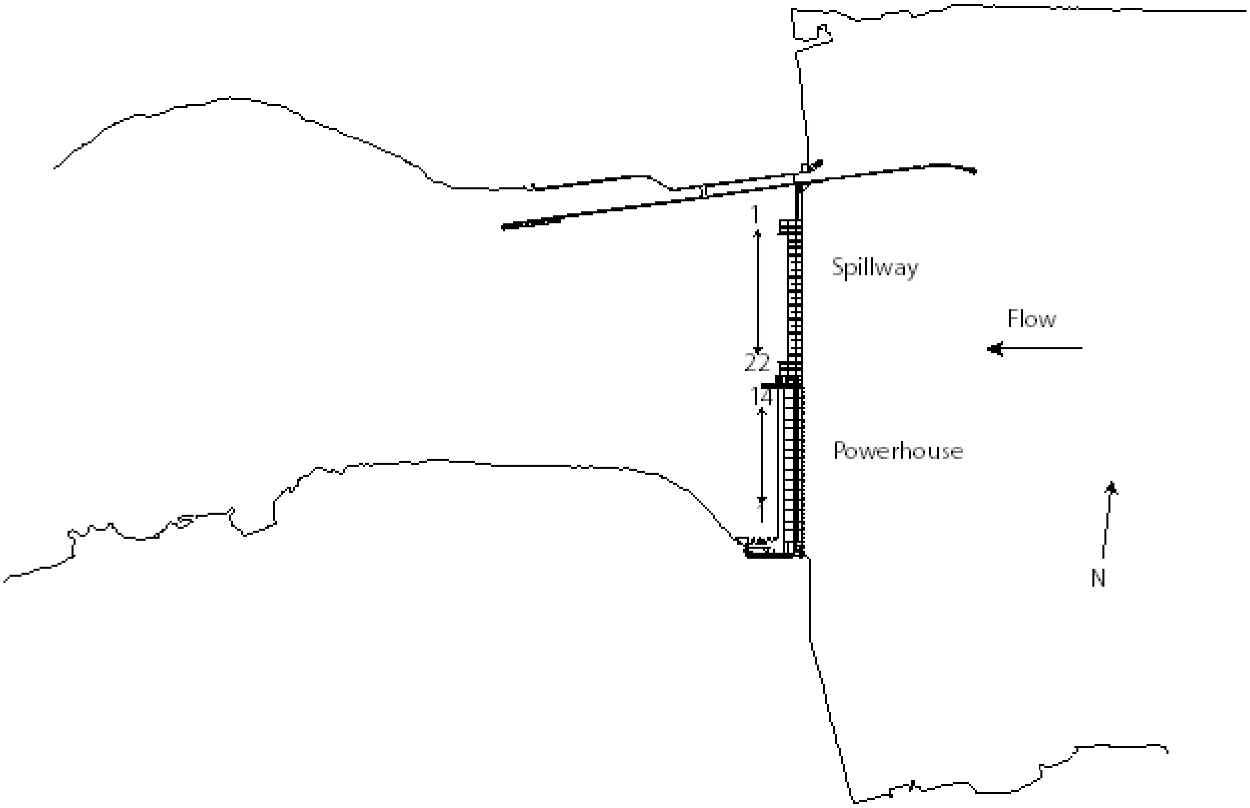


Figure 1.1. Plan View of McNary Dam Illustrating the Location of the Spillway and Powerhouse

Turbine unit intakes are fitted with extended-length submersible bypass screens (ESBSs) during the juvenile fish passage season (April–August), and through the fall for adult passage. The ESBSs have typically not been in place during March, but were installed prior to 1 March 2020, the first day of our spring study period. The ice and trash sluiceway has been permanently separated for use as the collection channel of the juvenile bypass facility (JBS). Adult steelhead passing downstream through the powerhouse are likely to be guided into the JBS whenever ESBSs are in place. The current JBS at McNary Dam became operational in 1994.

The 1,130 ft wide spillway is composed of 22 vertical lift gates, which are numbered sequentially starting from the Washington shore—the spill bay closest to the powerhouse is 22 (Figure 1.1). The spill gates are of a 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, thereby providing 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 spill bay is turned off by lowering the upper spill gate leaf onto the crest of the TSW. During operation, the upper spill gate leaf is raised above the water surface and the discharge over the TSW is controlled by the forebay water surface elevation. Under the current fish passage plan, the TSWs are removed for the summer juvenile fish passage season and remain out of operation until they are reinstalled in the spring. In the current study, the TSW was installed and operated in Spill Bay 20 during specified treatment periods in the winter and during periods of unplanned spill that were not part of a specified treatment period.

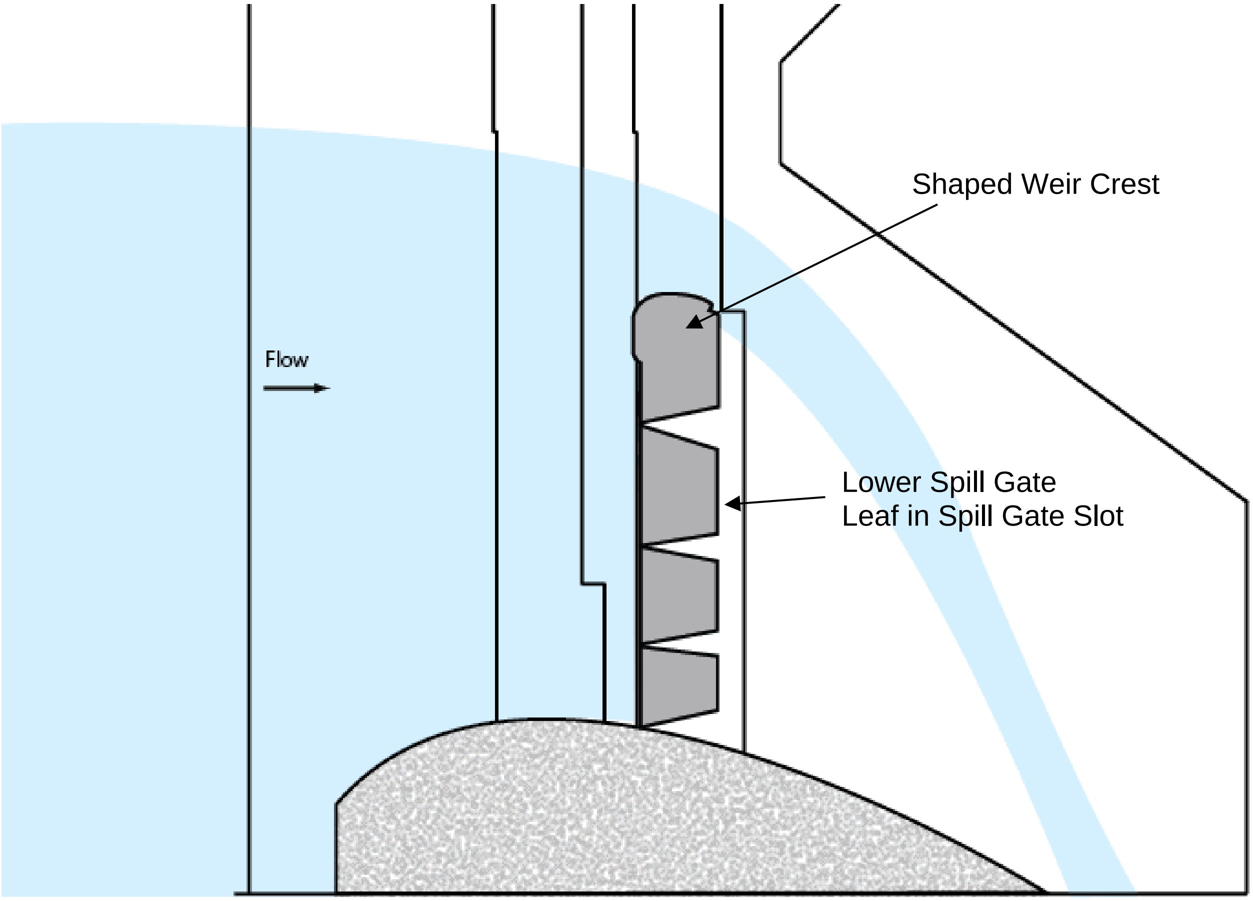


Figure 1.2. Structural Diagram (Cross Section) of the TSW

The gravity-flow auxiliary water-supply system that supplies water to the Washington shore fish ladder powers a 10 MW hydropower turbine unit, which 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)

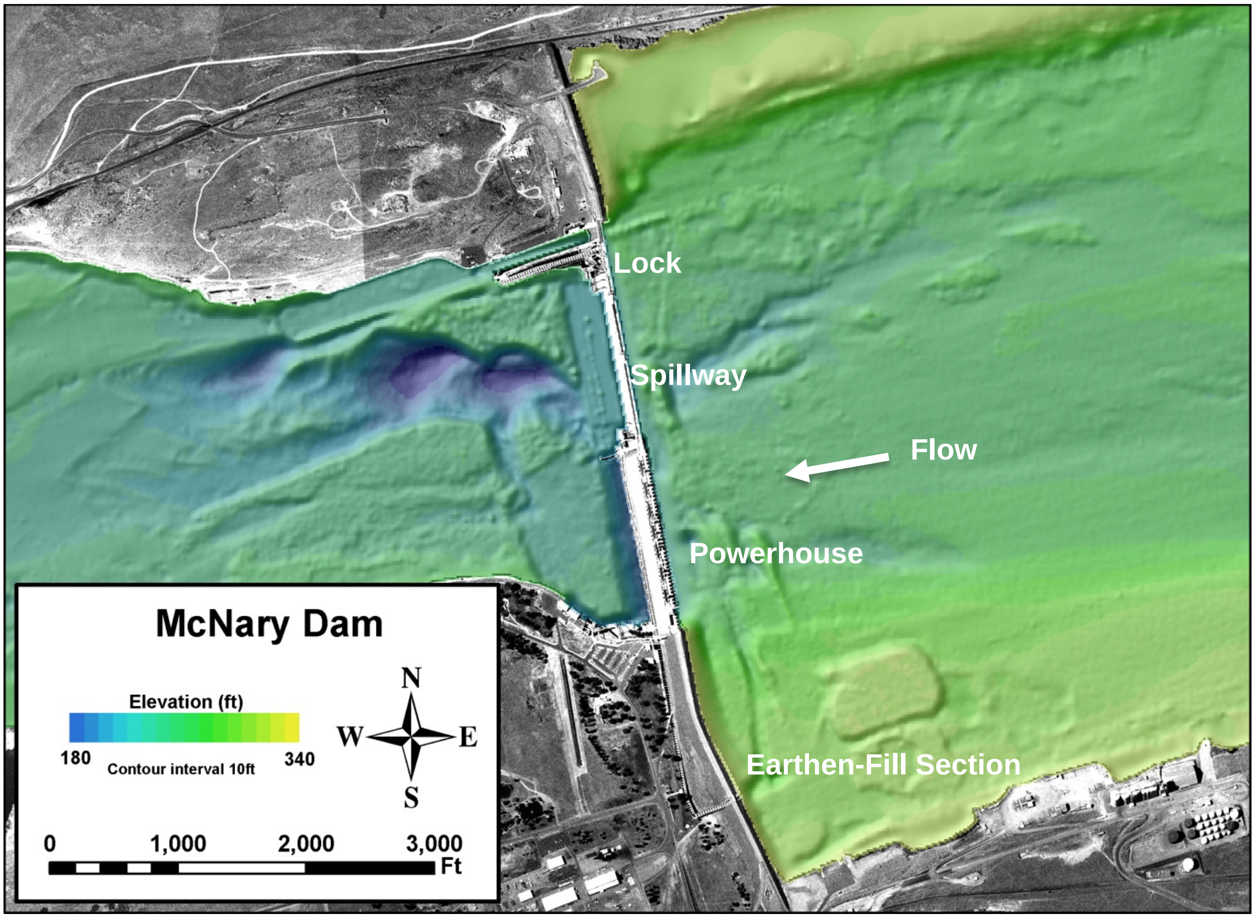


Figure 1.3. Plan View of McNary Dam Major Structural Features Showing River Bathymetry

1.4 Report Contents and Organization

This report contains five chapters and four appendices, including Chapter 1.0, Introduction; Chapter 2.0, Methods; Chapter 3.0, Results; Chapter 4.0, Discussion; and Chapter 5.0, References. The appendices contain additional information about equipment configuration and settings (Appendix A), raw data (Appendix B), and statistical methods (Appendix C).

2.0 Methods

This study employed the methods established in previous studies of winter passage of adult steelhead at McNary Dam (Ham et al. 2012a, 2012b, 2015) and The Dalles Dam (Khan et al. 2009). Fixed-aspect hydroacoustic techniques were used to quantify the number of adult steelhead-sized acoustic targets passing over the TSW, through turbine Units 1 and 10, or into the JBS at those turbine units at McNary Dam during the fall of 2019 (15 September to 15 November) and the spring of 2020 (1 March to 9 April). Two multibeam imaging sonars ("acoustic cameras") monitored fish upstream of Unit 10 (Slots B and C) and the TSW to quantify fish presence and identify times when non-salmonids such as American Shad (*Alosa sapidissima*) were present or abundant. The study plan called for monitoring passage through fall and spring study periods, and an experimental design that varied the timing and duration of TSW spill period treatments on a schedule that allocated 24 hours of TSW spill per week (Table 2.1 and Table 2.2). No spill through conventional bays was planned for the study periods.

2.1 Study Design

A stratified random block design was used to contrast the effect of the duration and diel timing of TSW spill periods on adult steelhead passage rates. Two sub-blocks differentiated by diel timing (day vs night), were randomly assigned to the first or last half of each weekly block (Table 2.1 and Table 2.2). Within each sub-block, two TSW spill treatments of differing durations (4-hour vs 8-hour) were randomly assigned within an early or late day. The start of day spill periods was set at 0700h, which is approximately the average time of dawn during the fall study period. The start of night spill periods was set at 1900h, approximately the average time of dusk for the fall study period. The available time window for the spring study period was shorter than that for fall study period, but the study designs were otherwise almost identical.

2.1.1 Experimental Treatment and Schedule

The fall study period began on 15 September 2019 and ended 15 November 2019. The spring study period began on 1 March 2020 and ended on 9 April 2020. Weekly blocks contained two 4-hour and two 8-hour blocks (Table 2.1 and Table 2.2). Day or night spill was randomly assigned to half-week sub-blocks. Within each sub-block, the spill period durations were randomly assigned to be first or last. Spill periods were separated by as much time as practical within the treatment design to reduce the potential for an earlier spill period to influence the current period. The separation among TSW spill periods during the latter part of the final block of each study period was constrained by the available days of spill. No spill through conventional deep-spill bays was planned for the study period.

Table 2.1. Planned Study Design for Gate Position during the Fall Study Period. Light gray shading differentiates blocks and dark gray shading indicates night spill periods.

Date	Block	Day	Open	Closed	Duration
9/15	1	Sunday	0700	1500	8
9/16		Monday			
9/17		Tuesday	0700	1100	4
9/18		Wednesday	1900	0300	8
9/19		Thursday			
9/20		Friday	1900	2300	4
9/21		Saturday			
9/22	2	Sunday	0700	1500	8
9/23		Monday			
9/24		Tuesday	0700	1100	4
9/25		Wednesday	1900	2300	4
9/26		Thursday			
9/27		Friday	1900	0300	8
9/28		Saturday			
9/29	3	Sunday	1900	2300	4
9/30		Monday			
10/1		Tuesday	1900	0300	8
10/2		Wednesday			
10/3		Thursday	0700	1100	4
10/4		Friday			
10/5		Saturday	0700	1500	8
10/6	4	Sunday	1900	0300	8
10/7		Monday			
10/8		Tuesday	1900	2300	4
10/9		Wednesday			
10/10		Thursday	0700	1100	4
10/11		Friday			
10/12		Saturday	0700	1500	8
10/13	5	Sunday	1900	2300	4
10/14		Monday			
10/15		Tuesday	1900	0300	8
10/16		Wednesday			
10/17		Thursday	0700	1500	8
10/18		Friday			
10/19		Saturday	0700	1100	4
10/20	6	Sunday			
10/21		Monday	0700	1100	4
10/22		Tuesday			
10/23		Wednesday	0700	1500	8
10/24		Thursday	1900	0300	8
10/25		Friday			
10/26		Saturday	1900	2300	4
10/27	7	Sunday			
10/28		Monday	0700	1500	8
10/29		Tuesday			
10/30		Wednesday	0700	1100	4
10/31		Thursday	1900	2300	4
11/1		Friday			
11/2		Saturday	1900	0300	8
11/3	8	Sunday			
11/4		Monday	0700	1100	4
11/5		Tuesday			
11/6		Wednesday	0700	1500	8
11/7		Thursday	1900	0300	8
11/8		Friday			
11/9		Saturday	1900	2300	4
11/10	9	Sunday			
11/11		Monday	0700	1500	8
11/12		Tuesday			
11/13		Wednesday	0700	1100	4
11/14		Thursday	1900	2300	4
11/15		Friday	1900	0300	8

Table 2.2. Planned Study Design for Gate Position during the Spring Study Period. Light gray shading differentiates blocks and dark gray shading indicates night spill periods.

Date	Block	Day	Open	Closed	Duration
3/1	1	Sunday	0700	1500	8
3/2		Monday			
3/3		Tuesday	0700	1100	4
3/4		Wednesday	1900	0300	8
3/5		Thursday			
3/6		Friday	1900	2300	4
3/7		Saturday			
3/8	2	Sunday	0700	1500	8
3/9		Monday			
3/10		Tuesday	0700	1100	4
3/11		Wednesday	1900	2300	4
3/12		Thursday			
3/13		Friday	1900	0300	8
3/14		Saturday			
3/15	3	Sunday			4
3/16		Monday	1900	2300	
3/17		Tuesday	1900	0300	8
3/18		Wednesday			
3/19		Thursday	0700	1100	4
3/20		Friday			
3/21		Saturday	0700	1500	8
3/22	4	Sunday	1900	0300	8
3/23		Monday			
3/24		Tuesday	1900	2300	4
3/25		Wednesday			
3/26		Thursday	0700	1100	4
3/27		Friday			
3/28		Saturday	0700	1500	8
3/29	5	Sunday	1900	2300	4
3/30		Monday			
3/31		Tuesday	1900	0300	8
4/1		Wednesday			
4/2		Thursday	0700	1500	8
4/3		Friday			
4/4		Saturday	0700	1100	4
4/5	6	Sunday	0700	1500	8
4/6		Monday	1900	2300	4
4/7		Tuesday	1900	0300	8
4/8		Wednesday			
4/9		Thursday	0700	1100	4

2.2 Hydroacoustic Sampling System

Fish passage was estimated using fixed aspect hydroacoustic techniques. At the powerhouse, Precision Acoustic Systems, Inc. (PAS) 420-kHz Split-Beam Transducers (Figure 2.1) with a nominal beam angle of 6 degrees were used to sample fish passing unguided into turbines or guided into the JBS in study Slots A and B of Units 1 and 10 (Figure 2.2). The two transducers within each study slot of a turbine unit were sampled by a sounder (PAS-103 Split-Beam), for a total of four sounders sampling the powerhouse locations. Three split-beam transducers each with a nominal beam angle of 10 degrees and one sounder were used to sample fish passing over the TSW in Spill Bay 20. Split-beam data collection was accomplished using PAS Harp–SB Split-Beam Data Acquisition/Signal Processing Software—a DOS-based application that controlled each sounder. A PAS-203 Split-Beam 4-Channel Transducer Remote Multiplexer allowed each sounder to sample up to four transducers in sequence (see Appendix A for system configurations). A ping rate of 21 pps was selected for all systems to minimize reverberation noise. Pings were transmitted with a pulse width of 100 ms. Each powerhouse intake transducer was sampled in sequence 15 times per hour for 240-second intervals. TSW transducers were sampled in sequence 10 times per hour for 360-second intervals. The sample files included the sequence of pings, with information about any target echoes within the beam during each ping.

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

Transducers sampling guided fish were attached to a trash rack structural horizontal member at an elevation of 239 ft MSL near the center of the intake, and were oriented to look up toward the intake ceiling and aimed 31 degrees downstream of the trash rack plane (Figure 2.2). To protect the transducer cables from debris, water flow, and trash raking, cables were routed to the intake deck through conduit secured vertically to the downstream face of the trash rack. Transducers for sampling unguided fish were attached to a crossmember of the guidance screen (ESBS) structure at an elevation of 270 ft MSL, oriented to look down toward the intake floor and angled 24 degrees upstream from vertical (Figure 2.2). Cables were routed horizontally along the ESBS structural horizontal beam to either edge, then up through the screen slot to the intake deck and through a passageway to the forebay side of the intake deck, where they could be connected to the multiplexer.

The range cutoff for guided sample volumes was the same as those used during the 2013–2014 study (Ham et al. 2015; Figure 2.2). In other words, only fish passing the guided beam at ranges beyond the guided cutoff range were included in the passage estimation process. A similar cutoff range was used for the unguided sample beam to exclude areas where passage was highly unlikely, but where variability in flow sometimes resulted in numerous noise targets.

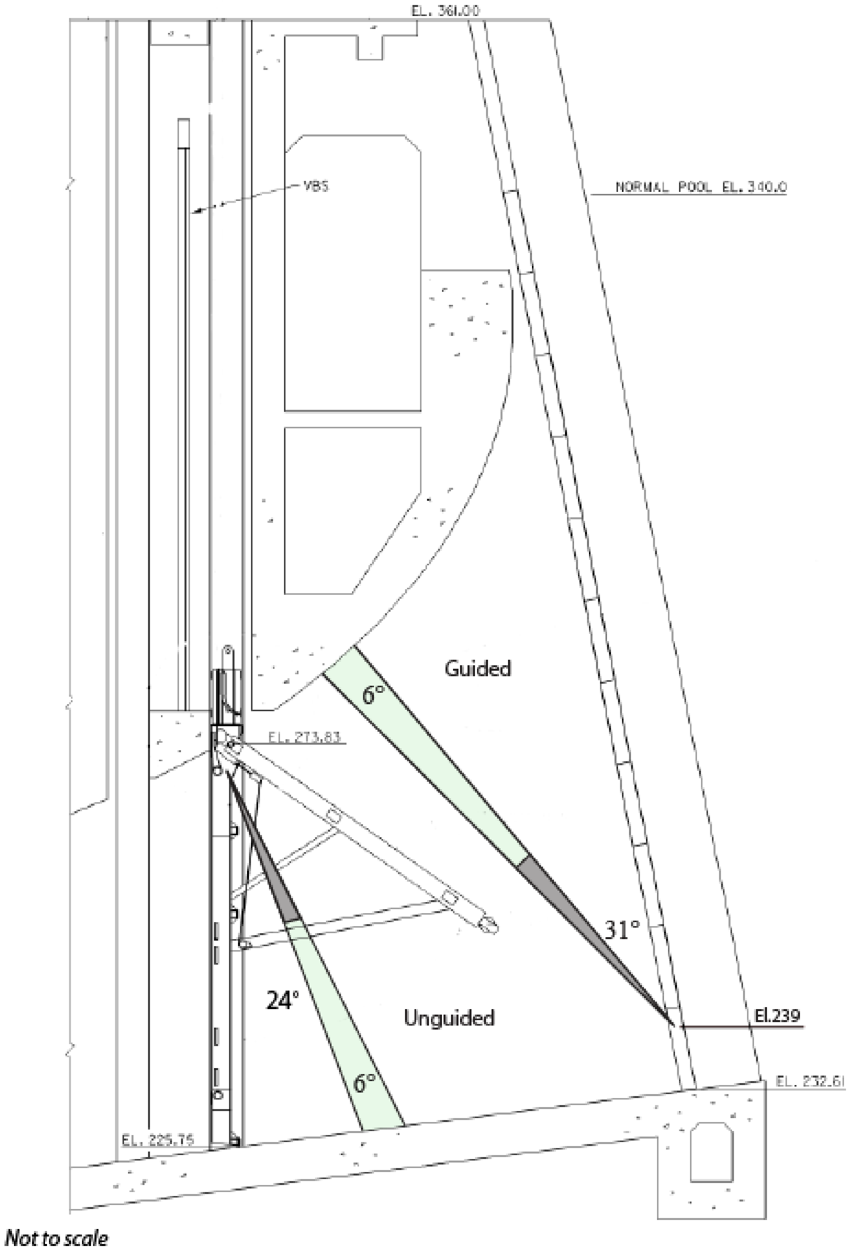


Figure 2.2. Side View of the Turbine Intake Transducer Deployments at McNary Dam

Three split-beam transducers with a nominal beam angle of 10 degrees were attached to the upstream vertical face of the dam’s spillway ogee, just below the curve at an elevation of 284 ft MSL (Figure 2.3) and oriented to look up to the water surface. To sample as close to the TSW crest and spill bay pier noses as possible without structural interference, all three transducers were aimed at approximately 17.5 degrees downstream of vertical and spaced equally horizontally to cover the maximum width while avoiding interference from the spill bay pier noses. Transducer cables were routed north from each transducer horizontally across the ogee to a pier nose, then vertically up to the surface through an existing trolley pipe for protection against water flow and debris.

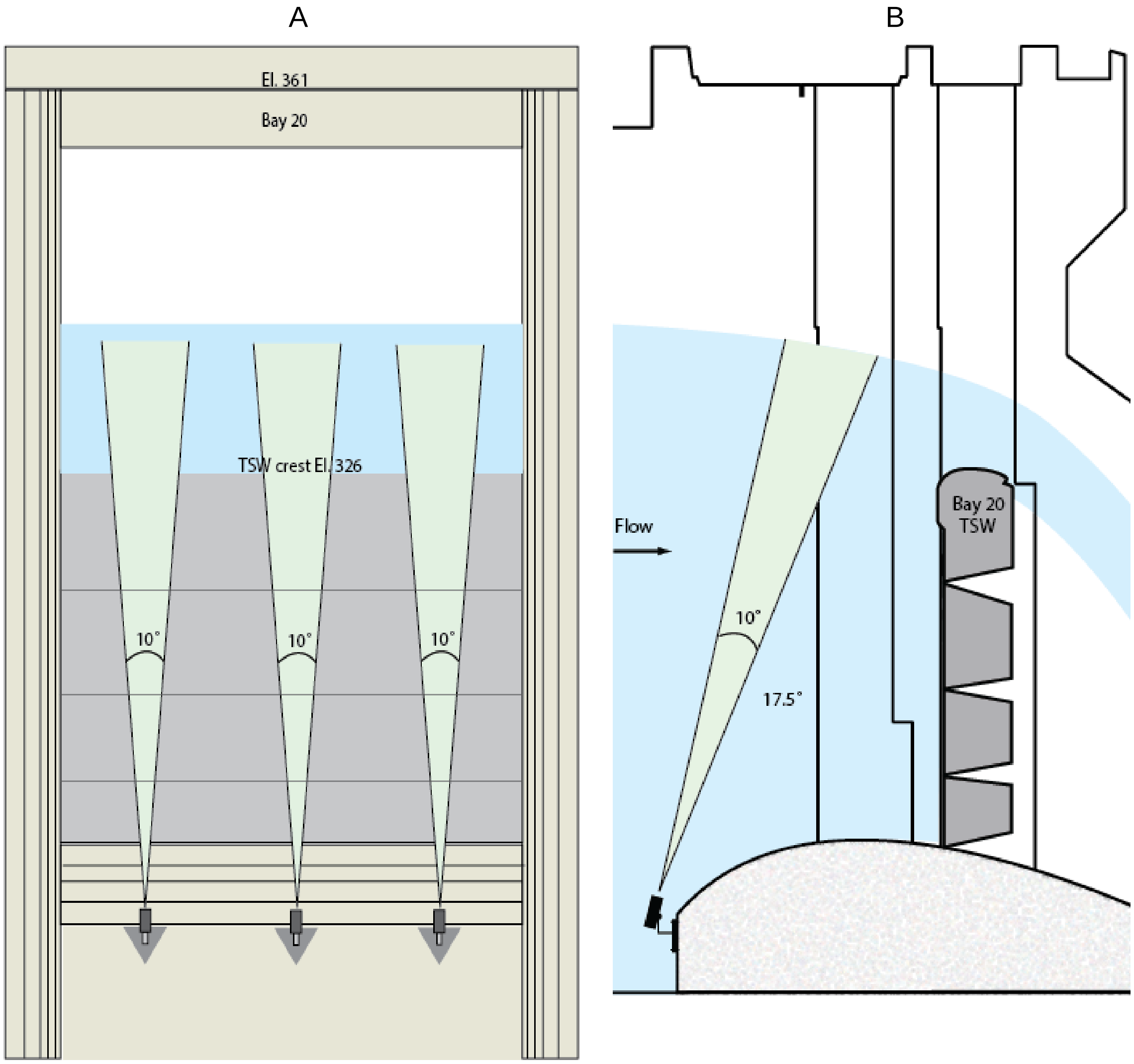


Figure 2.3. Diagram of Mounting Locations and Sample Volumes of Transducers Sampling TSW Passage. Panel A illustrates a front elevation view from upstream of the TSW (from the East) with water flowing away from the viewer (to the West). Panel B illustrates a side elevation view of the TSW (from the North) with water flowing to the right (to the West).

2.3 Imaging Sonar Sampling

Two high-resolution imaging sonars (BlueView, Model P900-45, Teledyne Marine; Figure 2.4) were used for the fall study period. The imaging sonars provided a way to visualize fish shapes and behavior under conditions in which 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 the 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 2013–2014 study (Ham et al. 2015) to estimate the relative abundance and behavior of adult steelhead and adult shad.

Imaging sonars used an ultrasonic frequency of 900 kHz and sampled a 45-degree wide by 20-degree deep volume of water. One imaging sonar was deployed in the Unit 21/22 pier nose trolley pipe and oriented to look north to view the forebay region upstream of the Spill Bay 20 TSW (Figure 2.5). The second imaging sonar was deployed in the Unit 10/11 pier nose trolley pipe and oriented to look south to view the forebay region upstream of Unit 10 Slots B and C trash racks (Figure 2.6). Both imaging sonars were operated from 14 September to 15 November 2019 and 1 March to 9 April 2020. The TSW imaging sonar was set at an elevation of 333 ft MSL, approximately 7.7 ft below the forebay normal operating pool water surface, and the Unit 10 imaging sonar was deployed at an elevation of 326 ft MSL.

Figure 2.4. Imaging Sonar Attached to Trolley and Prior to Deployment into the Trolley Pipe

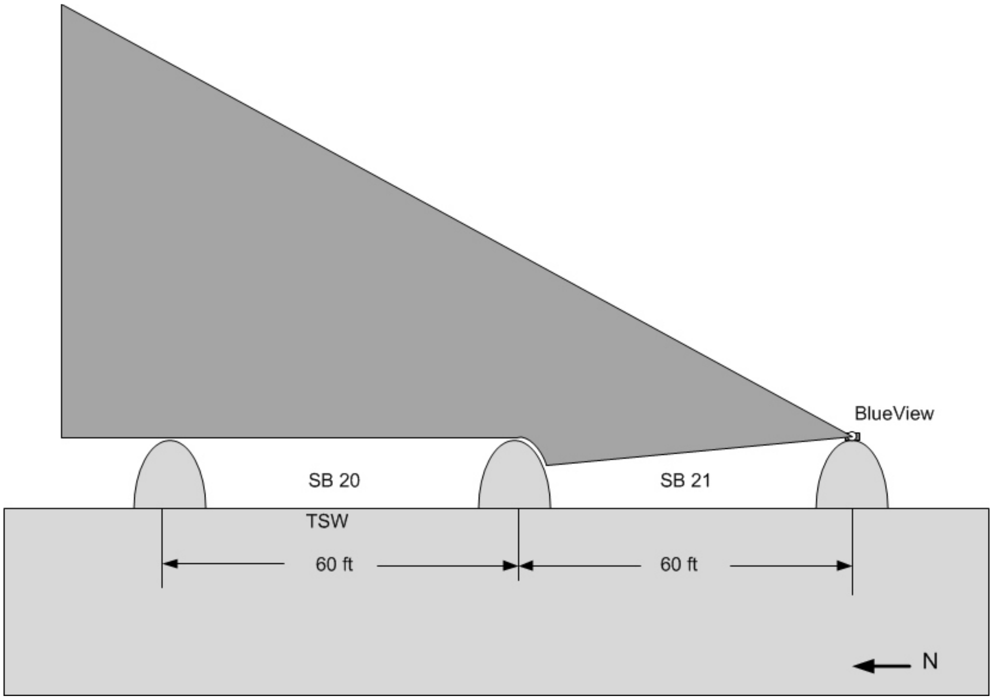


Figure 2.5. Imaging Sonar Sampling Area at the TSW in Spill Bay 20

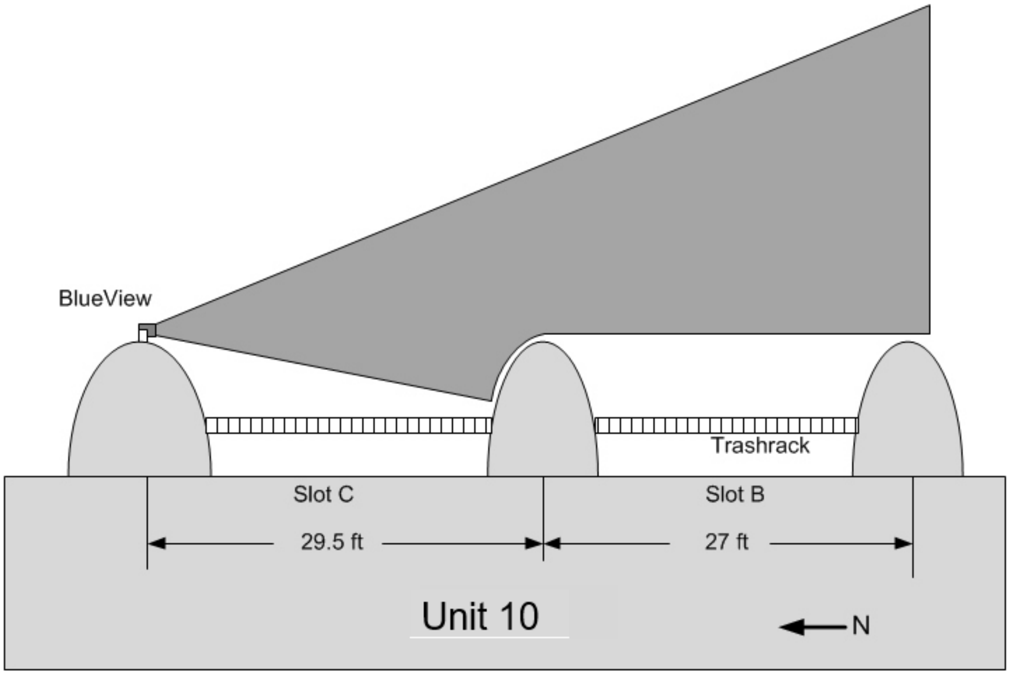


Figure 2.6. Imaging Sonar Sampling Area at Powerhouse Unit 10

2.4 Data Processing

To estimate fish passage and evaluate it in the context of dam operations, data collected from sounders were processed to identify fish tracks from echoes created by individual fish. Counts of fish tracks were subsequently expanded to estimate fish passage through each route. Passage estimates were integrated with dam operations and treatment information to allow for the comparison of passage among treatments. This section describes the process that derives the estimates of fish passage from the raw data.

2.4.1 Dam Operations

Dam operations data, which were provided by the Walla Walla District USACE, included the flows through each passage route on a 5-minute basis as collected by the data-acquisition systems. These data were combined with the fish passage data for analysis of relationships between fish passage and flow. 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. The autotracker identifies linear features in echograms, which exhibit characteristics consistent with smolt-sized fish committed to passage by the monitored route, and subsequently saved as tracks. Each track represents a fish passing through the transducer beam.

2.4.3 Detectability and Effective Beamwidths

The movement characteristics (e.g., speed and direction) of fish 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 having been 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 beamwidth. The nominal beamwidths of 6 degrees assigned to a transducer do not accurately reflect the shape of the detection area for a transducer. The effective beamwidth is a measure that more accurately represents the cross-sectional area across which a transducer can detect smolt-sized fish moving at the speed and direction that are characteristic of each deployment type. Effective beamwidths 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.

2.4.4 Spatial and Temporal Expansion of Track Counts

Under the acoustic screen model, the number of tracks within the beam is expanded spatially and temporally to estimate total passage through a single passage route. Hourly passage was estimated by expanding the number of fish that passed through the beam for the cross-sectional area sampled (Equation ((A.1))) and the sampled fraction per hour (Equation ((A.2))):

$$W_{ij} = \frac{I_j}{2R_i \tan\left(\frac{\theta_j}{2}\right)} \qquad ((A.1))$$

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 beamwidth of the transducer at the j^th^ location; and

$$\mathrm{X}_{jh} = \left(\frac{K}{k}\right)\sum_{i=1}^{n_{jh}} W_{ijh} \qquad ((\mathrm{A}.2))$$

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.

2.4.5 Imaging Sonar Data Processing

Both imaging sonars were pre-programmed to collect 15-minute samples at 1-hour intervals. Recorded images for the 4-hour block periods (0700–1100h and 1900–2300h) were processed beginning 1 hour prior to TSW operation through the last hour of operation (for a total of 5 hours). For the 8-hour block periods (0700–1500h and 1900–0300h), data processing started 1 hour prior to the gate opening, followed by the first hour of operation, then at three randomly selected hours within the block, and through the last hour of operation (for total of 6 hours). These sampled periods were processed using BlueView ProViewer software (Teledyne Marine). A count was made of the targets of each adult steelhead-size species of fish (e.g., adult shad, adult steelhead, or other adult steelhead-sized fish) 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 if they re-entered the field of view during the same sample period. Additional behaviors noted included milling (movement within the field of view with no consistent directionality), movement direction (i.e., north, south, or east), and schooling (coordinated movements of multiple individuals). Other unidentified fish were noted, as were periods of significant entrained air resulting from windy conditions, and drifting debris.

2.5 Data Analysis

Data analysis consisted of estimating fish passage numbers and integrating them with the river flow and other conditions within specific time periods and passage routes. These general analysis results were then summarized to address specific questions of interest, including how TSW treatments influenced the magnitude and timing of adult fish passage. Both spatial and temporal variations in the sampling were taken into account. The variances were calculated and carried through to the final estimates. The detailed statistical methods are described in Appendix C.

3.0 Results

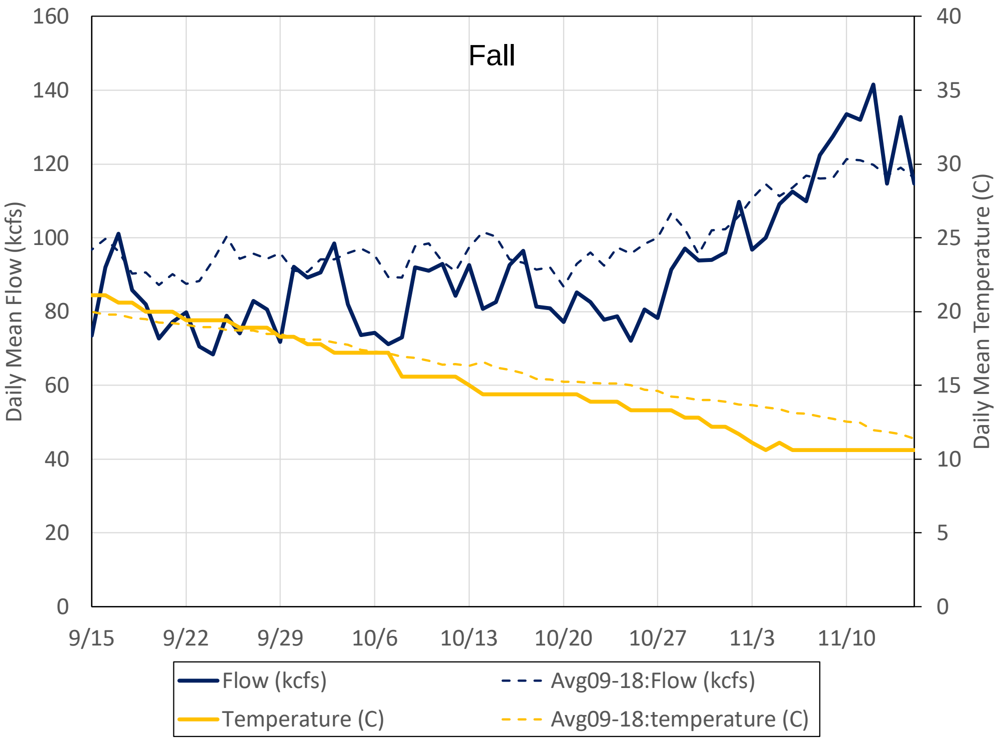
Many aspects of the river environment or dam operations influence fish passage, and many of them are not related to the treatments of interest in this study. Before presenting the results of the treatment comparisons, it is useful to examine how river conditions varied throughout the experimental period to provide context for passage trends. In the following sections, we present information about river conditions, trends in passage, and treatment comparisons.

3.1 Study Conditions

The environmental conditions and the dam operations during each study period provide context for understanding how TSW operation influences adult fish passage. In general, river flows were slightly below average for the fall study period and well below average for the spring study period.

3.1.1 River Discharge, Spill, and Temperature

This study monitored the passage of adult salmonids through two turbine units at the powerhouse of McNary Dam and over the TSW in Spill Bay 20 from 15 September 2019 to 15 November 2019 and from 1 March 2020 to 9 April 2020. River discharge was somewhat below average during much of the fall study period and well below average during the spring study period (Figure 3.1). The water temperature was near average overall with periods of above and below-average temperatures during the fall study period. Both study periods are outside the time of year when spill for downstream juvenile passage (including TSW operation) has been implemented (USACE 2019, 2020). Some periods of forced spill through conventional spill bays occurred and are presented with the TSW spill treatment operations in Section 3.2.



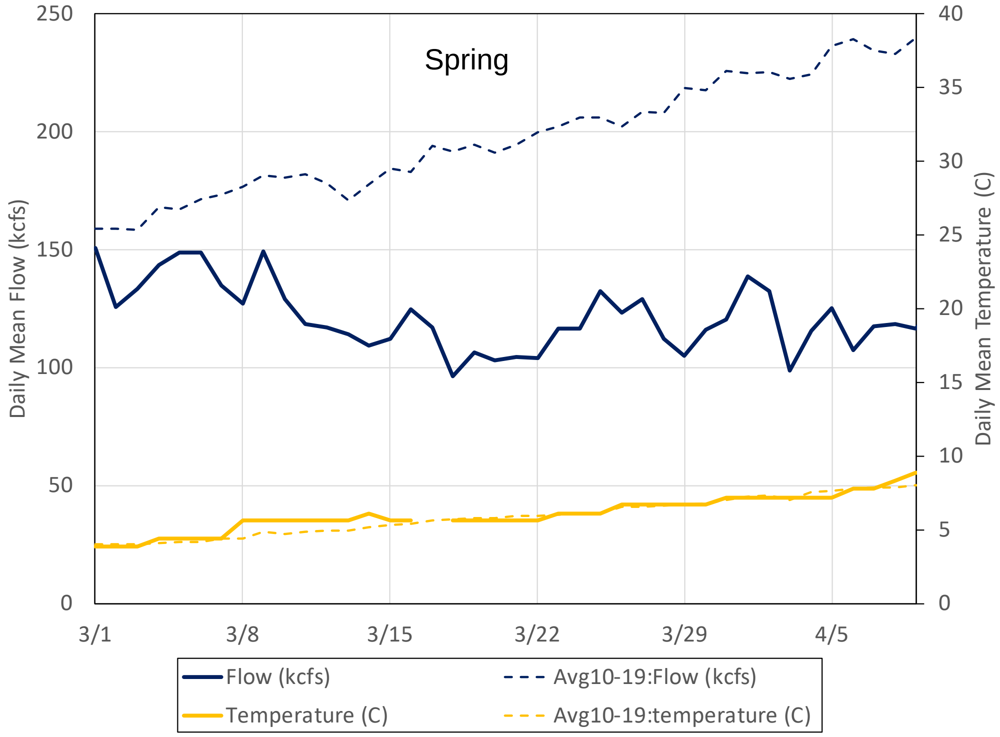


Figure 3.1. Daily Total Discharge and Temperature (solid lines) and 10-Year Averages (dashed lines) for Fall 2019 (top) and Spring 2020 (bottom). Source: www.cbr.washington.edu/dart/dart.html.

3.1.2 Adult Fish in the Vicinity of McNary Dam

A separate effort is expected to provide additional information about the passage and migration success of adult steelhead overshoots at McNary Dam using passive integrated transponder (PIT)-tag detections. Until those results are available, a simple summary of PIT-tag detection data (ptagis.org) is presented to provide context for fish detected in hydroacoustic sampling.

3.1.2.1 Fall 2019

In the period between 1 August 2019 and 30 November 2019, 1,649 adult steelhead were detected in McNary Dam fish ladders. Within this time period, the middle 95% of passage occurred between 13 August and 1 November and the middle 80% of passage occurred between 4 September 2019 and 24 October 2019 (Figure 3.2).

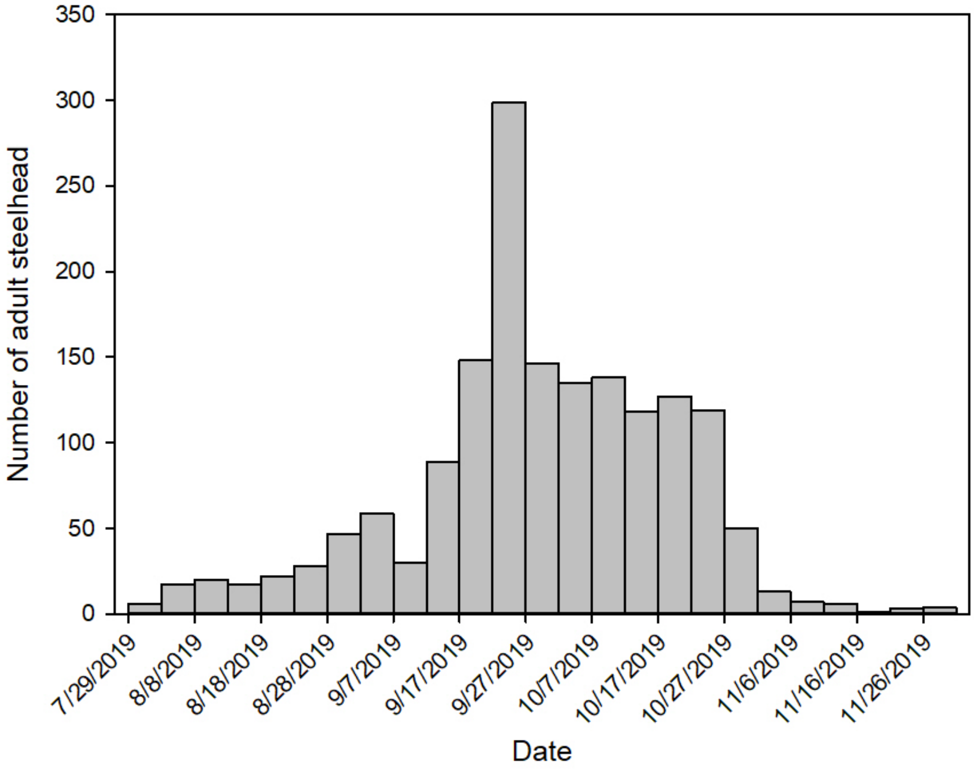


Figure 3.2. Distribution of Adult Steelhead Detections on Fish Ladder PIT Antennas during Fall 2019

A total of 1,122 of the detected fish were tagged as juveniles and 527 were tagged as adults (Table 3.1). A total of 1,034 of the juveniles originated from upstream of McNary Dam and 88 originated downstream. Of the juveniles that originated from downstream of McNary Dam, 67 originated from the John Day River, 20 from the Umatilla River, and 1 from the Hood River. Of the 88 known-origin fish that originated from downstream of McNary Dam, 18 (20.5%) were last detected in their natal stream, 46 (52.3%) were last detected in the McNary Dam fish ladder, 23 (26.1%) were last detected in a non-natal-origin basin (primarily the Snake), and 1 (1.1%) was last detected in the McNary Dam JBS.

Of the 1,034 known-origin fish that originated from upstream of McNary Dam, 917 (88.7%) were last detected in their natal basin, 71 (6.9%) were last detected in the McNary Dam fish ladder, 44 (4.3%) were last detected in a non-natal-origin basin upstream of McNary Dam, and 2 (0.2%) were last detected downstream of McNary Dam (1 strayed into the Deschutes River and the other was last detected at the John Day Dam [JDA] JBS).

Of the 527 unknown-origin adult steelhead detected at McNary Dam, 424 (80.5%) were last detected in the Snake River, 49 (9.3%) were last detected in the McNary Dam ladders, 47 (8.9%) were last detected in the mid- or upper-Columbia River, and 6 (1.3%) were last detected downstream of McNary Dam (4 in the John Day River, 2 in the Umatilla River, and 1 in the JDA fish ladder).

Table 3.1. Origins of Adult Steelhead Passing McNary Dam Near the Time of the Study

Origin Upstream or Downstream of McNary Dam	Basin of Origin	Location of Last Detection	*n*
Marked & released as juveniles			
Downstream (*n* = 88)	John Day River (*n* = 67)	McNary Dam ladder	28
		Snake River	19
		John Day River	18
		McNary Dam JBS	1
		Wells Dam ladder	1
	Umatilla River (*n* = 20)	McNary Dam ladder	17
		Snake River	3
	Hood River (*n* = 1)	McNary Dam ladder	1
Upstream (*n* = 1,034)	Snake River (*n* = 797)	Snake River	766
		McNary Dam ladder	21
		Mid/Upper Columbia	8
		Deschutes River	1
		JDA JBS	1
	Mid/Upper Columbia (*n* = 237)	Mid/Upper Columbia	151
		McNary Dam ladder	50
		Snake River	36
Marked & released as adults			
Unknown (*n* = 527)	Unknown (*n* = 527)	Snake River	424
		McNary Dam ladder	49
		Mid/Upper Columbia	47
		John Day River	4
		Umatilla River	2
		JDA ladder	1

3.1.2.2 Spring 2020

Fewer adult steelhead were detected in the spring of 2020 than in the fall of 2019. A total of 41 adult steelhead were detected in the McNary Dam fish ladders during the spring study period. These fish were last detected in the McNary Dam fish ladders no earlier than 25 February 2020 and first fish was detected no later than 9 April 2020. Within this time period, the middle 80% of first detections of these fish occurred between 25 February 2020 and 6 April 2020. Figure 3.3 displays the unique detection events for these fish in the McNary Dam fish ladders.

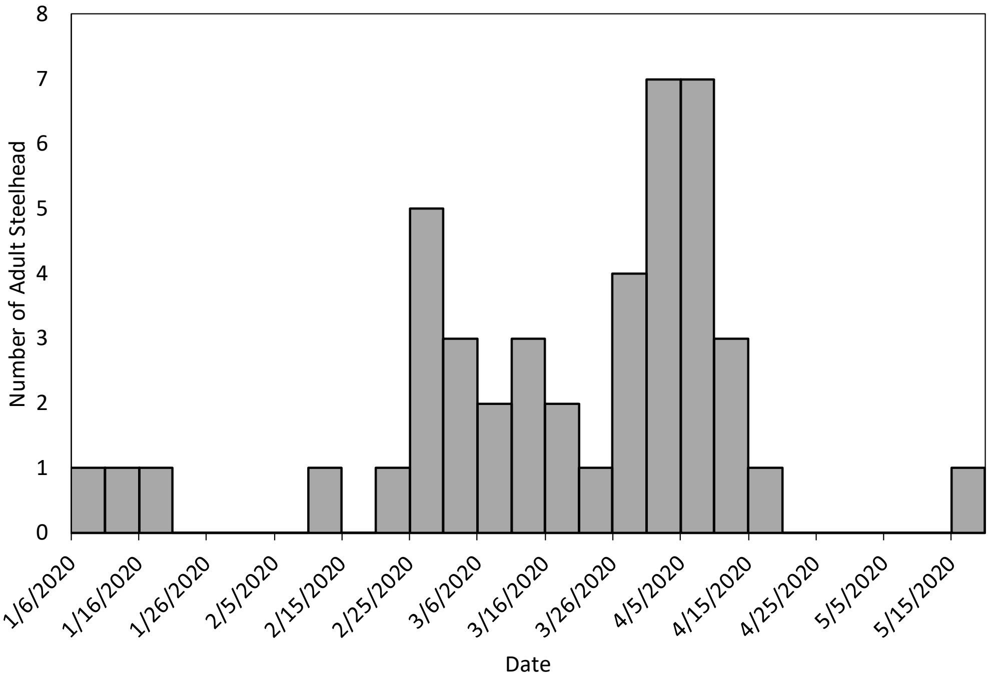


Figure 3.3. Distribution of Adult Steelhead Detections on Fish Ladder PIT Antennas during Spring 2020

A total of 22 of the fish detected during the spring period were tagged as juveniles (known origin) and 19 were tagged as adults. A total of 21 of those tagged as juveniles originated from upstream of McNary Dam and 1 originated from downstream. The 1 juvenile that originated from downstream of McNary Dam was tagged and released in Fifteen Mile Creek, near The Dalles, Oregon. This fish was last detected in the McNary Dam fish ladder on 28 February 2020 and was last detected in the John Day River on 13 March 2020.

Of the 21 known-origin fish that originated from upstream of McNary Dam, 17 (81.0%) were last detected in their natal basin, 2 (9.5%) were last detected downstream of McNary Dam in the Umatilla River, and 2 (9.5%) were last detected in the McNary Dam fish ladder.

- Of the 19 unknown-origin adult steelhead detected at McNary Dam,7 (36.8%) were last detected in the Snake River (4 of these fish were released at Bonneville Dam and 3 were released at Sherar’s Falls on the Deschutes),
- 1 (5.3%) was last detected in the Walla Walla River (this fish was released at Bonneville Dam),
- 8 were last detected in the McNary Dam fish ladder (3 released at Bonneville Dam, 1 at Sherar’s Falls, 2 at Lower Granite Dam, 1 at Prosser Dam, and 1 in Patit Creek [Touchet River tributary]), and
- 3 (15.8%) were last detected downstream of McNary Dam in the John Day River (1 of these fish was released at Sherar’s Falls and 2 were released at Lower Granite Dam).

3.2 Dam Operations

The mean discharge of each turbine unit or spill bay was calculated from 5-minute interval dam operations data supplied by the USACE[1] (Figure 3.4). The turbine units sampled for this study, Units 1 and 10, were operated often, resulting in a relatively high mean discharge. The TSW was operated for approximately 24 hours each week, so the mean discharge was low, relative to discharge when open (roughly 10 kcfs).

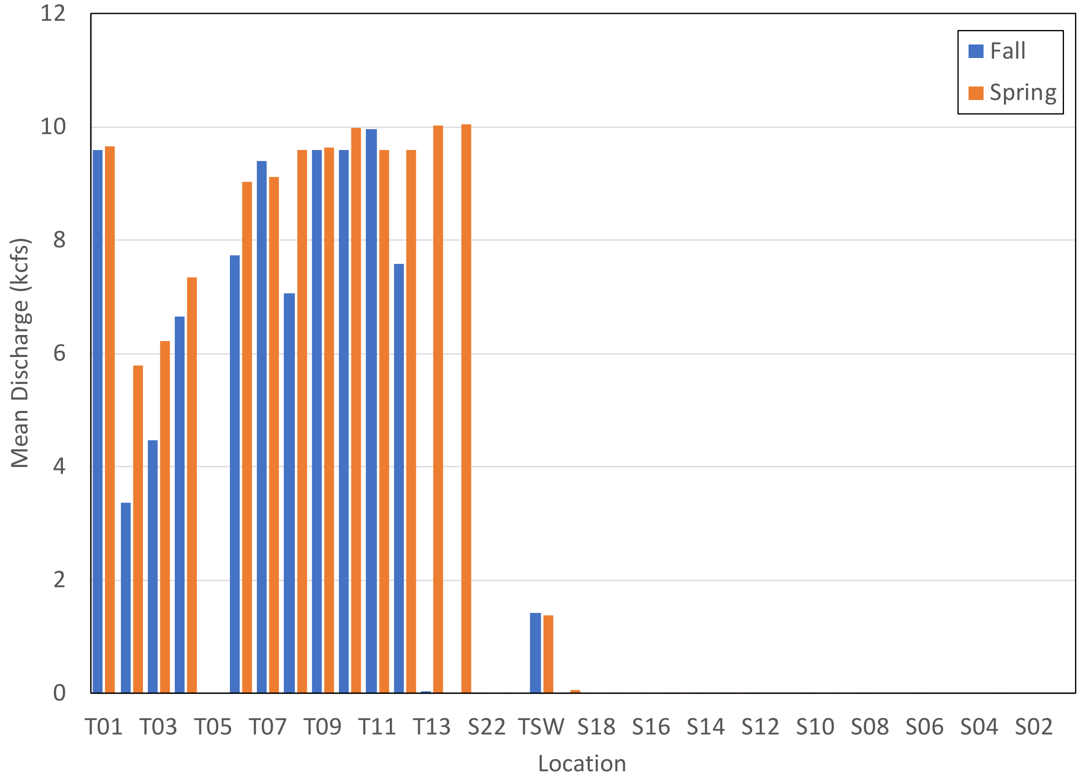


Figure 3.4. Mean Discharge by Location during the Fall and Spring Study Periods. (Data Source: USACE).

TSW discharge largely followed the treatment schedule (Figure 3.5). TSW flow values were corrected whenever data values indicated flow exceeded the discharge computed for a given forebay elevation. Discharge through deep-spill routes occurred infrequently during both study periods, but these occurrences require additional attention when interpreting the influence of TSW operation on adult steelhead passage. The original design assumed that no deep-spill or top-spill route of passage was available between planned TSW discharge periods.

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[1] The operations data obtained for the fall study period had a greater than expected number of gaps and apparent anomalies that we believe were a result of how the data were aggregated. We do not expect the impact of these gaps to be substantial, especially within the context of the planned analyses.

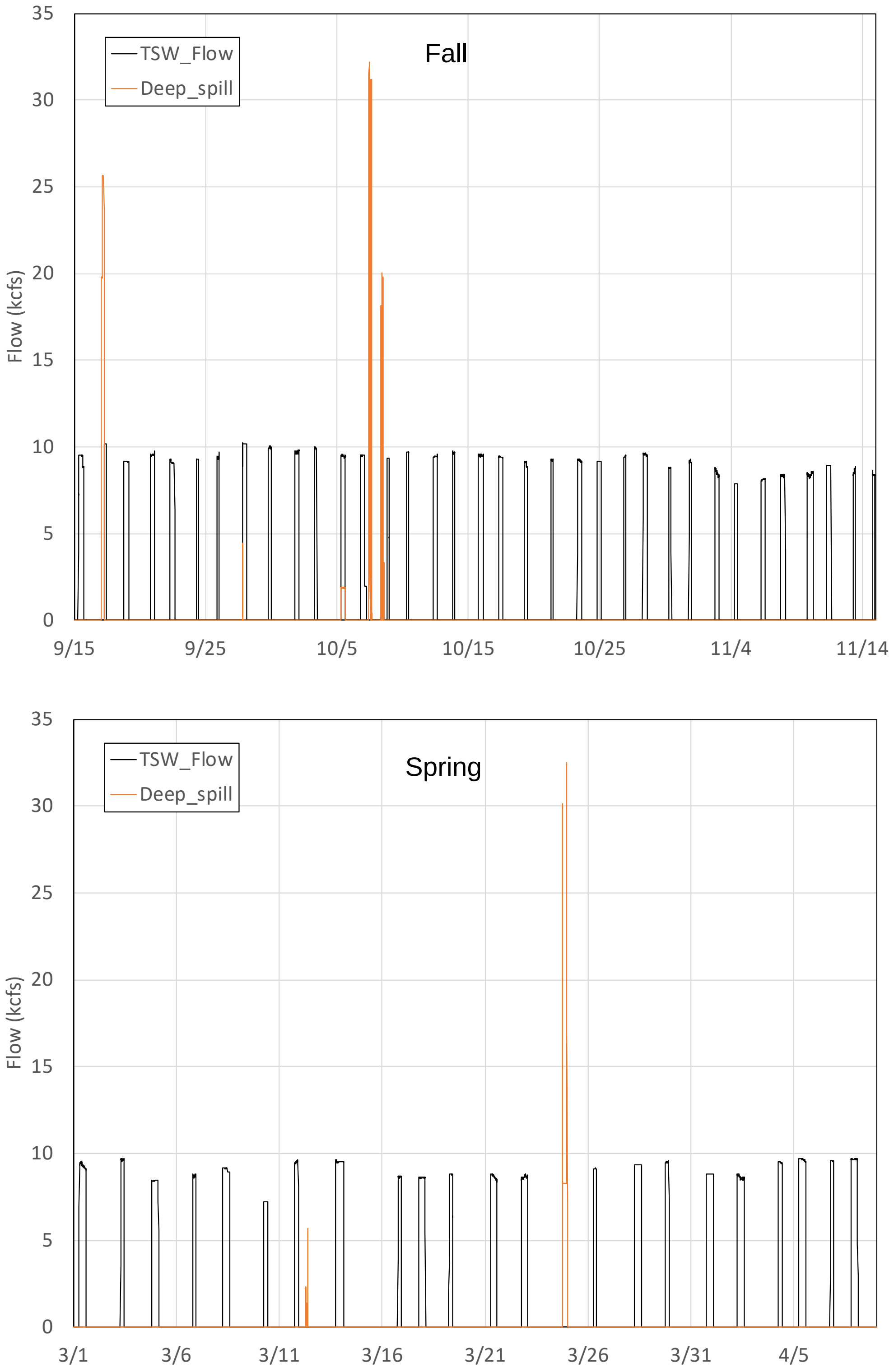


Figure 3.5. TSW Discharge during the Fall (upper) and Spring (lower) Study Periods. (Data Source: USACE).

3.3 Study Design Implementation

TSW spill treatment periods were implemented per the planned study design with a few notable deviations in timing or duration during the fall (Table 3.2) and spring (

Table 3.3) study periods. In Block 4 of the spring study period, the TSW did not operate during the planned 4-hour night treatment, causing a loss of that treatment type during that block. Other deviations were small variations in start or end time that did not materially alter the character of the treatment period. Because operational data are aggregated in 5-minute bins, deviations of 10 minutes or less (±5 minutes on each end of the period) were ignored. Passage during spill beyond the end of the planned spill duration was ignored, hence requiring no fix for analysis. Passage during periods shorter than planned was adjusted for analyses by computing passage rate across the implemented spill duration, not the planned duration.

3.4 Trends in Passage with TSW Operation

Although the study design was laid out to support a statistical test of the treatment factors, the small number of fish detected passing the TSW or the turbine units are insufficient to support that sort of analysis. An ad hoc approach to evaluating the effects of time of day and duration of TSW spill is detailed below.

3.4.1 Trends in TSW Passage among Treatments

This section evaluates how treatments varying in the diel timing or duration of TSW spill influence the timing and rates of adult steelhead passage through the TSW.

3.4.1.1 Trends in TSW Passage Following the Beginning of a TSW Spill Period

This section evaluates a question that fish managers have expressed about operating the TSW for adult steelhead passage: “How quickly do the fish respond to the opening of the TSW?” If we suppose that fish are milling around in the vicinity of the forebay face of the dam or spillway, seeking an opportunity to pass downstream, then opening the TSW may quickly attract fish to pass. Under this scenario, passage might occur rapidly after opening the TSW. Figure 3.6 allows us to interpret trends in passage after the opening of the TSW. In the fall study period, passage is relatively high in the initial 15-minute period following the onset of 4-hour TSW spill treatments, and it could be argued that passage appears to decline with time across the 4-hour window. The trend in passage during the 8-hour TSW spill treatments in the fall, however, is not consistent with the idea of declining passage. Passage is initially high but does not clearly decline throughout the 8-hour time period. The small number of fish detected passing during the spring would make it difficult to discern any trend that was not sizable and consistent, and no clear trend in passage is apparent during these spring TSW spill periods.

Table 3.2. Actual Study Design for Gate Position during the Fall Study Period. Shading differs according to treatment conditions. Red text indicates a deviation from the scheduled start or end time.

Date	Block	Day	Open	Closed	Duration
9/15	1	Sunday	0700	1700	8
9/16		Monday			
9/17		Tuesday	0700	1120	4
9/18		Wednesday	1915	0315	8
9/19		Thursday			
9/20		Friday	1900	0310	4
9/21		Saturday			
9/22	2	Sunday	0700	1500	8
9/23		Monday			
9/24		Tuesday	0700	1120	4
9/25		Wednesday	2130	2355	4
9/26		Thursday			
9/27		Friday	1900	0300	8
9/28		Saturday			
9/29	3	Sunday	1900	2300	4
9/30		Monday			
10/1		Tuesday	1900	0300	8
10/2		Wednesday			
10/3		Thursday	0700	1115	4
10/4		Friday			
10/5		Saturday	0700	1500	8
10/6	4	Sunday	1900	0610	8
10/7		Monday			
10/8		Tuesday	1900	2300	4
10/9		Wednesday			
10/10		Thursday	0700	1120	4
10/11		Friday			
10/12		Saturday	0750	1555	8
10/13	5	Sunday	1900	2300	4
10/14		Monday			
10/15		Tuesday	1900	0300	8
10/16		Wednesday			
10/17		Thursday	0725	1500	8
10/18		Friday			
10/19		Saturday	0700	1115	4
10/20	6	Sunday			
10/21		Monday	0700	1115	4
10/22		Tuesday			
10/23		Wednesday	0700	1515	8
10/24		Thursday	1920	0315	8
10/25		Friday			
10/26		Saturday	2000	2315	4
10/27	7	Sunday			
10/28		Monday	0700	1500	8
10/29		Tuesday			
10/30		Wednesday	0700	1100	4
10/31		Thursday	1900	2300	4
11/1		Friday			
11/2		Saturday	1900	0215	8
11/3	8	Sunday			
11/4		Monday	0700	1145	4
11/5		Tuesday			
11/6		Wednesday	0700	1500	8
11/7		Thursday	1900	0300	8
11/8		Friday			
11/9		Saturday	1900	2300	4
11/10	9	Sunday			
11/11		Monday	0720	1515	8
11/12		Tuesday			
11/13		Wednesday	0700	1115	4
11/14		Thursday	1900	2300	4
11/15		Friday	1845	03:00	8

Table 3.3. Actual Study Design for Gate Position during the Spring Study Period. Shading differs according to treatment conditions. Red text indicates a deviation from the scheduled start or end time. Yellow shading indicates a planned TSW spill treatment period during which the TSW did not operate.

Date	Block	Day	Open	Closed	Duration	Date	Block	Day	Open	Closed	Duration
3/1	1	Sunday	0700	1500	8	3/22	4	Sunday	1900	0255	8
3/2		Monday				3/23		Monday			
3/3		Tuesday	0700	1100	4	3/24		Tuesday	1900	2300	4>OFF
3/4		Wednesday	1900	0300	8	3/25		Wednesday			
3/5		Thursday				3/26		Thursday	0700	1100	4
3/6		Friday	1900	2300	4	3/27		Friday			
3/7		Saturday				3/28		Saturday	0700	1500	8
3/8	2	Sunday	0720	1520	8	3/29	5	Sunday	1915	2300	4
3/9		Monday				3/30		Monday			
3/10		Tuesday	0700	1115	4	3/31		Tuesday	1900	0300	8
3/11		Wednesday	1900	2300	4	4/1		Wednesday			
3/12		Thursday				4/2		Thursday	0700	1500	8
3/13		Friday	1900	0340	8	4/3		Friday			
3/14		Saturday				4/4		Saturday	0700	1115	4
3/15	3	Sunday			4	4/5	6	Sunday	0700	1500	8
3/16		Monday	1900	2300		4/6		Monday	1915	2300	4
3/17		Tuesday	1915	0320	8	4/7		Tuesday	1915	0315	8
3/18		Wednesday				4/8		Wednesday			
3/19		Thursday	0700	1025	4	4/9		Thursday	0700	1100	4
3/20		Friday									
3/21		Saturday	0700	1500	8						

A somewhat related question is whether the number of nearby likely downstream migrants is depleted quickly once the TSW is in operation. The present study design allowed us to evaluate whether passage rates in 8-hour periods of TSW spill were as high as those during 4-hour periods. Figure 3.7 compares passage rates between the TSW duration treatments for each study and diel period. To compare 4- and 8-hour durations using a common metric, passage rates were standardized to detections per hour. Although the low numbers of fish detected during the spring study period make it difficult to interpret trends, passage rates in the fall appear lower for the 8-hour duration. In the following section, we make a similar comparison between the first and last half of 8-hour periods, because they occurred within a much smaller time window, and would presumably have more similar conditions.

Passage rates for daytime tended to be higher than during nighttime for both fall and spring study periods. Table 3.4 compares passage rates for day and night periods, revealing that fall passage rates were approximately 4.76 times higher during daytime for 4-hour periods and 1.63 times higher for 8-hour periods. Spring ratios were more extreme; daytime rates for 4-hour periods were 10 times higher than nighttime rates. Rates for 8-hour periods during spring were the exception; they were slightly lower during daytime at 0.79 times those during nighttime.

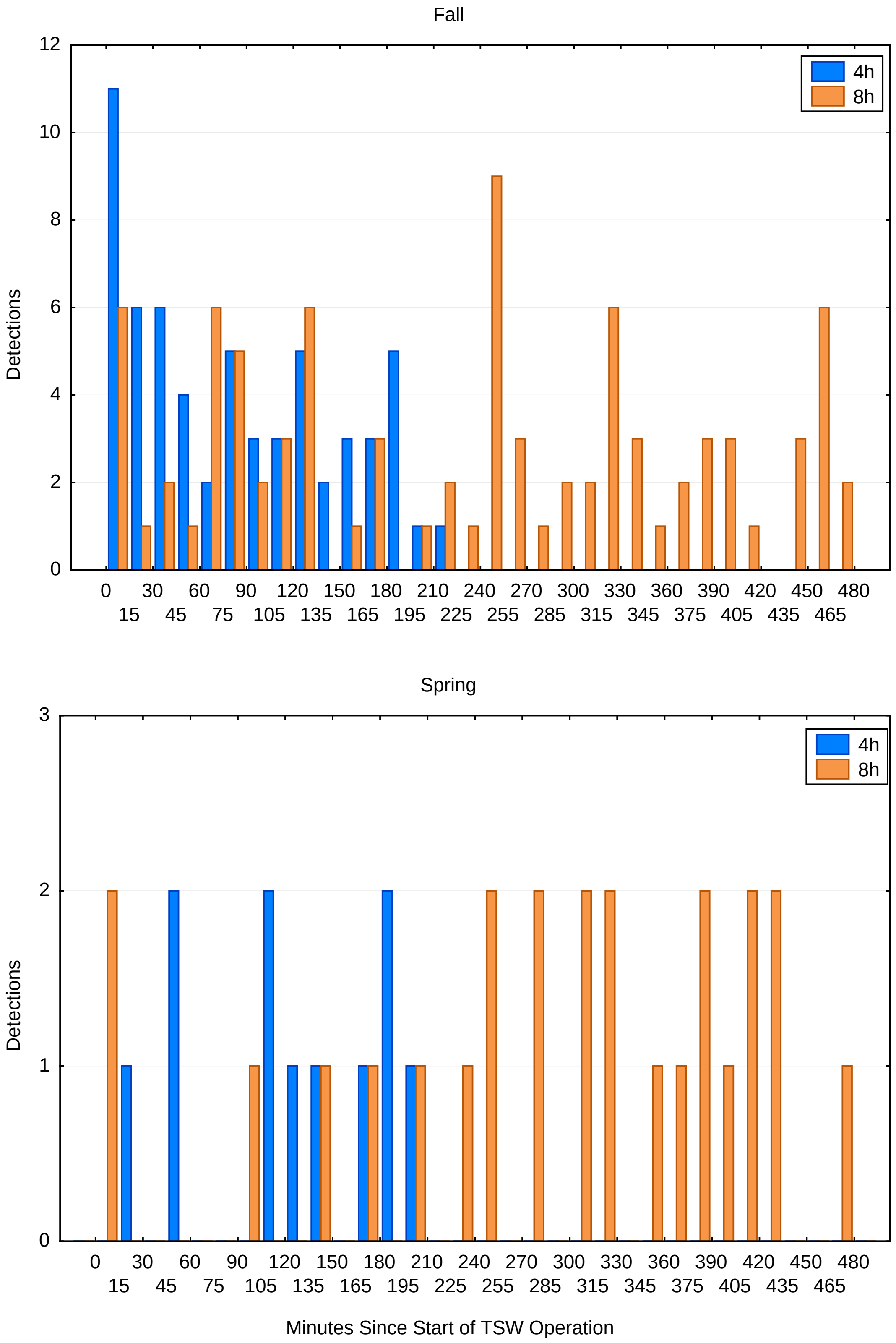
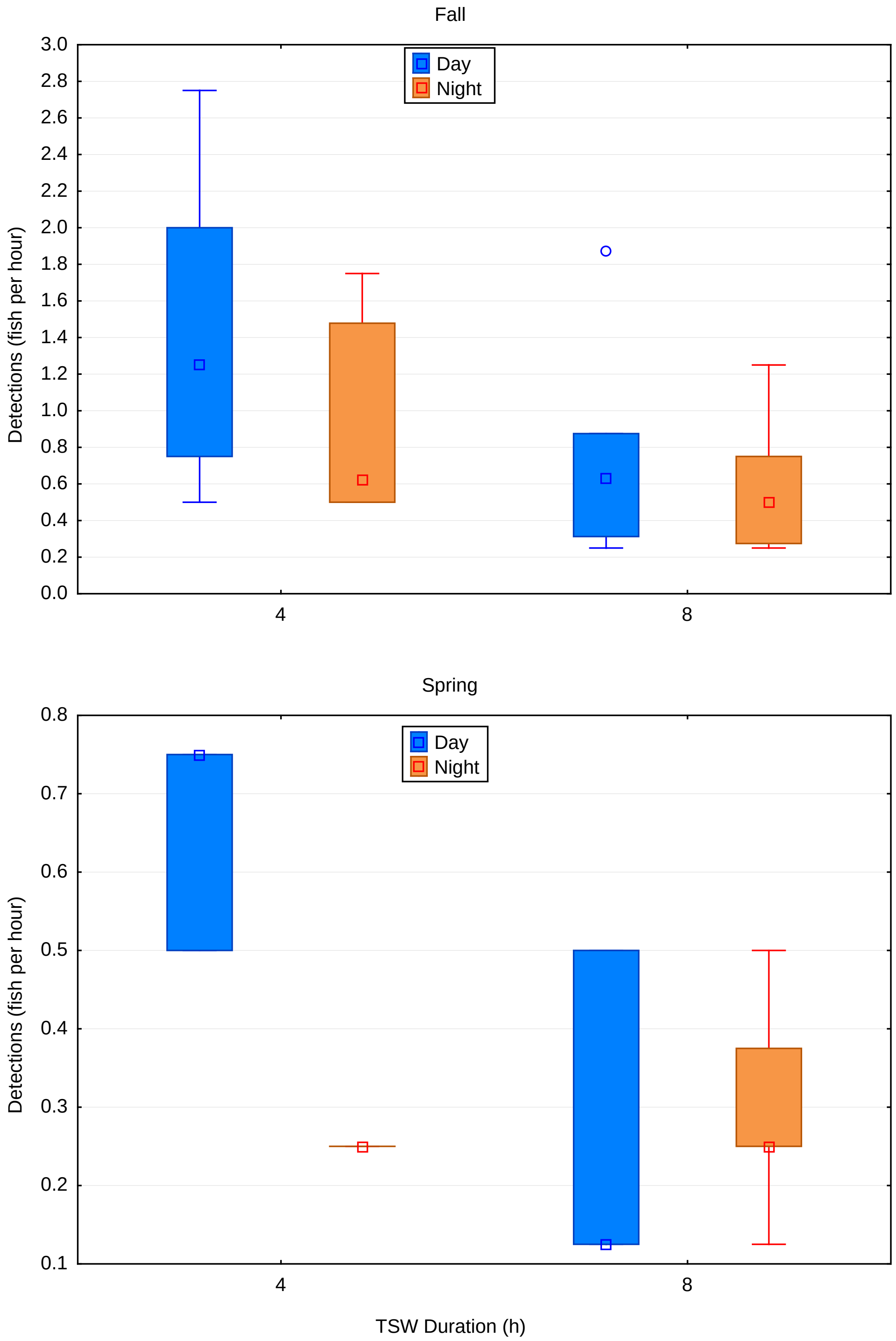


Figure 3.6. Trends in Passage after the TSW Was Opened during the Fall (top) and Spring (bottom) Study Periods


Fall

Spring

Figure 3.7. Box Plot of Detection Rates for 4- and 8-hour TSW Spill Durations during Day and Night Periods during Fall (top) and Spring (bottom). Boxes represent the middle two quartiles. Squares indicate the median value. Whiskers indicate non-outlier range. Circles indicate outliers.

Table 3.4. Relative Detection Rates per Hour for Day and Night Periods by Study Period

Study Period	Duration	Day	Night	D/N Ratio
Fall	4-hour	12.59	2.64	4.76
	8-hour	6.76	4.15	1.63
Spring	4-hour	2.50	0.25	10
	8-hour	1.38	1.75	0.79

3.4.1.2 A Closer Look at Passage Trends Relative to TSW Spill Duration

The trends in Figure 3.7 suggest that passage will become less with continuing TSW spill. However, that comparison was made among treatments that occurred on different days, which created a potential for other factors to influence the result. To minimize that possibility, we split the 8-hour duration treatment periods into a first and last 4-hour period. If the trend we observed above holds true, we would expect the latter half of the 8-hour duration periods to have lower passage rates. Figure 3.7 compares passage rates between the partial duration TSW treatment periods for each study and diel period. The original 4-hour study periods are included as a point of reference. There is no indication that passage rates are lower during the last half of an 8-hour TSW spill period during day or night for the fall study period. As before, the small numbers of fish passing during spring make it difficult to interpret apparent differences. Ideally, there would be no difference between the 4-our duration and the first half of the 8-hour duration periods, but we find relatively high passage rates for the 4-hour duration periods. With a few exceptions due to the vagaries of dam operations (as noted above), these periods would occur at the same time of day a few days apart, with nothing in the study design expected to influence passage. This suggests that factors other than the treatments are likely influencing passage rates. While comparing 4-hour and 8-hour periods suggested that passage rates were declining with TSW spill duration, evaluation of passage within 8-hour TSW spill periods found no evidence of a decline.

Table 3.5 compares mean passage rates between the first 4 hours of 8-hour TSW spill periods with the last 4 hours of an 8-hour TSW spill periods. For three of four comparisons, the mean passage rate during the first 4 hours was lower (ratio less than 1.0) than for the last 4 hours. In one comparison, the mean passage rate for the first 4 hours of an 8-hour period was 1.19 times that of the last 4 hours. This finding is consistent with the preceding plot in providing no support for the possibility that the number of potential migrants will become depleted soon after the onset of TSW operation.

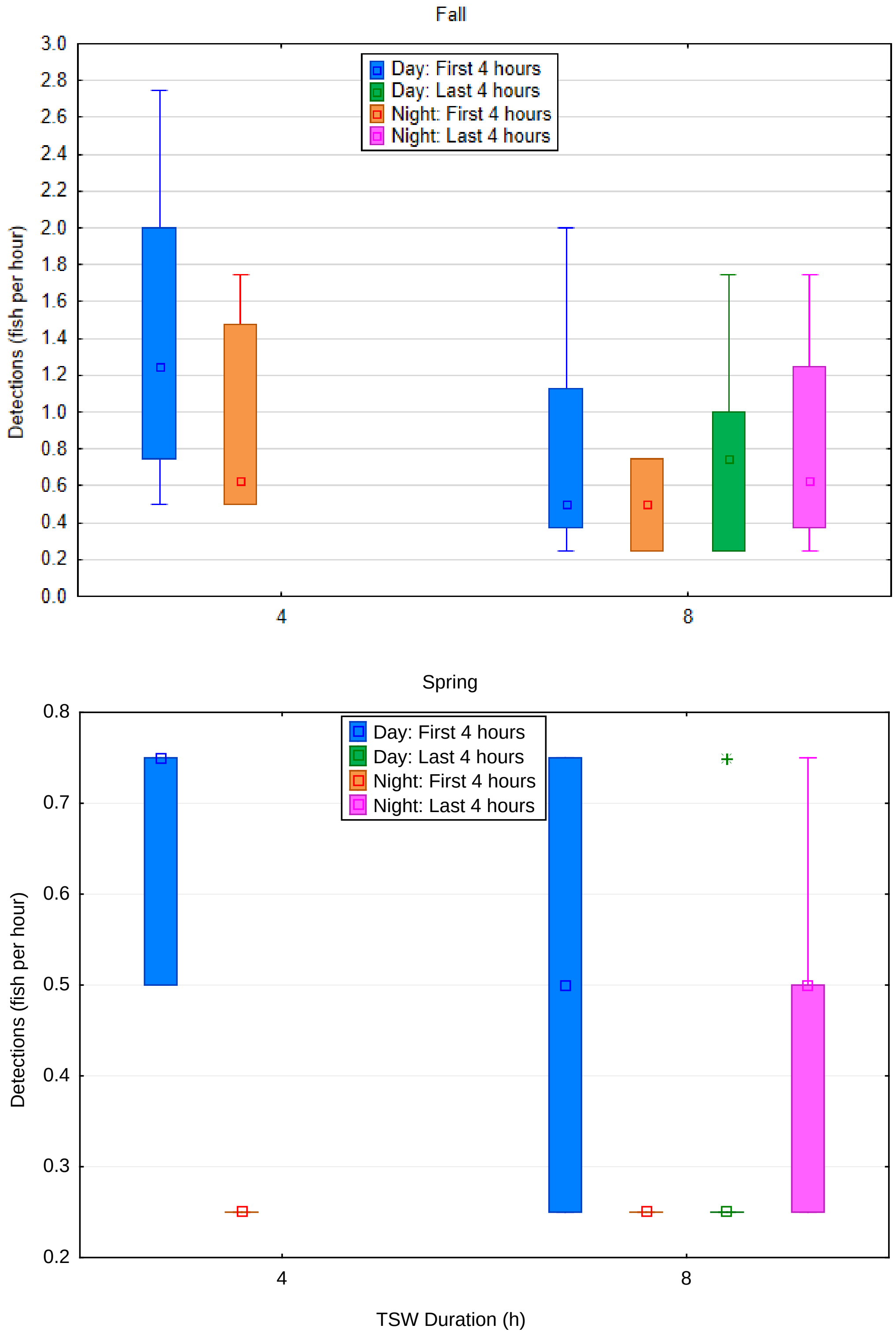


Figure 3.8. Box Plot of Detection Rates for 4- and 8-hour TSW Spill Durations during Day and Night Periods during Fall (top) and Spring (bottom). Boxes represent the middle two quartiles. Squares indicate the median value. Whiskers indicate non-outlier range. Circles indicate outliers. Star symbols indicate extreme values.

Table 3.5. Relative Passage Rates per Hour for the First and Last Half of 8-hour TSW Duration Spill Treatments by Study Period

Study Period	Diel Period	Hours 1 to 4	Hours 5 to 8	First vs Last 4 Hours Ratio
Fall	Day	3.13	2.63	1.19
	Night	1.90	3.25	0.58
Spring	Day	0.50	0.88	0.57
	Night	0.38	1.38	0.27

3.4.2 Fish Detected Upstream of the TSW

The imaging sonar monitoring fish upstream of the TSW is intended to provide information about fish that are near the entrance of the TSW. Figure 3.9 compares trends across the fall and spring study periods in the number of adult steelhead and shad/other species detected (non-expanded counts) upstream of the TSW with the number of adult steelhead detected passing through the TSW. The imaging sonar data included in the figure are a subsample of the total time available and exclude any times when the TSW was not operating. The trends of fish detected passing the TSW are not clearly correlated with either species group detected in the imaging sonar sampling zone just upstream of the TSW. The lack of correlation between hydroacoustic and imaging sonar detections of adult steelhead suggests that fish in the vicinity of the TSW are not immediately passing downstream, and that implies that fish behavior has the potential to influence when or where these fish pass. Adult shad and other non-salmonid fish were monitored as a quality control measure. If peaks in hydroacoustic passage were consistent with the times when large numbers of adult shad were in the vicinity of the passage route, then it would cause us to look for better ways to differentiate them from the adult steelhead. No correlation is evident between peaks in adult shad or other non-salmonid fish and hydroacoustic detections, which suggests that our filtering approach for these fish has been successful at removing them from our counts of adult steelhead in the hydroacoustic detections.

3.4.3 Fish Detected Upstream of the Powerhouse

The imaging sonar monitoring fish upstream of powerhouse Unit 10 is intended to provide information about fish that are in the forebay near the powerhouse. Figure 3.10 compares trends across the study period in the number of adult steelhead detected upstream of Unit 10 with the number of adult steelhead detected passing through the guided portions of Units 1 and 10. The imaging sonar data included in the figure are a subsample of the total time available and exclude any times when the TSW was not operating. The trends of fish detected passing either unit in the hydroacoustic sampling are not clearly correlated with the other unit or the numbers of adult steelhead detected in the imaging sonar sampling zone just upstream of Unit 10. The lack of correlation between hydroacoustic and imaging sonar detections of adult steelhead upstream of Unit 10 suggests that fish in the vicinity of the powerhouse are not immediately passing downstream, and that fish behavior has the potential to influence when or where these fish pass.

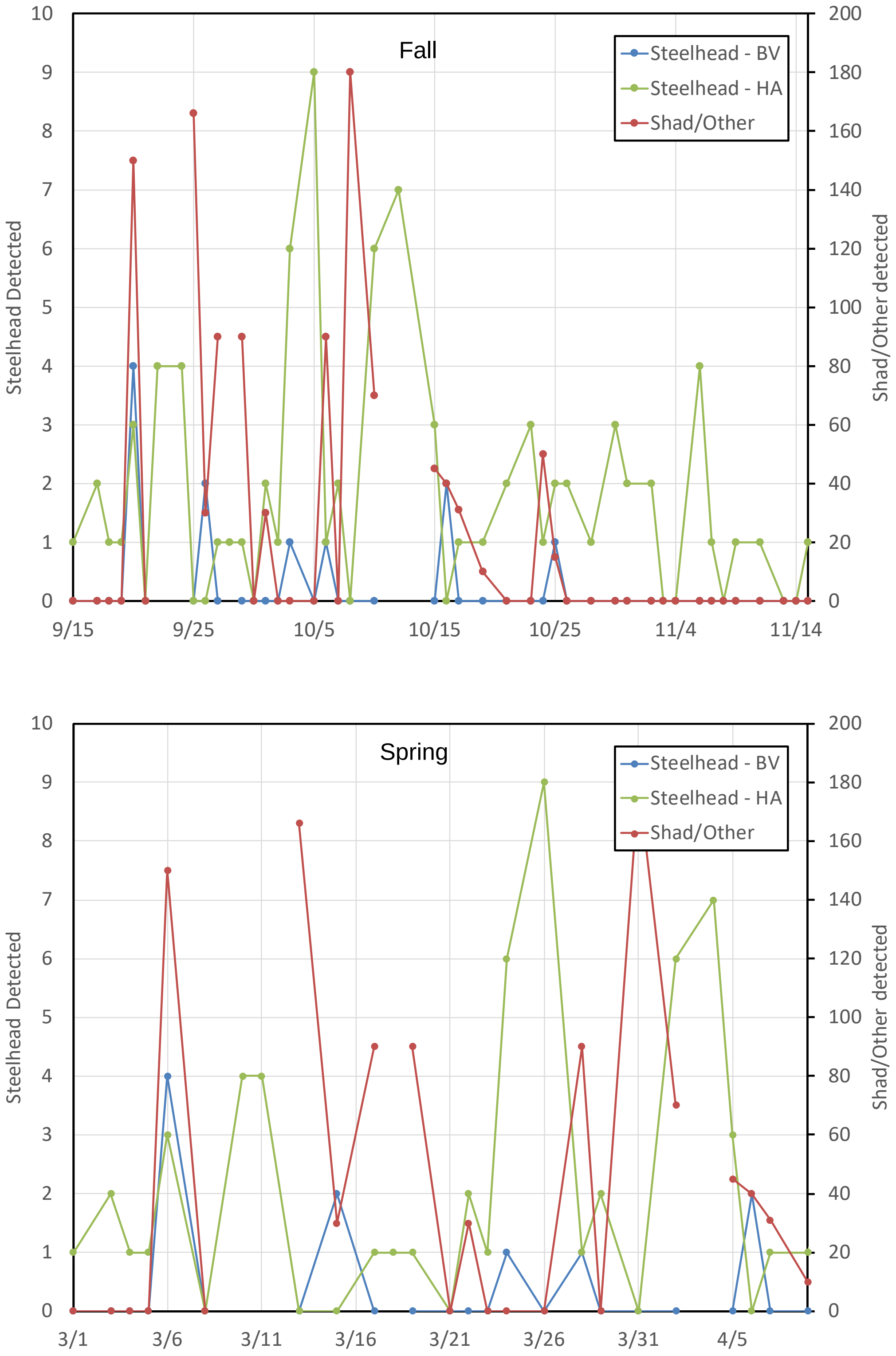


Figure 3.9. Trends in the Numbers of Fish Detected during Fall (top) and Spring (bottom) Upstream of the TSW Compared to Fish Detected Passing the TSW

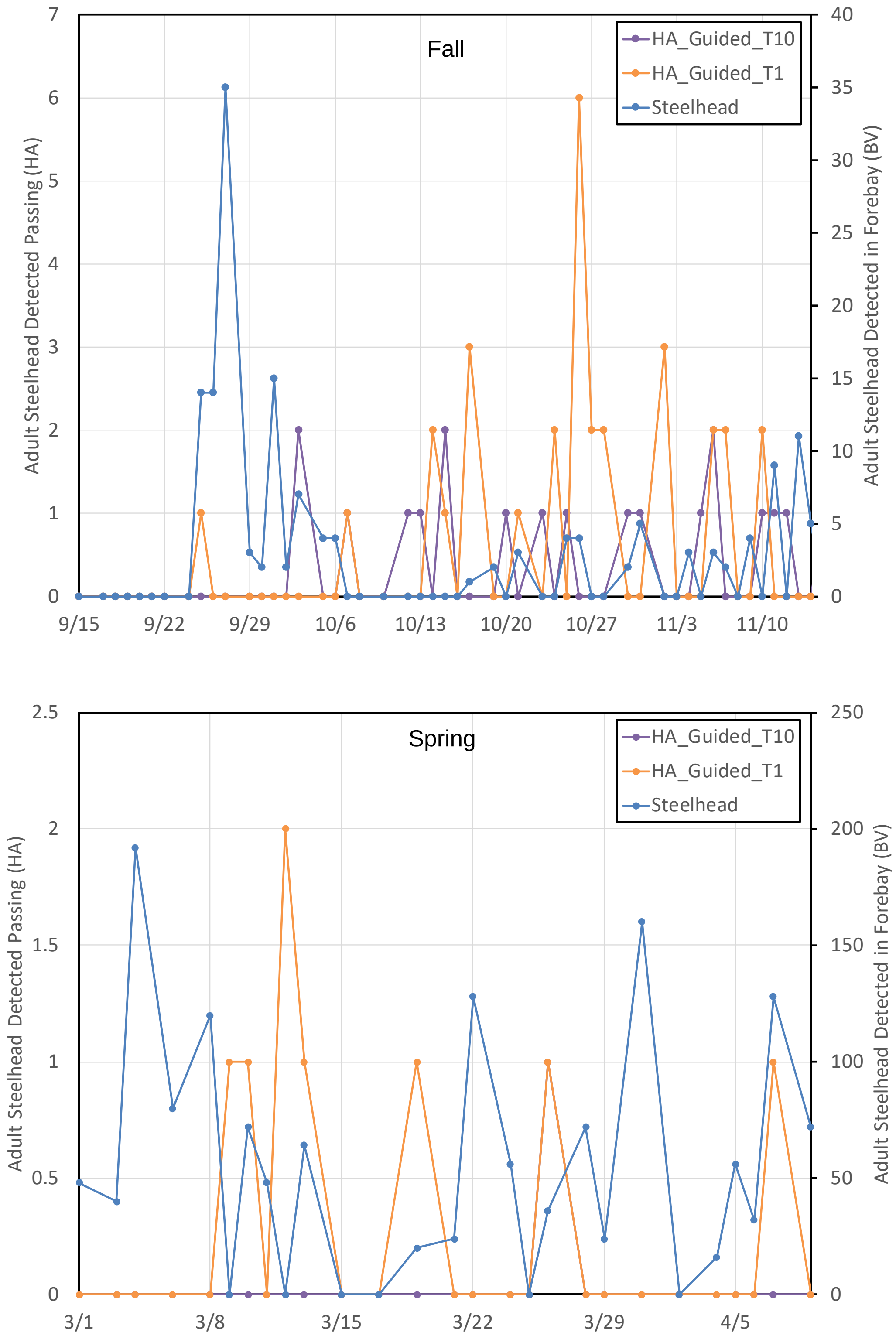


Figure 3.10. Trends in the Numbers of Fish Detected Upstream of Unit 10 Compared to Fish Detected Passing Units 1 and 10.

4.0 Discussion

This study contrasted TSW spill periods of differing durations and at different times of the day. The small number of fish detected passing the TSW and the smaller number of fish detected passing the turbine units were best suited to an ad hoc, exploratory approach to evaluating the effect of TSW spill. Spring adult steelhead passage rates estimated using hydroacoustics were less than half of those estimated during the fall study period, and that was consistent with our analysis of PIT-tagged fish likely to be in the vicinity during each study period.

Detections of fish in imaging sonar sampling areas upstream of the TSW and powerhouse were not correlated with detections of fish passing hydroacoustic sampling areas, which suggests that fish approaching the face of the dam can move within the forebay before passing. Other fish detected in the forebay in large numbers, such as adult shad, were able to be filtered out of adult steelhead passage counts and did not appear to be influencing hydroacoustic passage rate estimates.

A pulse of passage at the initial TSW opening was not consistent, but trends across 4- and 8-hour operational periods did not show a distinct decline in passage over time as TSW operation continued. Our findings do not indicate a reason to choose one 8-hour period over two 4-hour periods, or vice versa. This suggests that the duration of spill periods can be chosen based on operational or other considerations.

Passage rates were as much as two times higher during the daytime TSW discharge periods than during the nighttime TSW discharge periods. The experimental design of the current study used start times near dawn for day periods and near dusk for night periods. Current findings show that TSW spill periods beginning near dawn should be chosen if the desire is to increase downstream passage of adult steelhead. Further refinement of that recommendation may be possible by conducting further study of diel influences on adult steelhead passage.

Given that the diel timing of TSW discharge appears to have a greater influence on passage rates than duration, future study could focus on the influence of the diel period on passage. If 4-hour periods were chosen, a 24-hour weekly allocation of spill would provide six TSW discharge periods for developing a study design. That design could compare the best diel periods from the current study with other times of day to find the most effective times of day for passing adult steelhead over the TSW at McNary Dam.

5.0 References

Colotelo AH, BW Jones, RA Harnish, GA McMichael, KD Ham, ZD Deng, GM Squeochs, RS Brown, MA Weiland, GR Ploskey, X Li, and T Fu. 2013. *Passage Distribution and Federal Columbia River Power System Survival for Steelhead Kelts Tagged Above and at Lower Granite Dam*. PNNL-22101, prepared for the U.S. Army Corps of Engineers, Walla Walla District, Contract Number W912EF-08- D-0004, by Pacific Northwest National Laboratory, Richland, Washington.

Colotelo AH, RA Harnish, and BW Jones, and 10 other authors. 2014. *Passage Distribution and Federal Columbia River Power System Survival for Steelhead Kelts Tagged Above and at Lower Granite Dam, Year 2*. PNNL-23051, prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla Washington, by Pacific Northwest National Laboratory, Richland, Washington.’

Ham KD, PS Titzler, RP Mueller, and DM Trott. 2012a. *Hydroacoustic Evaluation of Adult Steelhead Fallback and Kelt Passage at McNary Dam, Winter 2010-2011*. PNWD-4154, prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington by Battelle-Pacific Northwest Division Richland, Washington.

Ham KD, PS Titzler, RP Mueller, and DM Trott. 2012b. *Hydroacoustic Evaluation of Adult Steelhead Fallback and Kelt Passage at McNary Dam, Winter 2011-2012*. PNWD-4362, prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla Washington, by Battelle-Pacific Northwest Division Richland, Washington.

Ham, KD., PS Titzler, and RP Mueller. 2015. *Evaluation of adult steelhead passage with TSW spill during the winter of 2014-2015 at McNary Dam*. Final report prepared for the U.S. Army Corps of Engineers, Walla Walla District by Pacific Northwest National Laboratory (Richland, Washington, PNNL-24856, Contract DE-AC05-76RL01830).

Keefer, ML, CT Boggs, CA Peery, and CC Caudill. 2008. “Overwintering distribution, behavior, and survival of adult summer steelhead: variability among Columbia River populations.” *North American Journal of Fisheries Management* 28:81-96.

Khan F, GE Johnson, and MA Weiland. 2009. *Hydroacoustic Evaluation of Overwintering Summer Steelhead Fallback and Kelt Passage at The Dalles Dam 2008-2009*. PNNL-18590, final report to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Normandeau Associates, Inc. 2014. *Direct Injury and Survival of Adult Steelhead Trout Passing a Turbine and Spillway Weir at McNary Dam*. Final report prepared for the U.S. Army Corps of Engineers, Walla Walla District by Normandeau Associates, Inc., Drumore, Pennsylvania.

Rayamajhi B, GR Ploskey, CM Woodley, MA Weiland, DM Faber, J Kim, AH Colotelo, Z Deng, and T Fu. 2013. *Route-Specific Passage and Survival of Steelhead Kelts at The Dalles and Bonneville Dams, 2012*. PNNL-22461, Pacific Northwest National Laboratory, Richland, Washington.

Richins, S.M. and J.R. Skalski. 2017. “Evaluation of the steelhead adult overshoot and fallback rates in the Columbia/Snake river basin and some factors influencing their rates of occurrence.” In: Volume XXVII, *The Design and Analysis of Salmonid Tagging Studies in the Columbia Basin*. Project No. 1989-107-00, Contract No. 74580. Prepared for the U.S. Department of Energy, Bonneville Power Administration, Portland, OR.

USACE. 2019. *2019 Fish Passage Plan: Lower Columbia & Lower Snake River Hydropower Projects. March 1, 2019 – February 29, 2020*. U.S. Army Corps of Engineers, Northwestern Division. Columbia Basin Water Management. CENWD-PDW-R (http://pweb.crohms.org/tmt/documents/fpp/2019/final/FPP19_Final_071119.pdf)

USACE. 2020. *2020 Fish Passage Plan: Lower Columbia & Lower Snake River Hydropower Projects. March 1, 2020 – February 28, 2021*. U.S. Army Corps of Engineers, Northwestern Division. Columbia Basin Water Management. CENWD-PDW-R (http://pweb.crohms.org/tmt/documents/fpp/2020/final/FPP20_Final_06-11-20.pdf)

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

System	Component	S/N	Channel	Location	Cable Length_S/N	Aiming Angle	Xducer el (ft)
A	Sounder	24					
	Remote Mux	11					
	Xducer 1	482	0	10A_unguided	313_171	24	270
	Xducer 2	469	1	10A_guided	250_199	31	239
B	Sounder	25					
	Remote Mux	15					
	Xducer 1	476	1	1A_guided	313_134	31	239
	Xducer 2	447	2	1A_unguided	280_148	24	270
I	Sounder	20					
	Remote Mux	23					
	Xducer 1	402	2	10B_unguided	231_118	24	270
	Xducer 2	465	3	10B_guided	282_178	31	239
J	Sounder	50					
	Remote Mux	29					
	Xducer 1	479	1	TSW_N	157_47	17.5	282
	Xducer 2	448	0	TSW_M	235_204	17.5	282
	Xducer 3	454	3	TSW_S	222_169	17.5	282
K	Sounder	21					
	Remote Mux	22					
	Xducer 1_Fall	406	0	1B_guided	220_136	31	239
	Xducer 2	400	1	1B_unguided	313_129	24	270
	Xducer 3_Spring	483	2	1B_guided	210_78	31	239

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

System	Sounder	Channel	Transducer	Receiver Gain (L) (dB)	Source Level (SL) (dB)	Receiver Sensitivity (G1) (dB)	Target Strength of Smallest On-axis Target (dB)	Voltage of Smallest On-axis Target (dB)	Target Strength of Largest On-axis Target (dB)	Voltage of Largest On-axis Target (dB)
A	24	0	482	8.00	211.57	-103.57	-56	3	-26	4.5
A	24	2	469	5.25	215.10	-104.35	-56	3	-26	4.5
B	25	1	476	6.75	213.66	-104.41	-56	3	-26	4.5
B	25	2	447	8.00	212.91	-104.91	-56	3	-26	4.5
I	20	0	402	8.25	212.36	-104.61	-56	3	-26	4.5
I	20	1	465	4.25	214.66	-102.91	-56	3	-26	4.5
J	50	0	479	3.01	211.71	-106.71	-56	2.6	-26	4.1
J	50	1	448	5.50	210.72	-108.22	-56	2.6	-26	4.1
J	50	2	454	2.50	211.95	-106.45	-56	2.6	-26	4.1
K	21	0	406	7.50	211.41	-106.91	-56	2.8	-26	4.3
K	21	1	400	4.25	211.17	-103.42	-56	2.8	-26	4.3
K	21	2	483	0.25	213.53	-101.78	-56	2.8	-26	4.3

Appendix B –Raw Data

Raw data for passage and dam operations is included as a separate excel file: MCN_Overshoot_2020_Final_Report_PNNL_30030_appendix_B.xlsx.

Appendix C – Statistical Methods

The purpose of this synopsis is to describe the statistical methods used in the analysis of the 2019 hydroacoustic evaluation of the effect of operating gate position on fish guidance efficiency (FGE) at McNary Dam. The study estimated passage through two units of the powerhouse, primarily to estimate FGE and gap loss.

C.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.

C.1.1 Estimating Unguided Passage

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

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

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

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

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 (C.1) by restricting summation over various subscripts in Equation (C.1) and analogously for the variance formula (C.2)).

C.1.2 Estimating Guided Passage

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

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

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

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

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 (C.3) by restricting summation over various subscripts in Equation (C.3) and analogously for the variance formula (C.4).).

C.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

$$\hat{\mathrm{T}} = \sum_{i=1}^{D}\sum_{j=1}^{24}\frac{C_{ij}}{c_{ij}}\sum_{k=1}^{c_{ij}} t_{ijk} , \qquad \text{(C.5)}$$

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 $(i=1,\ldots,D)$;

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

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

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

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

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

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

C.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

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

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 (C.7), characterizes the statistical uncertainty associated with the measurement of a fish passage or performance parameter.

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