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Hydroacoustic Evaluation of Juvenile Salmonid Passage and Distribution at Detroit Dam, 2011

FINAL REPORT

F Khan
IM Royer
GE Johnson
KD Ham

November 2012

Pacific Northwest
NATIONAL LABORATORY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Abstract

Pacific Northwest National Laboratory (PNNL) evaluated juvenile salmonid passage and distribution at Detroit Dam (DET) on the North Santiam River in Oregon for the U.S. Army Corps of Engineers Portland District (USACE) to provide data to support decisions being made about long-term measures to enhance downstream passage at DET and others dams in USACE's Willamette Valley Project. This study was conducted in response to regulatory requirements necessitated by the listing of Upper Willamette River Spring Chinook salmon (*Oncorhynchus tshawytscha*) and Upper Willamette River steelhead (*O. mykiss*) as threatened under the Endangered Species Act. The results of the hydroacoustic study of juvenile salmonid passage and distribution at DET provide new and, in some cases, first-ever data on passage estimates, run timing, distributions, and relationships between fish passage and environmental variables at DET from February 2011 through February 2012. This information will inform management decisions about the design and development of surface passage and collection devices to help restore Chinook salmon populations in the North Santiam River watershed above DET.

Summary

This report presents the results of an evaluation of juvenile salmonid passage and distribution at Detroit Dam (DET) on the North Santiam River in Oregon. The study was conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers Portland District (USACE). The goal of the study was to provide fish passage and distribution data to support decision-making about long-term measures for enhancing downstream salmonid passage at DET and others dams in USACE's Willamette Valley Project.

During the year-long study period—February 20, 2011 to February 12, 2012—the objectives of the hydroacoustic evaluation of smolt-size[1,2] fish passage and distribution at DET were as follows:

1. Estimate passage rates, run timing, horizontal distribution, and diel distribution at the *turbines*.
2. Estimate passage rates, run timing, passage efficiency and effectiveness relative to total project passage (turbines plus spillway), horizontal distribution, and diel distribution at the *spillway*.
3. Estimate passage rates, run timing, passage efficiency and effectiveness relative to total project passage (turbines plus regulating outlet), and diel distribution at the *regulating outlet*.
4. Analyze relationships between daily fish passage and Julian day, total project discharge, forebay elevation, forebay elevation delta, and water temperature.
5. Estimate vertical distribution and an abundance index for smolt-size fish in the forebay near the upstream face of the dam.
6. Characterize the acoustic sizes of smolt-size fish passing the dam.

The fixed-location hydroacoustic technique was instituted to accomplish the objectives of this study. Transducers (420 kHz) were deployed in each of the two turbine penstock intakes, above the operating regulating outlet (RO) entrance, at Spill Bays 4 and 5, and on the dam face (between the penstock intakes and spillway). A total of nine transducers (two single beams and seven split beams) were used. To alleviate the lack of species discrimination in the hydroacoustic data, we interpreted the data using species composition data from tailrace screw trap. Few smolt-size non-salmonid fish passed DET, therefore the hydroacoustic estimates reflect salmonid fishes. Hydroacoustic samples were collected 24 h/d during the year-long study, except for during periods when we had to wait to replace damaged transducer cables (Spillway and RO) and for short periods for data download.

The forebay pool elevation of DET follows a "rule curve" managed by the USACE Reservoir Control Center. In 2011, the forebay pool elevation began to increase in early February, peaked on May 9 at El. 476 m (1,562 ft), held at a mean elevation of 476 m (1,561 ft) through August (summer; Conservation Pool), and decreased for during fall, from September through November. From late November to the beginning of February 2012, forebay elevation fluctuated due to runoff from winter rain events. The minimum pool elevation for the study period occurred on December 27 at 439.4 m (1,442 ft). We present

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[1] While we can discriminate between size classes of fish, we cannot discriminate between salmonid species and non-salmonid species with hydroacoustic data.

[2] For the purpose of analysis in this study, smolt-size fish were defined as 90 mm < fork length < 300 mm. The lengths are approximations based on acoustic target strength.

results for four periods based on distinct patterns in pool elevation: Refill (February 1 – April 30, 2011); Conservation Pool (May 1 – August 31); Drawdown (September 1 – November 15); and Winter Pool (November 16, 2011 – February 1, 2012).

Turbine discharge remained fairly constant between February 15 and late March, with a daily average of 790 m^3/s (~27.9 kcfs). Discharge started increasing through April, with daily peaks on March 25 of 2,537 m^3/s (~90 kcfs) and on April 21 of 2,699 m^3/s (~95 kcfs) (Figure 3.2). Daily turbine discharge fluctuated between May and June, ranging from 378 m^3/s (~13.4 kcfs) to 1,955 m^3/s (~69 kcfs), after which, remained fairly constant between July and August, with a daily average of 398 m^3/s (~14 kcfs). From September until the end of the study period in February 2012, daily turbine discharge was generally high and fluctuated widely due to rain events, ranging from 370 m^3/s (~13 kcfs) on September 6 to 3,336 m^3/s (~118 kcfs) on February 7.

The study results provide data about passage estimates; run timing; and horizontal, diel, and vertical distributions and relationships between fish passage and environmental variables at the dam. Findings from this one year of study should be applied carefully because annual variation can be expected due to the variability in adult salmon escapement, egg-to-fry and fry-to-smolt survival rates, reservoir rearing and predation, dam operations, and weather, etc. We summarize the findings from the hydroacoustic evaluation of juvenile salmonid passage and distribution at DET as follows:

- For the year-long study period, an estimated total of 210,948 smolt-size fish (±4,705 fish, 95% confidence interval [CI]) passed through the three routes (turbines, spillway, and RO) of the dam.
- An estimated 182,526 smolt-size fish (±4,660 fish, 95% CI) passed through the turbines between February 20, 2011 and February 12, 2012. Run timing peaked in winter months.
- Turbine passage rates for smolt-size fish (>~90 mm and <300 mm fork length) were highest during late fall, winter and early spring months. Passage was lowest during summer months.
- Horizontal distribution for hours when both turbine units were operated simultaneously indicated Unit 2 passed almost twice as many fish as Unit 1.
- Diel distribution for turbine passage was fairly uniform, indicating fish were passing the turbines at all times of the day.
- A total of 5,083 smolt-size fish (± 312 fish, 95% CI) were estimated to have passed via the spillway when it was open between June 23 and September 27, 2011. From June 23 through September 22 when only Spill Bay 5 was open, we estimated 3,405 ± 188 (95% CI) fish passed via spill. Daily passage was low at the spillway during June through August, and increased in September.
- From September 23 through 27, the USACE conducted a “free flow” test during Drawdown by opening both Spill Bays 4 and 5. Forebay elevation started at approximately 470.5 m (~1,543 ft) on September 23 and ended at 469.7 m (1,541 ft) (crest elevation) on the morning of September 27. We estimated a total of 1,678 ± 248 (95% CI) smolt-size fish passed the two bays during this period. Daily spillway passage peaked on September 25 at 651 ± 157 (95% CI) fish.

- When the spillway (Bay 5) was operated simultaneously with the turbines (a total of 183 hours), spillway efficiency[3] was 0.72 and effectiveness[4] was 2.69. That is, when the spillway was open, 72% of the fish passing the dam used the spillway and 28% passed into the turbines.
- Horizontal distribution at the spillway for hours when Bays 4 and 5 were operated simultaneously indicated both bays passed similar numbers of fish.
- Diel distribution at the spillway (Spill Bay 5) shows a distinct peak in fish passage between mid-morning and mid-afternoon and low passage at night.
- We estimated that 23,339 smolt-size fish (± 572 fish, 95% CI) passed via the RO when it was open from October 29 through November 12, 2011, January 2 through 6, and January 20 through February 3, 2012. During the October–November period, RO passage peaked at 1,086 fish on November 5, with a second peak on November 7 (1,075 fish). (The turbines were out of service from November 1 through 8 and all water passed the dam through the RO during this period.)
- When the RO was operated simultaneously with the turbines (a total of 72 hours), RO efficiency was 0.33 and effectiveness was 0.89.
- Diel distribution for RO passage was variable, indicating fish were passing the RO at all times of the day.
- In multiple regression analyses, a relatively parsimonious model was selected that predicted the observed fish passage data well. The best model included forebay temperature at depth, forebay elevation, total discharge, hours of daylight, and the operation period.
- The vertical distribution of smolt-size fish in the forebay near the face of the dam showed fish were generally distributed throughout the water column during all four operational periods. During the Refill and Conservation Pool periods, vertical distribution was bi-modal with surface-layer and mid-water modes. Patterns for day and night distributions were variable. Fish were distributed above and below the thermocline when it was present (during Conservation Pool and Drawdown periods).
- Forebay fish abundance was relatively uniform across the study year; a distinct peak occurred in mid-March.
- The mean acoustic size (target strength) of fish at the turbines was fairly consistent at -50 dB among the passage peaks during the year-long study. This corresponds to a fish length of about 100 mm. Mean target strength for fish at the spillway during September indicated average fish length of about 150 mm. For the two analysis periods for the RO, acoustic sizes corresponded to 105 mm fish in November and ~60 mm fish in January.

We draw the following conclusions from the hydroacoustic evaluation of juvenile salmonid passage and distribution at DET from February 2011 through February 2012:

- The non-obtrusive hydroacoustic data from this study are reliable because passage patterns were similar to those observed in the direct-capture data from the tailrace screw trap.

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[3] Spillway efficiency is estimated as spillway passage divided by total project passage.

[4] Spillway effectiveness is estimated by the fish:flow ratio—proportion fish passage at a route (e.g., spillway) divided by proportion of water through that route out of the total project.

- The variable vertical distribution of fish we observed indicates the need for careful consideration of development of surface passage or collector devices.
- The horizontal distribution of turbine passage should be considered for placement of proposed surface collectors or passage devices.

We offer the following recommendations for future research at DET to support the design of fish passage or collection systems:

- Consider conducting a quick, focused test of surface spill to demonstrate whether juvenile salmonids will pass at a time of year when emigrants are typically migrating downstream.
- Consider additional evaluations of the RO (such as different gate openings and different forebay pool elevations, when the pool elevation is below the spillway crest) as a non-turbine route to pass juvenile salmonids.
- Collect additional data on vertical distribution, including species composition and spatially and temporally detailed data.
- Consider conducting mobile hydroacoustic surveys coupled with direct observations to provide estimates of juvenile salmonid distribution and abundance by fish size class in the DET reservoir (e.g., Ploskey et al. 2012).

In closing, the spatially and temporally high-resolution data reported herein provide detailed estimates of vertical, horizontal, diel, daily, and seasonal passage and distributions and analyses of relationships between fish passage and environmental variables at DET from February 2011 through February 2012. This information is applicable to management decisions about the design and development of surface passage and collection devices to help restore Chinook salmon populations in the North Santiam River watershed above Detroit Dam.

Preface

This study was conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers, Portland District (USACE), to support research and management decisions to restore anadromous fish runs in the Willamette River basin. The USACE technical lead was Robert Wertheimer (503-808-4709) and the PNNL project manager was Fenton Khan (509-371-7230). The data are archived at PNNL offices in Richland, Washington. This final report is a project deliverable (PNNL Project No. 60518). PNNL is operated by the Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC05-76RL01830.

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Acronyms and Abbreviations

°C	degree(s) Celsius or Centigrade
AIC	Akaike's information criterion
BiOp	Biological Opinion
CI	confidence interval
d	day(s)
dB	decibel(s)
deg	degree(s)
El.	elevation
ESA	Endangered Species Act
ft	foot(feet)
ft3/s	cubic feet per second
h	hour(s)
kHz	kilohertz
DET	Detroit Dam
FL	fork length
LOP	Lookout Point Dam
m	meter(s)
m3/s	cubic meter(s) per second
mm	millimeter(s)
min	minute(s)
msl	mean sea level
NMFS	National Marine Fisheries Service
ODFW	Oregon Department of Fish and Wildlife
PAS	Precision Acoustic Systems
PNNL	Pacific Northwest National Laboratory
pps	ping(s) per second
RO	regulating outlet
s	second(s)
TS	target strength
µPa	micro-Pascal(s)
USACE	U.S. Army Corps of Engineers, Portland District
WVP	Willamette Valley Project

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1.0 Introduction

This report presents the results of an evaluation of juvenile salmonid passage and distribution at Detroit Dam (DET) on the North Santiam River in Oregon from February 2011 through February 2012. The study was conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers, Portland District (USACE). The goal of the study was to provide fish passage and distribution data to support decision-making related to long-term measures to enhance downstream passage at Detroit and other dams in USACE's Willamette Valley Project.

1.1 Background

Salmon and steelhead populations in the Willamette River basin have been adversely affected by development and operation of hydroelectric dams in the basin. The collective set of dams, referred to as the Willamette Valley Project (WVP), is owned and operated by the USACE. WVP dams have blocked access to historical spawning habitat, altered river discharge patterns, affected water temperature and sediment supply, and caused mortality to migrating anadromous fish (Keefer and Caudill 2010). In 1999, Upper Willamette River spring Chinook salmon (*Oncorhynchus tshawytscha*) and Upper Willamette River steelhead (*O. mykiss*) were listed as threatened under the Endangered Species Act (ESA). Subsequently, the National Marine Fisheries Service (NMFS) issued a Biological Opinion (BiOp), called the Willamette Project BiOp, on the operation of the WVP in the Willamette basin (NMFS 2008).

The BiOp requires the USACE to improve operations and structures to reduce impacts on Upper Willamette River Spring Chinook salmon and steelhead caused by the WVP (NMFS 2008). As a part of these requirements, the USACE must develop interim operations and investigate the feasibility of surface collection structures and mechanisms to convey downstream migrating fish safely past various dams. In a draft plan for WVP research, monitoring, and evaluation, the USACE posed the following management questions (USACE 2009):

- What are the continuing effects of the Willamette Valley Project on Willamette ecosystem function and on ESA-listed fish species?
- What can effectively be done to protect, improve, restore, or mitigate for affected species, their habitat, and related ecosystem function while also maintaining authorized Willamette Project functions?

Therefore, an understanding of when, where, and how many juvenile salmonids pass through the dams, the relative efficiency of existing routes at passing them, temporal and spatial passage distributions, and fish behavior in near-dam forebay areas will be important for fisheries managers and the USACE to have in designing operations and structures that collect and/or pass juvenile salmonids safely and efficiently (USACE 2009; AECOM and BioAnalysts 2010; Keefer et al. 2011).

One of the USACE's priority projects for research on juvenile salmonid migration characteristics during 2011 was Detroit Dam on the North Santiam River, a tributary of the Willamette River in west-central Oregon (Figure 1.1). Fish passage facilities, upstream or downstream, were not included in the original design and construction of DET, a high-head storage dam that became operational in 1953. Construction of DET and its re-regulating project, Big Cliff Dam, located about three miles downstream, resulted in an approximately 70 – 100% loss of salmon habitat in the North Santiam watershed, which historically supported a significant production of spring Chinook salmon (Keefer and Caudill 2010).

Detroit Dam

Figure 1.1. Map of the Willamette Basin (from Figure 2.1, NMFS 2008)

An appropriate technique for investigating fish passage and distribution at hydropower projects is fixed-location hydroacoustics (Thorne and Johnson 1993). Fixed-location hydroacoustics provides useful estimates of fish passage rates into portals at dams because it has high spatial and temporal sampling intensity and is non-obtrusive. However, species identification using hydroacoustics is not possible, which is why direct-capture data are used to complement hydroacoustic data when species composition is uncertain (Ploskey and Carlson 1999). At DET, juvenile salmonid and non-salmonid fishes definitely pass the dam as is evident from screw-trap data collected below DET by the Oregon Department of Fish and Wildlife (Keefer et al. 2011). In general, hydroacoustics-based fish passage research conducted at Columbia River basin dams has informed USACE and fisheries managers. Research topics over the last 25 years have included spill efficiency, horizontal and vertical distributions, seasonal and diel distributions, surface flow outlet efficiency, and dam operations effects (e.g., Johnson et al. 1992, 2005; Khan et al. 2009, 2010, 2012; Ploskey and Weiland 2006; Ploskey et al. 2007). Use of hydroacoustic techniques is appropriate to advance understanding of juvenile salmonid passage and distribution at DET.

1.2 Objectives

During the year-long study period—from February 20, 2011 through February 12, 2012 – the objectives of the hydroacoustic evaluation of fish passage[1] and distribution at DET were as follows:

1. Estimate passage rates, run timing, horizontal distribution, and diel distribution at *turbines*.
2. Estimate passage rates, run timing, passage efficiency and effectiveness relative to total project passage (turbines plus spillway), horizontal distribution, and diel distribution at the *spillway*.
3. Estimate passage rates, run timing, passage efficiency and effectiveness relative to total project passage (turbines plus regulating outlet), and diel distribution at the *regulating outlet*.
4. Analyze relationships between daily fish passage and Julian day, total project discharge, forebay elevation, forebay elevation delta, and water temperature.
5. Estimate vertical distribution and an abundance index for smolt-size fish in the forebay near the upstream face of the dam.
6. Characterize the acoustic sizes of fish passing the dam.

1.3 Study Site Description

Detroit Dam (Figure 1.1, Figure 1.2, and Figure 1.3) is located on the North Santiam River near Detroit, Oregon. The Congressionally authorized purposes of DET are flood control, power generation, irrigation, recreation, navigation, and water quality. The dam has a powerhouse with two Francis turbine units, each with one penstock intake, a total generating capacity of 100 megawatts, and a total hydraulic capacity of 151.2 (m^3/s) (5,340 ft^3/s). Maximum forebay pool elevation is rated at 479.8 m (1,574 ft) above msl[2], full pool is rated at 478.2 m (1,569 ft), Conservation pool (normal operating pool) is at elevation 476.6 m (1563.5ft) and minimum flood control pool elevation is 442 m (1,450 ft) (http://www.nwd-wc.usace.army.mil/report/det.htm).

The dam has four regulating outlets (ROs) (two upper, two lower) and six spill bays that serve as other means of passing water through the dam in addition to the turbines. Operation of the upper ROs and spill bays depend on forebay pool elevation, turbine operations, runoff conditions, season of year, and other related factors. The lower ROs are currently not operational. The spillway is operated in summer months, during Conservation pool, for downstream water temperature control, that is, to pass warm surface water to mix with cold water from the turbines in the tailrace, to provide suitable water temperature conditions below the dam for upstream migrating Chinook salmon and steelhead. The upper ROs may be used for downstream water temperature control in early fall, when the forebay pool elevation is below the spillway crest, and during late fall and winter rain events to pass excess water.

Not all ROs and spill bays were operational in 2011. Only the upper north (facing the upstream side of the dam) RO and Spill Bays 4 and 5 were used in 2011 (see Figure 2.1). The upper north RO

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[1] All passage rate and distribution data are for smolt-size fish. For the purpose of analysis in this study, smolt-size fish were defined as 90 mm <fork length <300 mm. The lengths are approximations based on acoustic target strength (Love 1977).

[2] All elevations in this report are relative to mean sea level.

centerline is at El. 408.4 m (1,340 ft). The turbine penstock intake centerline at the trash racks is at El. 427.6 m (1,403 ft). And, the spillway crest (ogee) is at El. 469.7 m (1,541 ft).

Figure 1.2. Aerial Photograph of Detroit Dam (courtesy of the USACE, http://www.nwd-wc.usace.army.mil/report/det.htm)

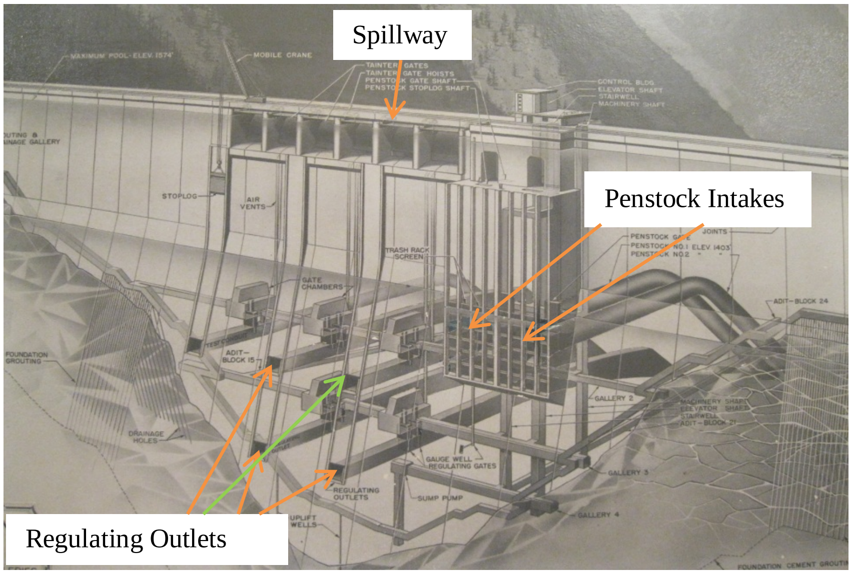

Figure 1.3. Upstream Face of DET Showing Locations of the ROs, Spillway, and Turbine Penstock Intakes. Spill bays and penstock intakes are numbered from left to right. Green arrow is pointing to the RO operated during this study. Photo taken with permission from a drawing at DET.

1.4 Report Contents

The ensuing sections of this report contain the study methods (Section 2.0), results (Section 3.0), discussion (Section 4.0), and literature cited (Section 5.0). Appendix A contains the hydroacoustic system parameters.

2.0 Methods

The general study approach, hydroacoustic systems, transducer locations and orientations, sampling design, and data processing and analysis are described in the following sections.

2.1 General Approach

The fixed-location hydroacoustic technique was used to accomplish the objectives of this study. This technique, conceived by Carlson et al. (1981) for single-beam acoustic systems, is described by Thorne and Johnson (1993). In addition to single-beam technology, split-beam technology is an important element of fixed-location hydroacoustics; Simmonds and MacLennan (2005) explain split-beam hydroacoustics. The general approach was to deploy a combination of single-beam and split-beam transducers to sample fish, and apply the acoustic screen model (Johnson 2000) to estimate fish passage rates and distributions. Split-beam data were used to estimate the average backscattering cross section of fish for detectability modeling and to determine the direction of fish travel through sampling volumes to allow for meeting the assumptions of the acoustic screen model. The methods used in this study were similar to those used in other hydroacoustic fish passage distribution studies for the USACE (e.g., Johnson et al. 2005; Khan et al. 2009, 2010; Ploskey et al. 2003, 2005), including those at Lookout Point Dam on the Middle Fork Willamette River during 2010 (Khan et al. 2012).

2.2 Hydroacoustic Equipment Deployment

Data collection involved the use of one single-beam hydroacoustic system and three split-beam systems (Precision Acoustic Systems [PAS], Seattle, Washington). All systems operated at 420 kHz. The data-collection systems consisted of either Harp-1B (single-beam) or Harp-SB (split-beam) Data Acquisition/Signal Processing software (Hydroacoustic Assessments, Seattle, Washington) installed on a data-acquisition computer controlling a PAS-103 Multi-Mode Scientific Sounder. The PAS-103 sounders controlled transducers deployed in each turbine penstock intake, above the RO entrance, below Spill Bays 4 and 5, and on the dam face (Figure 2.1). A total of nine transducers (two single beams and seven split beams) were deployed at the dam (Table 2.1). During data collection, all systems used a voltage output threshold range of -39 to -56 dB re: 1 μPa at 1 m. For perspective, a -39 dB target strength can be obtained by ensonifying a 216-mm fish (fork length [FL]) within 15 deg of dorsal aspect or a 300-mm fish (FL) about 40 degrees off of dorsal aspect (Love 1977). A -56 dB target strength corresponds approximately to a fish of 30-mm FL. Echo sounder transmission rates were 33 pings per second (pps) at the turbines, 25 pps at the RO, 25 pps at the spillway, and 10 pps for the dam-face transducers.

2.2.1 Transducer Optimization

We undertook a multi-step, quality-controlled process from transducer mount design to final system configuration. First, we developed designs for transducer mounts and had them reviewed and approved by the USACE engineers and DET project personnel. Second, field trials were undertaken to optimize the mount design. Third, aiming angles and ping rates were tested in the field. And, fourth, the optimum configuration for each hydroacoustic system was established with single- and split-beam transducers deployed to sample fish passage at the spillway, RO, and turbines, and vertical distribution at the dam face (Table 2.1; Figure 2.1). Transducers were positioned to sample volumes in a way that would minimize ambiguity in ultimate fish passage routes and the potential for multiple detections of the same fish. Khan et al. (2011) documented the deployment and optimization for the hydroacoustic transducers at DET during 2011.

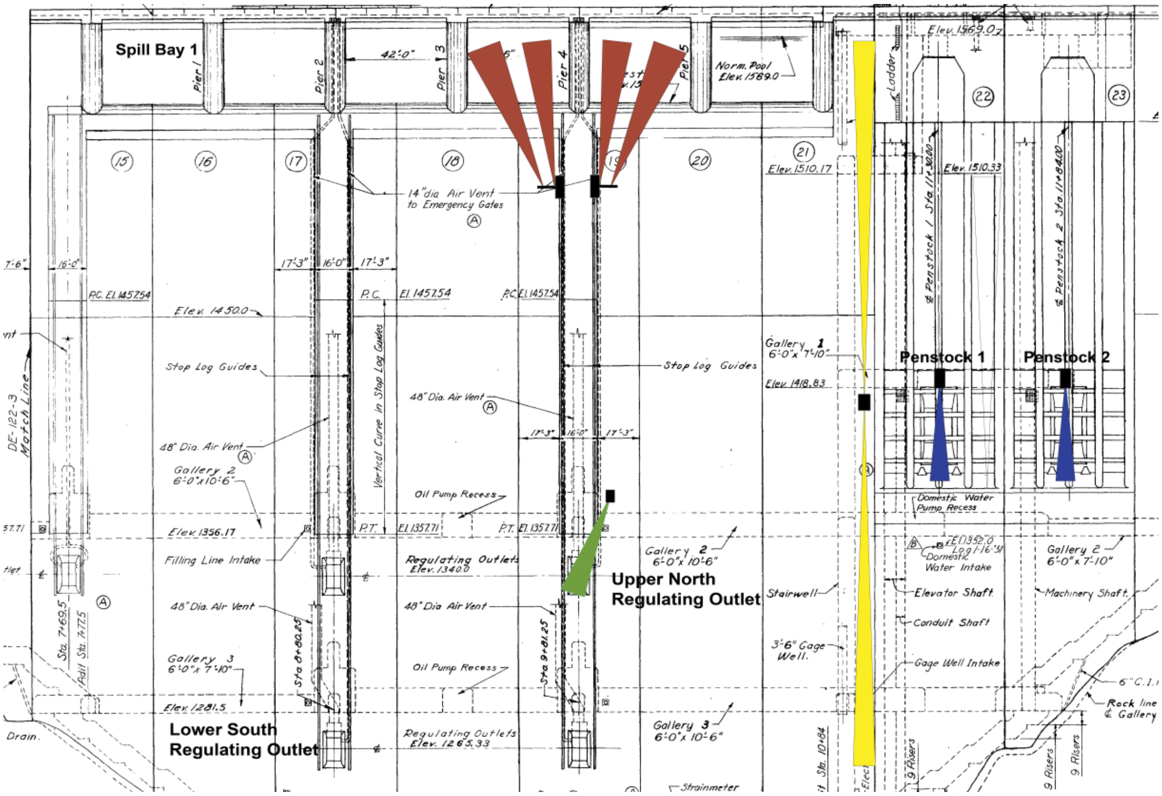

Figure 2.1. Front View of Detroit Dam from the Forebay Showing Transducer Locations (original drawing courtesy of the USACE). One down-looking 10-deg split-beam transducer (green triangle) sampled fish passage into the upper north RO. Four 10-deg split-beam transducers that sampled fish passing the spillway are shown in red in front of Spill Bays 4 and 5. Two 6-deg single-beam transducers, one down-looking and one up-looking, were deployed at the same location (yellow triangle in the figure) and sampled vertical distributions of fish in the forebay. Two 6-deg split-beam transducers sampled fish passage at the penstock intakes (blue triangles). Spill bays and penstocks are numbered from left to right (south to north).

Table 2.1. Sample Locations, Transducers, Spatial Sampling Intensity, Aiming Angle, and Ping Rate Settings at Detroit Dam in 2011–2012

Location	Hydroacoustic Equipment	Beam Width (deg)	Elevation Installed (m)	Aiming Angle (deg)	Ping Rate (pps)
Turbine	Split-beam transducers (2)	6	435	52[a]	33
Spillway	Split-beam transducers (4)	10	457	10.5 & 26[b]	25
Regulating Outlet	Split-beam transducer (1)	10	426	11[b]	25
Forebay (dam face)	Single-beam transducers (2)	6	430	vertical[a]	10

a. From horizontal. The spillway and RO transducers are all aimed 9 deg upstream from the face of the dam to avoid any structural interference.
b. From vertical off of a plane perpendicular to the spillway face.

2.2.2 Turbine Penstock Intakes

One 6-deg split-beam transducer was installed inside each of the two turbine penstock intakes (Figure 2.1). Divers installed the transducers at the top of the trash racks at El. 435 m (1,428 ft) (Figure 2.2). The transducer mounts were designed to fit between the vertical bars of the trash rack. This design allowed divers to secure the mount to the trash rack of each intake from the forebay. Each transducer was aimed down at 52 degrees off horizontal. After installation and with the turbines operating, a variety of ping rates were tested to select the best rate. We optimized the sampling rate at 33 pps and each penstock intake was sampled for a total of 30 min/h.

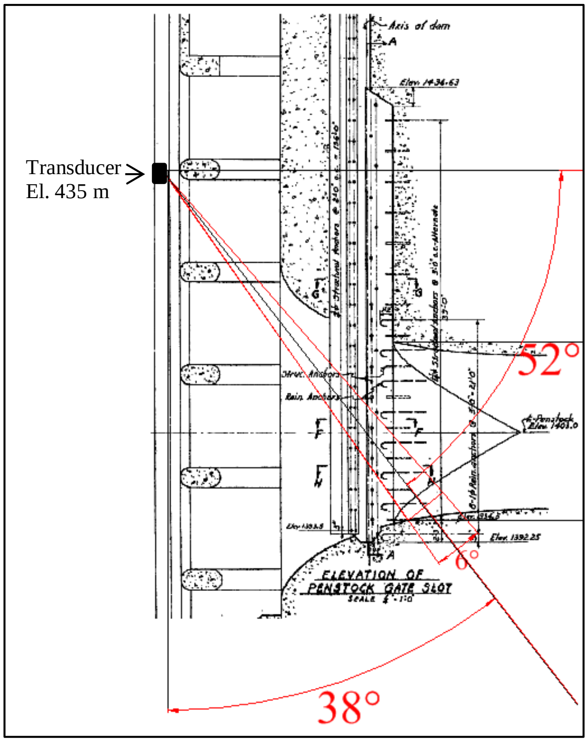

Figure 2.2. Cross-Sectional View of a Transducer Deployment at a Penstock Intake and Aiming Angle (red lines) (original drawing courtesy of the USACE)

2.2.3 Spillway

Transducers for the spillway were only installed at Spill Bays 4 and 5 because the other bays were not operational during this study (Figure 2.3). Transducer mounts, each with two up-looking 10-deg split-beam transducers, were anchored at El. 457.2 m (1,500 ft) to both sides of the pier separating Spill Bays 4 and 5, one mount aimed towards Spill Bay 4 and one towards Spill Bay 5, for a total of four transducers (Figure 2.3). To cover the maximum area of a particular spill bay, two transducers were mounted on one pole mount and aimed at calculated angles from vertical. The transducer closest to the base was aimed 10.5 deg off of a vertical plane through the transducer and perpendicular to the spillway face, while the distally mounted transducer was aimed 26 deg off of the a vertical plane through that transducer and perpendicular to the spillway face. We optimized the sampling rate at 25 pps and each bay was sampled for a total of 60 min/h. It should be noted that only Spill Bay 5 was used for most of the study period because it was the priority bay for spill. Therefore, Spill Bay 5 was sampled every minute in the hour when it was operated. When both Spill Bays 4 and 5 were operated, each bay was sampled for a total of 30 min/h.

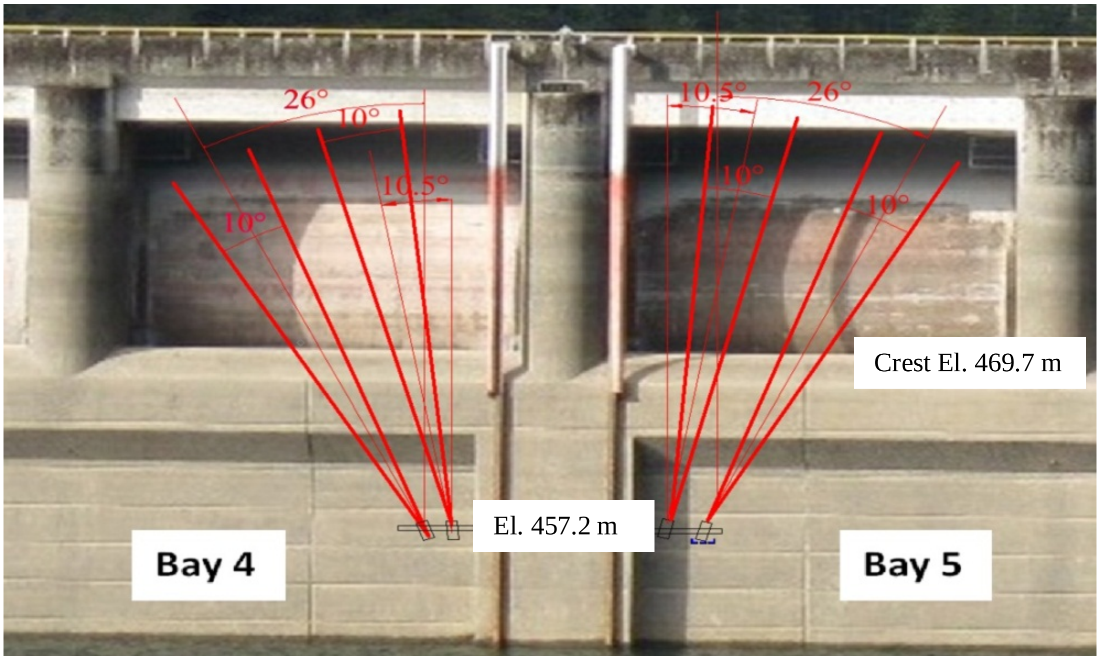

Figure 2.3. Front View of Spill Bays 4 and 5 Depicting the Orientation and Aiming Angles (red lines) of the DET Spillway Transducers

2.2.4 Regulating Outlet

Only the upper, north RO was operated during our study period (Figure 2.1). Therefore, we deployed one down-looking, 10-deg split-beam transducer at the uppermost, north corner of the RO gate, at El. 426 m (1,397.6 ft), and aimed down at calculated angles across the RO portal (Figure 2.4 and Figure 2.5). During the dive installation, proper aiming was determined by transmitting sound energy (“pinging”) at 25 pps and examining the data for echoes from the bottom head gate stop at the RO portal. We optimized the sampling rate at 25 pps and the RO was sampled for a total of 60 min/h.

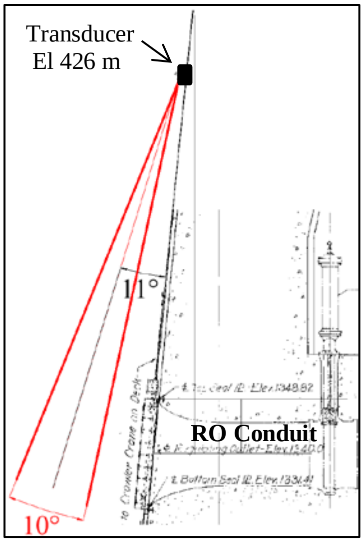

Figure 2.4. Cross-Sectional View of a Transducer Deployment with Calculated Angle at the RO (original drawing courtesy of the USACE)

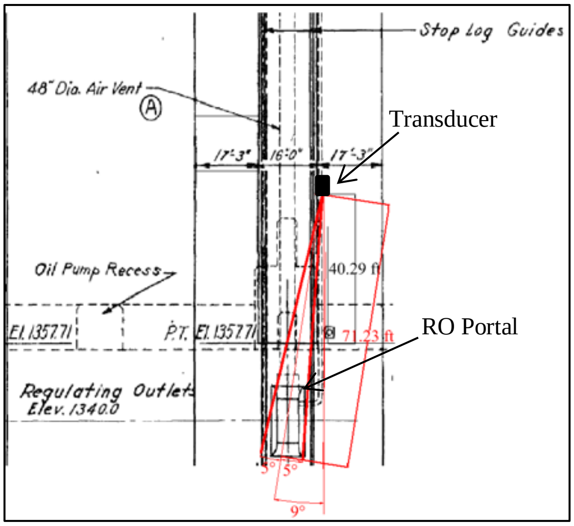

Figure 2.5. Front View of the RO Depicting the Orientation of a Transducer (original drawing courtesy of the USACE)

2.2.5 Forebay Dam Face

A pair of 6-deg single-beam transducers, one up-looking and one down-looking, was installed on the concrete face of the dam, between the penstock intakes and the spillway, to obtain vertical distribution information about juvenile fish near the face of the dam (Figure 2.1). Divers installed the mount with transducers at El. 430 m. The mount was concrete anchored to the face of the dam. We optimized the sampling rate at 10 pps and each transducer was sampled for a total of 30 min/h.

2.3 Sampling Design

Systematic samples of fish passage, i.e., same order among sampling locations each hour, were collected at 1-min intervals 24 h/d for all active transducers. Each location was sampled 30 or 60 times per hour depending on the number of transducers connected to the echo sounder. The transducers at the penstock intakes and forebay dam face sampled continuously through the year-long study period, except when data were downloaded (10–20 minutes per week). The spillway and RO transducers were interrogated only when either portal was open.

2.4 Data Processing and Passage Estimation

The data processing and reduction methods used were similar to those used by Khan et al. (2009, 2010, and 2012). After the acoustic echo data were collected in the field and archived, they were processed to extract fish tracks. At this stage in the analysis, we were careful to set the tracking parameters to include all fish at the expense of including spurious tracks. Next, to separate acceptable from unacceptable tracks, we filtered the data using fish track characteristics such as contrast, echo count, linearity, mean pulse width, mean target strength, noise count average, noise index, pulse width, slope, and speed. For quality assurance, sub-sets of the data were manually checked to ensure that valid fish tracks remained after filtering.

Mean target strength, approximating fish size, was used to distinguish fish targets. Recall, during data collection, the maximum target strength was -39 dB re: 1 µPa at 1 m and the minimum target strength was -56 dB. During data analysis, we used the target strength (TS) measurement to select and perform analyses for smolt-size fish (these sizes are *approximations*):

“smolt-size” fish: -39 dB > TS > -56 dB, corresponding to ~300 mm > X > ~90 mm

The process used to estimate passage rates from filtered tracked fish involved spatial and temporal expansions of raw counts. Briefly, each fish track that passed the filtering process was weighted spatially to account for the sample width of the acoustic beam at the target’s mid-range relative to the width of the depth bin it sampled; i.e., fish passage at unsampled portions of a passage route was estimated by extrapolating from the sampled portions. The sum of these weighted fish was then extrapolated temporally by the hourly sampling fraction (60/total minutes of sample time per hour per location). Project operations data provided by the USACE were used to identify times when passage routes were closed; only open routes were included in the analysis.

The hourly passage rate data for each transducer were used to estimate various performance metrics. Equations for each estimator follow. Let x_{ijky} be the expanded fish passage count in the i^{th} transducer ($i = 1, ..., x$) during the j^{th} hour ($j = 1, ..., 24$) of the k^{th} day ($k = 1, ..., d_y$) during y^{th} study period, where d_y is the number of study days in the y^{th} study period.

Total juvenile-size fish passage count for the y^{th} study period was estimated by the formula

$$\hat{TP}_y = \sum_{i=1}^{6} \sum_{j=1}^{24} \sum_{k=}^{d_y} x_{ijky} \qquad (2.1)$$

Daily juvenile-size fish count for the k^{th} day in the y^{th} study period for analysis of run timing was estimated by the formula

$$\hat{DP}_{ky} = \sum_{i=1}^{6} \sum_{j=1}^{24} x_{ijky} \qquad (2.2)$$

Hourly juvenile-size fish count for the j^{th} hour in the y^{th} study period for analysis of diel distribution was estimated by the formula

$$\hat{HP}_{jy} = \sum_{i=1}^{6} \sum_{k=1}^{d_y} x_{ijky} \qquad (2.3)$$

Johnson et al. (2005) describe methods to estimate variances for the passage rate estimates. The variances associated with each passage rate estimate were likely underestimated because between-intake variability in passage within a given turbine unit could not be accounted for because of sampling limitations. The 95% confidence intervals (CIs) for total and daily passage rates were calculated as follows:

$$CI = \pm 1.96 * \sqrt{Variance} \qquad (2.4)$$

We used correlation and regression methods (Sokal and Rohlf 1981) to analyze relationships between total fish passage and total project discharge, forebay elevation, and change in forebay elevation. This study did not involve comparisons of experimental treatments.

2.5 Statistical Analysis Methods

If relationships among environmental variables and fish passage can be identified, they may help guide the selection of effective management options. We sought to identify relationships among fish passage and environmental variables through evaluations of correlations and through generalized linear regression techniques. Table 2.2 contains variables used in this exploration. Variables with obvious non-normal distributions were transformed as needed to achieve a distribution better approximating normality.

For multivariate analysis, we used a generalized linear regression approach (GLZ, Statistica 11, www.statsoft.com). We began the variable selection process using the full list of variables in Table 2.2, with L_Tot_Passage serving as the dependent variable. Variables were selected using a best subsets approach and ranking of models based upon Akaike Information Criteria (AIC; Anderson et al. 1994). AIC is an *a priori* model-building process that compares different candidate models given a specified set of variables applied to an observation data set. It provides a unitless AIC score for each subset model that is built with the intent to avoid over-parameterization in the model. The formula for an AIC score is

$$\text{AIC} = 2k - 2\ln(L)$$

where, L = maximized value of the likelihood function of the estimated model and k = number of parameters in the model.

Table 2.2. Variables Evaluated for Relationships to Fish Passage (Tot_Passage)

Variable	Description	Transform	Type
DayHours	Hours of daylight (civil twilight)	None	Continuous
Forebay_Delta	Daily change in mean forebay elevation in ft	None	Continuous
Forebay_Elev	Forebay elevation in ft	None	Continuous
Ops_Period	The reservoir storage operation period (Refill, Conservation Pool, Fall Drawdown, or Winter)	None	Categorical
Peaking	Value set to 1 if peaking operations occur that day, 0 if operation is continuous	None	Categorical
Temp_0.5ft	Forebay temperature (^{o}C) at 0.5-ft depth	None	Continuous
Temp_180ft	Forebay temperature (^{o}C) at 180-ft depth	None	Continuous
Tot_Discharge	Discharge through all outlets	Log_{10} (L_Tot_Discharge)	Continuous
Tot_Passage	Fish passage through all routes	Log_{10} L_Tot_Passage	Continuous

The score reflects a trade-off between the lack of fit and the number of parameters in the model, and the preferred model is the one with the lowest AIC value, because it minimizes the information lost from the “true” unknown model. The model with the highest likelihood is the best fit to the observed data, although a model with fewer parameters or one having parameters carefully chosen to diminish correlation effects may be a better fit to the underlying phenomena. For example, when there is a high degree of correlation among variables in the model, the AIC score is lower and the *P*-value higher, but the strength of the effects is diminished by the presence of correlated variables. A low AIC score by itself does not indicate the real-world strength of the model’s predictive power. Choosing models with more interaction terms can greatly expand understanding of the relationships among the variables in the model and allows more hypotheses to be tested. Candidate models having AIC values within 1–2 of the minimum AIC score are considered to have substantial support and can be evaluated further for final selection. The model-building output may provide more than one model within 1–2 AIC values of the minimum. The model chosen includes the constitutive terms from any interaction terms, as recommended by Brambor et al. (2006).

The candidate models for predicting fish passage were built using Generalized Linear/Nonlinear Regression techniques in Statistica version 11 (www.statsoft.com) to create and evaluate the best subsets of explanatory variables. The many possible models were evaluated using AIC. Where necessary, variables were transformed (log10) to reduce departures from a normal distribution (Table 2.2). Total project discharge and total fish passage were transformed to log10 values. AIC multiple regression assumes normal distribution of residuals.

To avoid including highly correlated dependent variables in the model, correlation among variables was examined. Where independent variables are highly correlated the coefficient estimates can change erratically in response to small changes in the model or data. Bivariate scatterplots were also produced to examine relationships among variables.

Many different sets of models were run to include different groupings of variables because using all variables at once was beyond the capabilities of the software program. For each set, the full model was specified to include two-way interactions of continuous variables. The best subsets of those model terms were run and ranked by their AIC scores. From the set of models with AIC scores within 2 of the minimum AIC value, we selected models that included each original variable, which was included in an interaction term. The selected model was evaluated for its ability to predict passage. The model equation result is the inverse of the natural log of the predicted value, in the form

$$\text{Expected value} = \exp(B_0 + B_1{*}V_1 + B_2{*}V_2\ldots\ldots + B_n{*}V_n)$$

3.0 Results

The results from the study are presented in three sections: dam operations, direct-capture data, and fish passage and distribution. Hydroacoustic data are interpreted relative to direct-capture data from DET tailrace in the Discussion (Section 4).

3.1 Dam Operations

Dam operations data include forebay pool elevation, forebay water temperature, turbine, spillway, and RO discharge, and turbine operations. Dam operations data provide context for the fish passage and distribution results.

3.1.1 Forebay Environment

The forebay pool elevation of DET follows a "rule curve" managed by the USACE Reservoir Control Center. The rule curve dictates lowering the forebay pool elevation in fall to prepare for storage and flood control during winter months. Generally, the fall Drawdown of the pool begins on or after September 1 and Refill begins on or around February 1. In the results sections that follow, data are presented for four periods based on distinct patterns (changes) in pool elevation (Figure 3.1):

- Refill (February 1 – April 30, 2011)
- Conservation Pool (May 1 – August 31)
- Drawdown (September 1 – November 15)
- Winter Pool (November 16, 2011 – February 1, 2012).

3.1.1.1 Forebay Elevation

In 2011, the forebay surface elevation began to increase in early February, peaked on May 9 at El. 476 m (1,562 ft), held at a mean elevation of 476 m (1,561 ft) through August for the summer Conservation Pool, and decreased during the fall Drawdown from September through November (Figure 3.1). From late November to the beginning of February 2012, forebay elevation fluctuated due to runoff from winter rain events. The minimum pool elevation for the study period occurred on December 27 at 439.4 m (1,442 ft).

3.1.1.2 Forebay Temperature

Forebay water temperature data were obtained from the USACE temperature string in the forebay, which logged hourly data from 0.15 m (0.5 ft) below the surface to a depth of 54.86 m (180 ft). Temperature was not monitored at deeper depths because water temperatures below 54.86 m are assumed to be isothermal. From February to the end of May, the temperature of the water column averaged between 4.0°C and 5.5°C (Figure 3.1). Between June and November, the temperature was stratified; during June, the temperature in the top 12 m of water ranged from 6.0 to 10.0°C and averaged 5.0°C at depths greater than 12 m; between July and November, the top 15 m of water ranged from 10.0 to 20.0°C and the layers below that averaged 12.0°C between depths of 15 to 25 m and 6.0°C below 25 m. During December and February, temperature in the water column averaged about 5.0°C.

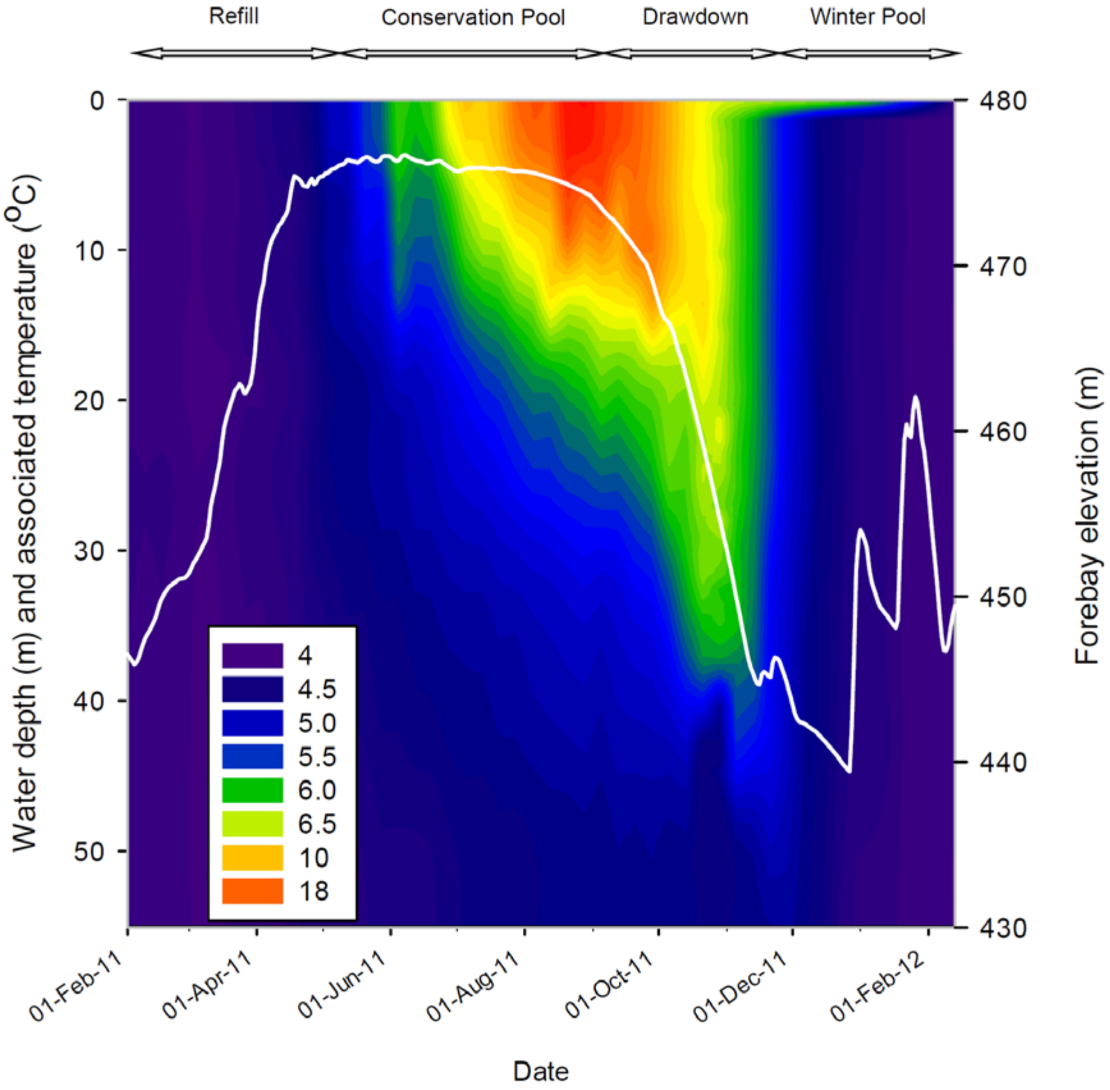

Figure 3.1. Daily Average Surface Elevation (meters above msl) (solid white line; right y axis) and Temperature (deg C) of the Water Column (contour plot; left y axis) of the Forebay at DET from February 2011 through February 2012. The four pool elevation periods are designated above the graph (arrows). Data were provided by the USACE Willamette Valley Project (WVP) operations office.

3.1.2 Project Discharge

During our study, turbine discharge for the Refill period remained fairly constant between February 15 and late March, with a daily average of 790 m^3/s (~27.9 kcfs), before increasing through April, with two peaks, one on March 25 at 2,537 m^3/s (~90 kcfs) and the other on April 21 at 2,699 m^3/s (~95 kcfs)

(Figure 3.2). For the Conservation Pool period, between May and June, daily turbine discharge fluctuated, ranging from 378 m^3/s (~13.4 kcfs) to 1,955 m^3/s (~69 kcfs), after which it remained fairly constant between July and August—the daily average was 398 m^3/s (~14 kcfs). From September until the end of the study period on February 13, during Drawdown and Winter Pool, turbine discharge was generally high and fluctuated widely due to the fall Drawdown and rain events, ranging from 370 m^3/s (~13 kcfs) on September 6 to 3,336 m^3/s (~118 kcfs) on February 7. The turbines were out of service from July 5 through10 and November 1 through 8.

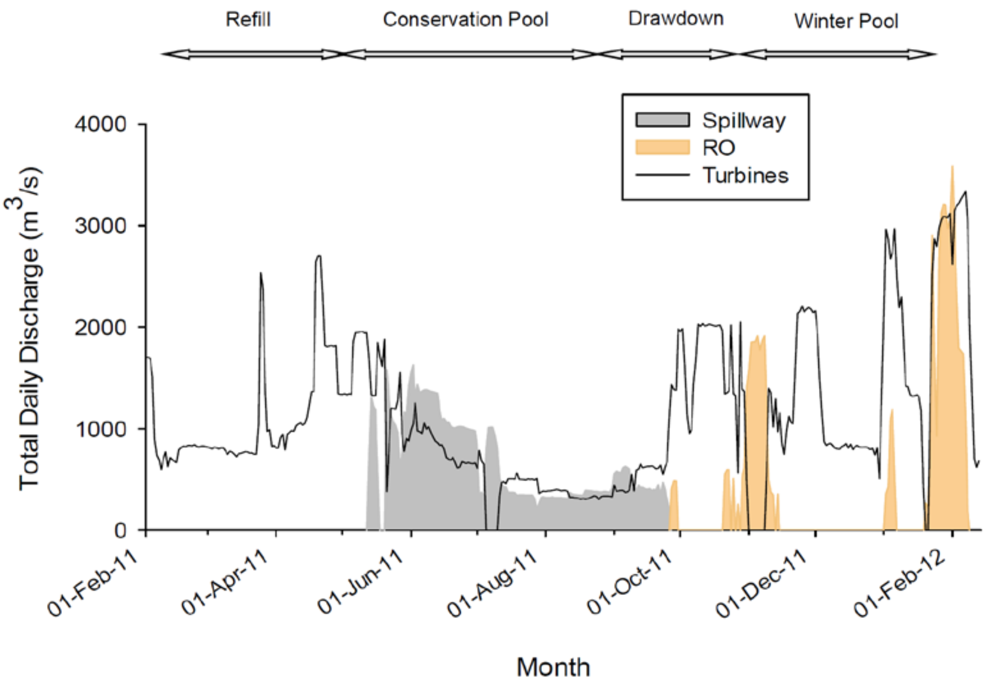

Figure 3.2. Daily Discharge for the Turbines, Spillway, and Regulating Outlets at DET from February 2011 Through February 2012. Arrows at the top indicate the four pool elevation periods mentioned earlier. Data were obtained from the USACE WVP operations office.

The spillway was operated for downstream water temperature control during the Conservation Pool and Drawdown periods, from May 13 through September 26 (Figure 3.2). Daily spillway discharge ranged from a peak of 1,628 m^3/s (~57 kcfs) on June 2 to a low of 203 m^3/s (~7 kcfs) on July 28. The RO was operated for downstream water temperature control during Drawdown for three days in September (27–29) and from October 21 through November 14, and again in the winter, during rain events, for a few days in January (2–6) and from January 20 through February 8. During the fall, RO daily discharge ranged from 258 m^3/s (~9 kcfs) to 1,914 m^3/s (~68 kcfs) and in the winter, daily discharge ranged from 219 m^3/s (~8 kcfs) to 3,585 m^3/s (~127 kcfs).

3.1.3 Turbine Operations

Throughout the year (February 2011 – February 2012), DET turbines typically were operated for power-peaking during the morning (~0400–0900 h) and evening (~1600–2200 h), although operations at other times also occurred (Figure 3.3 and Figure 3.4. The turbines were out of service from July 5 through 10 and November 1 through 8 Figure 3.4). During the turbine outage in July, the spillway was used to pass water through the dam and for the outage in November, the RO was used to pass water. Turbine operations varied by units and hours throughout the year, depending on power demand and maintenance schedules (Figure 3.4). Generally, only one turbine was used in February and March, July through September, and during December. Both turbines were used during the other months. Turbine usage was moderate to heavy between February and June (11 to 24 h/d), low in July and August (less than 10 h/d), and moderate to heavy again between September and February (11 to 24 h/d). Both turbines were operated heavily (24 h/d), except for a few days in January and February (Figure 3.3).

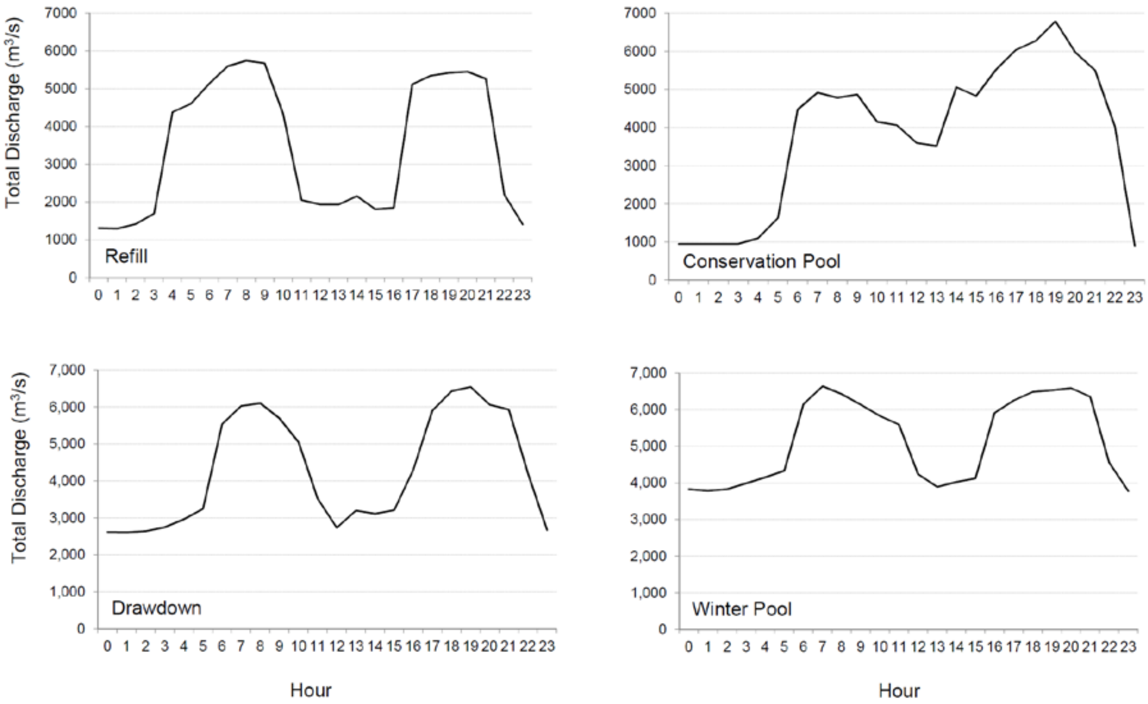

Figure 3.3. Diel Distribution of Turbine Discharge, by the Four Distinct Pool Elevation Periods, from February 2011 through February 2012. Data were obtained from the USACE WVP operations office.

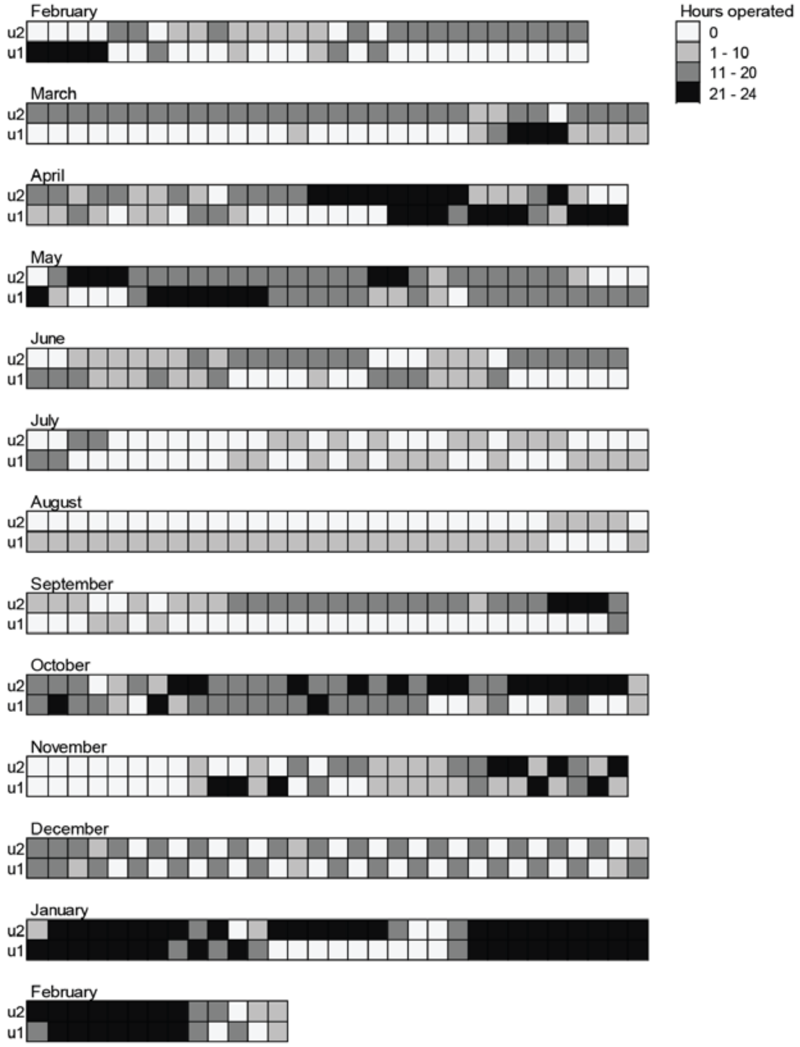

Figure 3.4. Turbine Operations by Month from February 2011 through February 2012. Turbine units are designated as U1 (unit 1) and U2 (unit 2). The columns in the grid represent 24-h periods. Data were obtained from the USACE WVP operations office.

3.2 Direct Capture Data

To provide context for the downstream passage results of our study, the Oregon Department of Fish and Wildlife (ODFW) provided data on counts and species composition of juvenile fish obtained from their sampling efforts in the DET reservoir and tailrace. The overall catch in the reservoir traps during 2011 comprised nine species (Monzyk et al. 2012): bluegill *(Lepomis macrochirus)*, brown bullhead *(Ameiurus nebulosus)*, Chinook salmon (marked and unmarked), cutthroat trout *(O. clarkia)*, dace *(Rhinichthys* spp.*)*, kokanee *(O. nerka)*, mountain whitefish *(Prosopium williamsoni)*, pumpkinseed *(Lepomis gibbosus)*, rainbow trout *(O. mykiss)*, and sculpin *(Cottus* spp.*)*. The tailrace screw-trap data obtained between April (when it was installed) and December 2011 comprised mainly Chinook salmon (marked and unmarked) and kokanee, with mysid shrimp (*Mysis relicta,)* pumpkinseed, and few rainbow trout completing the species composition (Monzyk et al. 2012). Of the juvenile Chinook salmon sampled at the tailrace trap between May and December, most passed the dam during August through December

(Figure 3.5; Romer et al. 2012). Size of juvenile Chinook salmon in the screw trap ranged from 56 to 171 mm FL for April through July and from 75 to 325 mm FL (with a mean of 148 mm) for August through December (Figure 3.6; Romer et al. 2012). Few kokanee were captured in the trap during spring and summer, a majority was captured in late October and early November, and numbers decreased to very few in late November. The mean fork length for kokanee was 102 mm (Figure 3.6).

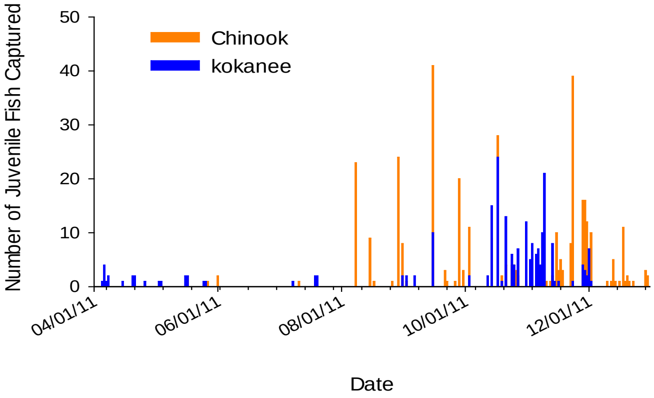

Figure 3.5. Direct Capture Abundance of Juvenile Chinook Salmon and Kokanee from the Screw-Trap in the Tailrace of Detroit Dam on Days When the Trap were Serviced During 2011 (data courtesy of ODFW). The screw trap was installed in April and sampled through December.

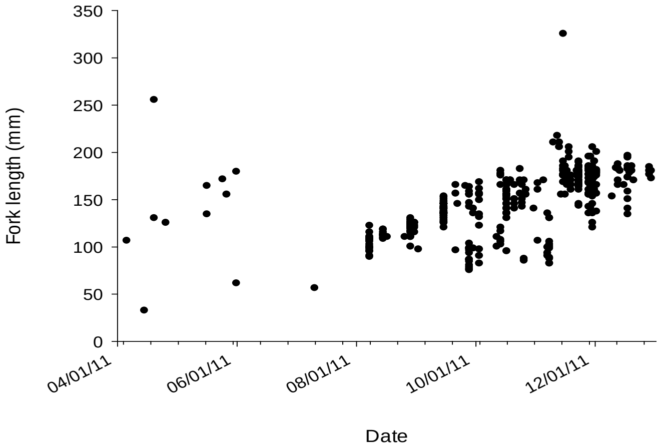

Figure 3.6. Size of Juvenile Chinook Salmon and Kokanee from the Screw Trap in the Tailrace of Detroit Dam During April Through December 2011 (data courtesy of ODFW)

3.3 Fish Passage and Distribution

The fish passage and distribution results for DET are organized into six sections corresponding to the objectives (Section 1.2): 1) turbine passage and distribution; 2) spillway passage and distribution; 3) RO passage and distribution; 4) relationships between passage and environmental conditions; 5) forebay vertical distribution and abundance index; and 6) acoustic sizes.

3.3.1 Turbines

3.3.1.1 Passage Estimates and Run Timing

Over the entire study period from February 20, 2011 through February 12, 2012, an estimated total of 182,526 smolt-size[7] fish (±4,660 fish, 95% CI) passed through turbines. Downstream passage of juvenile fish occurred throughout much of the year-long study period[8] (Figure 3.7). Run timing peaked on January 23, 2012 (5,284 fish), with other peaks in late fall, winter, and early spring months. Passage was high between February and mid-May 2011 (averaging 637 fish/d) and low (zero to <100 fish/d) for most of the summer months. The passage rate began to increase again at the end of September, with a pulse of 3,713 fish on November 24, after which it decreased to low numbers in December (averaging 202 fish/d), before increasing to yearly high numbers in January and February 2012 (averaging 2,333 fish/d) (Figure 3.7).

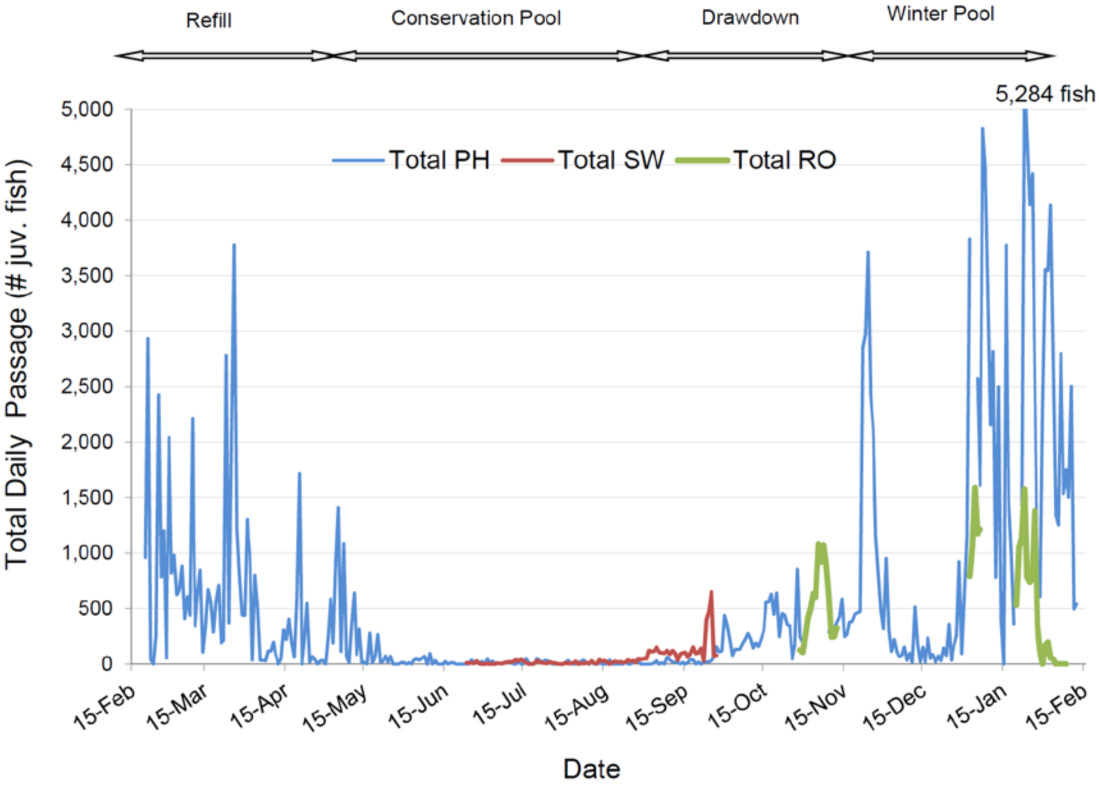

Figure 3.7. Estimated Total Daily Passage of Smolt-Size Fish at Turbines (PH), Spillway (SW), and Regulating Outlet (RO) – February 20, 2011 through February 12, 2012. Arrows at the top indicate the four distinct pool elevation periods mentioned earlier.

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[7] Note that while we can discriminate between size classes of fish, we cannot discriminate between salmonid species and non-salmonid species with hydroacoustic data. For the purpose of analysis in this study, smolt-size fish were defined as 90 mm <fork length <300 mm. The lengths are approximations based on acoustic target strength.

[8] Note that the turbines were out of service July 5 – 10 and November 1 – 8.

3.3.1.2 Horizontal Distribution

Horizontal distribution of fish passage during hours when both turbine units were operated simultaneously (a total of 615 hours) (Figure 3.4) and appreciable numbers of fish were passing the dam, indicates Unit 2 passed almost twice as many fish as Unit 1 (Figure 3.8). Each turbine passed about the same amount of water, because each was operating for the same amount of time and at full capacity (data were obtained from the USACE WVP operations office).

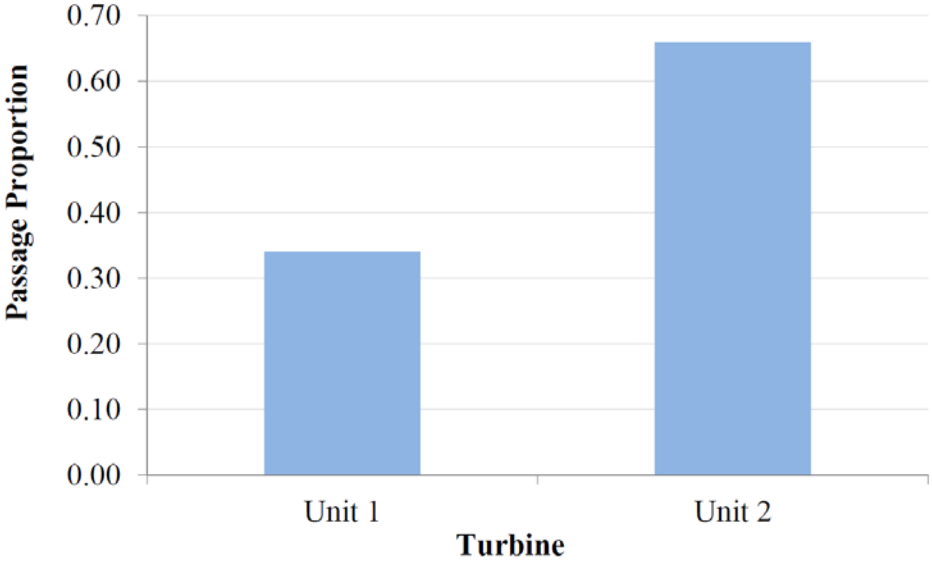

Figure 3.8. Horizontal Distribution of Smolt-Size Fish Passage at the Turbines When Both Units Were Operating

3.3.1.3 Diel Distribution

Diel distribution for smolt-size fish during the study period was fairly uniform, indicating fish were passing the turbines at all times of the day (Figure 3.9). However, separate diel distributions for the four pool elevation periods revealed pulses in fish passage during morning and evening power-peaking hours of the Refill and Drawdown periods and were variable during the Conservation Pool and Winter Pool periods (Figure 3.10).

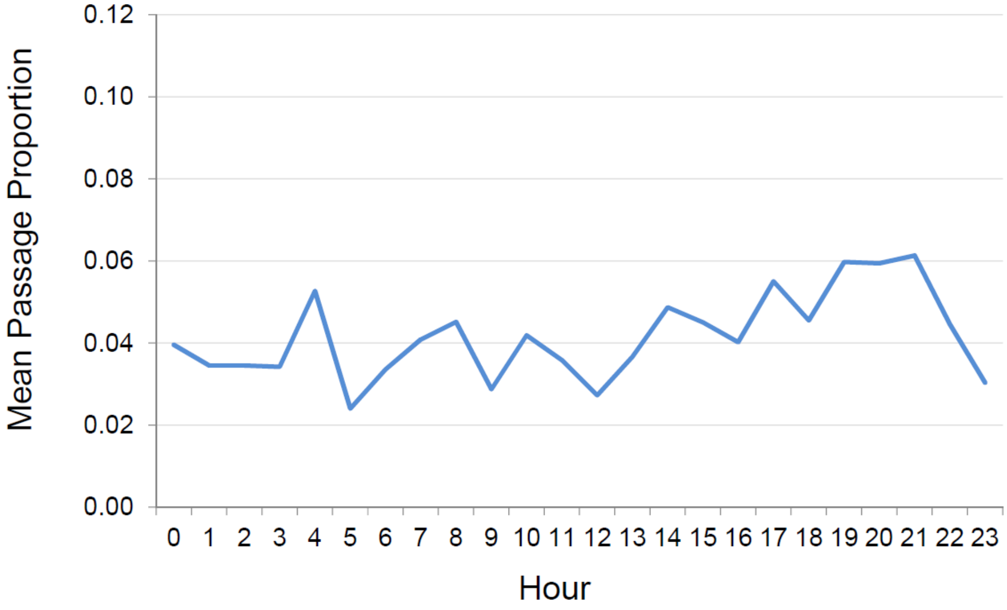

Figure 3.9. Diel Distribution of Smolt-Size Fish at the Turbines for the Entire Study Period (February 20, 2011 – February 12, 2012)

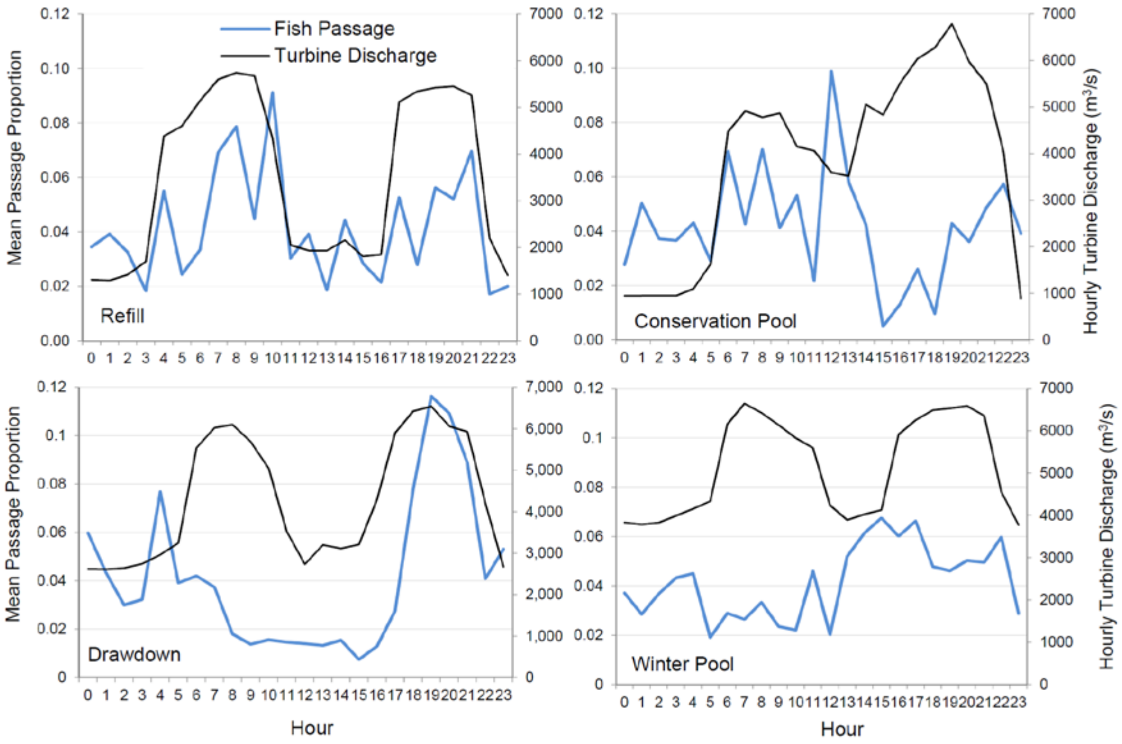

Figure 3.10. Diel Distribution of Smolt-Size Fish Separately for the Four Distinct Pool Elevation Periods. Blue lines represent fish data as the hourly proportions of total passage. Black lines represent total hourly turbine discharge (m^3/s). Discharge data were obtained from the USACE WVP operations office.

3.3.2 Spillway

3.3.2.1 Passage Estimates and Run Timing

We estimated a total of 5,083 smolt-size fish (± 312 fish, 95% CI) passed via the spillway when it was open between June 23 and September 27, 2011[9]. Recall, the turbines were out of service from July 5 through July 10 and the spillway was the only route used to pass water through the dam. From June 23 through September 22 when only Spill Bay 5 was used, an estimated 3,405 ± 188 (95% CI) smolt-size fish passed via spill. Daily passage was low at the spillway during June through August, and began increasing in September 2011 (Figure 3.11). Spillway discharge increased on September 1 (554 m^3/s), from an August average of 353 m^3/s, and averaged 592 m^3/s between September 1 and 8, before decreasing to an average of 400 m^3/s for the rest of the month. The increase in fish passage, starting on September 1, coincided with the increase in discharge (Figure 3.11).

From September 23 through 27, during Drawdown, the USACE conducted a “free flow” test by opening both Spill Bays 4 and 5. At the start of the test, on the morning of September 23, forebay pool elevation was at approximately 470.5 m (1,543 ft), and on the morning of September 27, when the test ended, the pool elevation was at approximately 469.7 m (1,541 ft) (spillway crest elevation; no more water could pass the spillway). We estimated 1,678 ± 248 (95% CI) smolt-size fish passed the two bays during this period. Daily spillway passage peaked on September 25 at 651 ± 157 (95% CI) fish (Figure 3.11).

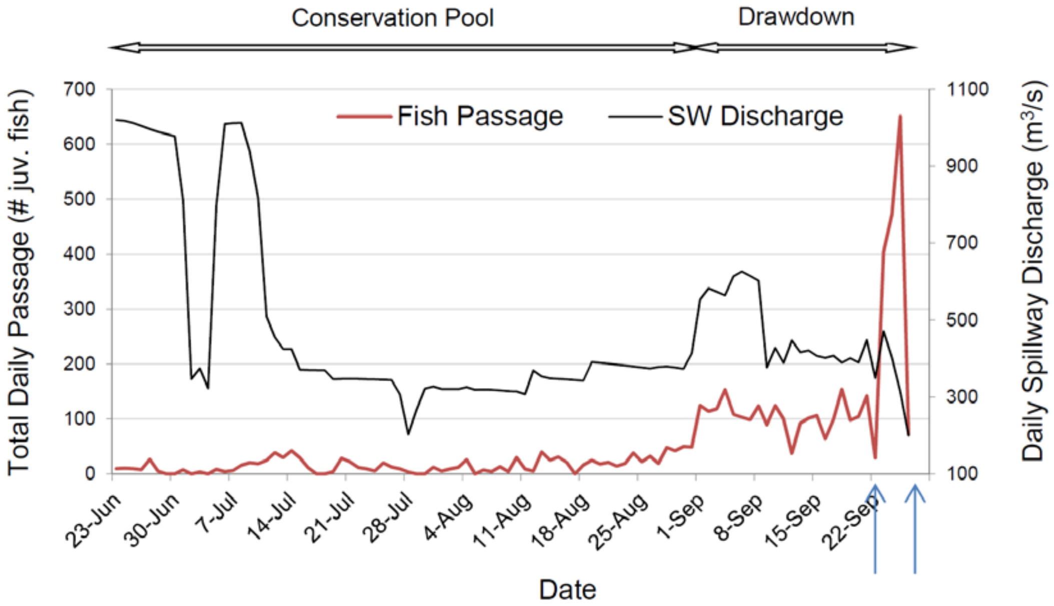

Figure 3.11. Estimated Daily Passage of Smolt-Size Fish at the Spillway. Red lines represent fish passage. Black lines represent daily spillway discharge (m^3/s). The two blue arrows on the X axis indicate the period when Spill Bays 4 and 5 were open for the “free flow” test. Arrows at the top indicate two pool elevation periods mentioned earlier. Discharge data were obtained from the USACE WVP operations office.

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[9] We did not collect data between May 13 and June 21 because of damaged transducer cables, which were replaced by divers on May 21.

3.3.2.2 Passage Efficiency and Effectiveness

When the spillway (Spill Bay 5) was operated simultaneously with the turbines, which only occurred in September (a total of 183 non-consecutive hours), spillway efficiency[10] was 0.72 and effectiveness[11] was 2.69 (Table 3.1). That is, when the spillway was open, 72% of the fish passing the dam used the spillway and 28% passed into the turbines.

Table 3.1. Spillway Passage Efficiency and Effectiveness

Passage Route	Discharge proportion	Spillway Efficiency	Spillway Effectiveness
Spillway	0.27	0.72	2.69
Turbines	0.73	NA	NA

3.3.2.3 Horizontal Distribution

Horizontal distribution of fish passage when both Spill Bays 4 and 5 were operated simultaneously, during the "free flow" test (September 23 – 27), indicates both bays passed similar numbers of fish (Figure 3.12). Each bay passed about the same amount of water because the gate opening of each was identical and each was operating for the same amount of time.

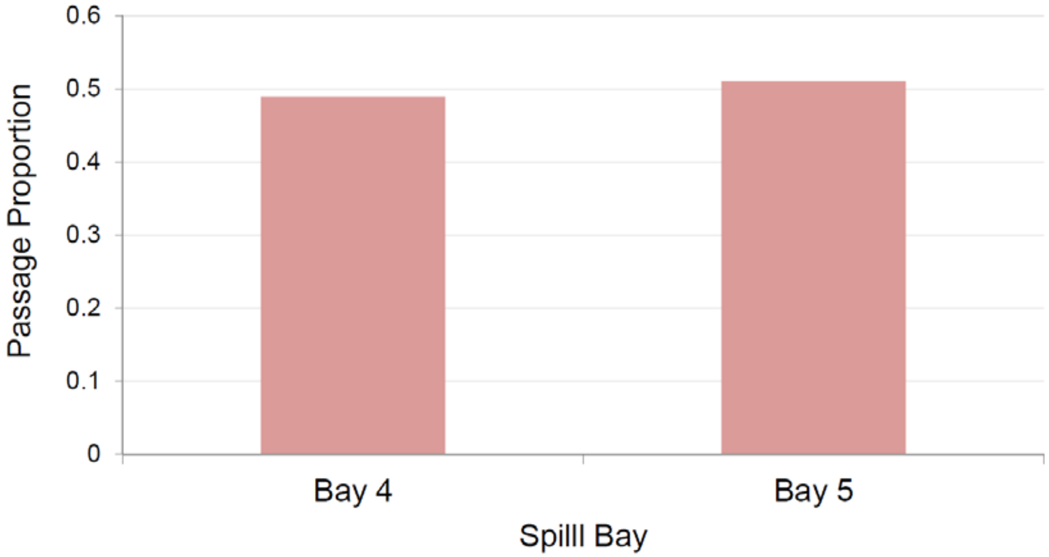

Figure 3.12. Horizontal Distribution of Smolt-Size Fish Passage at Spill Bays 4 and 5 When Both Spill Bays Were Operated from September 23 Through 27

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[10] Spillway efficiency is estimated as spillway passage divided by total project passage.

[11] Spillway effectiveness is estimated by the fish:flow ratio—the proportion of fish passage at a route (e.g., spillway) divided by the proportion of water through that route out of the total project.

3.3.2.4 Diel Distribution

Diel distribution for smolt-size fish during periods when the spillway (Spill Bay 5) was operated 24h/d and fish passed that route shows a distinct peak in passage between mid-morning and mid-afternoon and low passage at night (Figure 3.13). This peak coincided with a peak in spillway discharge.

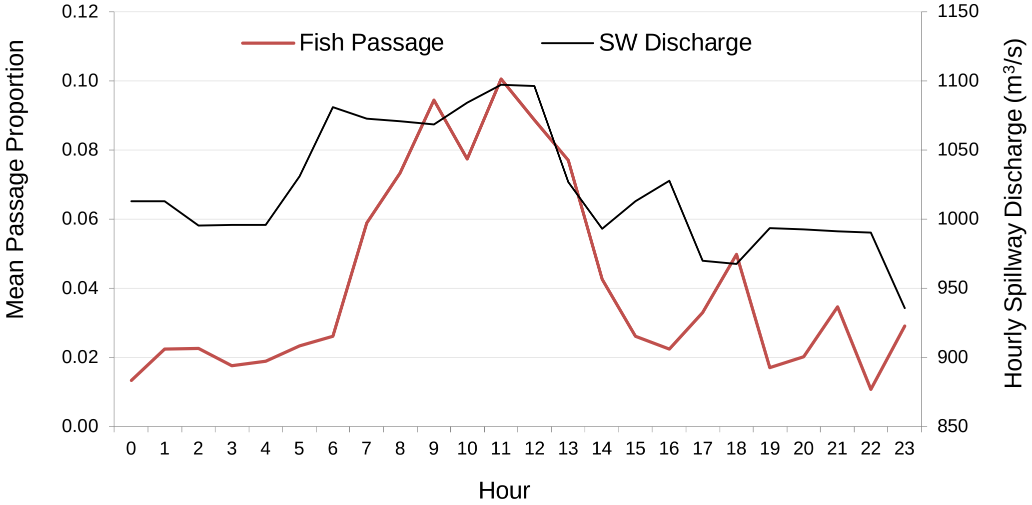

Figure 3.13. Diel Distribution of Smolt-Size Fish Passage at Spill Bay 5. Red line represents fish data as the hourly proportions of total passage. Black line represents total hourly turbine discharge (m^3/s). Discharge data were obtained from the USACE WVP operations office.

3.3.3 Regulating Outlet

3.3.3.1 Passage Estimates and Run Timing

We estimated that 23,339 smolt-size fish (± 572 fish, 95% CI) passed via the RO when it was open from October 29 through November 12, 2011[12], January 2 through 6, and January 20 through February 3, 2012. During the October–November period, RO passage peaked at 1,086 fish on November 5, a second peak occurred on November 7 (1,075 fish) (Figure 3.14). Recall, the turbines were out of service from November 1 through November 8 and the RO was the only route used to pass water through the dam.

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[12] We did not collect data during RO operations in September (27 – 29) and October 21 – 27 because of damaged transducer cables, which were replaced by divers on October 28.

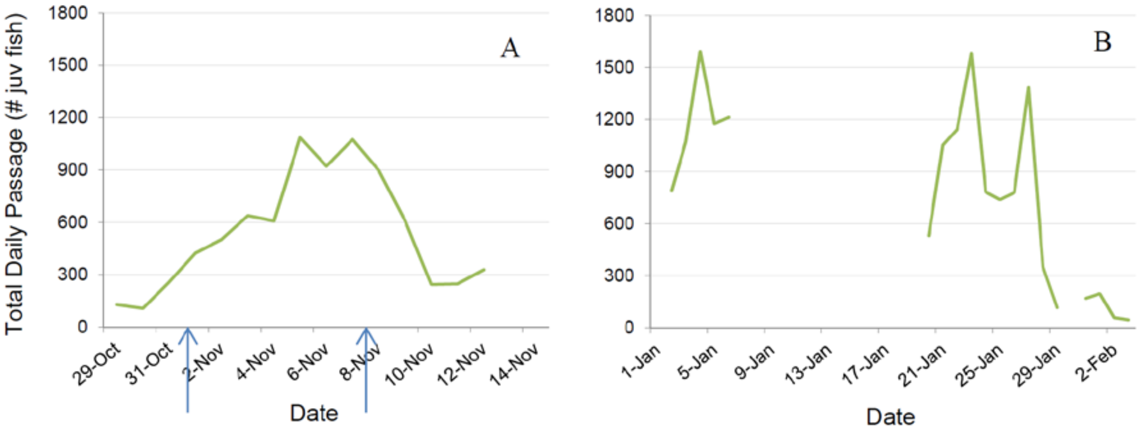

Figure 3.14. Estimated Daily Passage of Smolt-Size Fish at the Regulating Outlet from October Through November 2011 (A) and January Through February 2012 (B). The two blue arrows on the X axis (A) indicate the period when turbines were out of service.

3.3.3.2 Passage Efficiency and Effectiveness

When the RO was operated simultaneously with the turbines, which occurred for a few days at the end of October and beginning of November, 2011, and for several days in January, 2012 (a total of 72 non-consecutive hours), RO efficiency[13] was 0.33 and effectiveness[14] was 0.89 (Table 3.2). That is, when the RO was open, 33% of the fish passing the dam used the RO and 67% passed into the turbines.

Table 3.2. RO Passage Efficiency and Effectiveness

Passage Route	Discharge proportion	RO Efficiency	RO Effectiveness
RO	0.37	0.33	0.89
Turbines	0.63	NA	NA

3.3.3.3 Diel Distribution

Diel distribution for smolt-size fish during periods when the RO was operated all day and fish passed that route shows a distinct trough in passage in mid-afternoon (Figure 3.15). Otherwise, diel passage was reasonably uniform at the RO.

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[13] RO efficiency is calculated as RO passage divided by total project passage.

[14] RO effectiveness is the ratio of fish:flow proportions for the RO out of the total project.

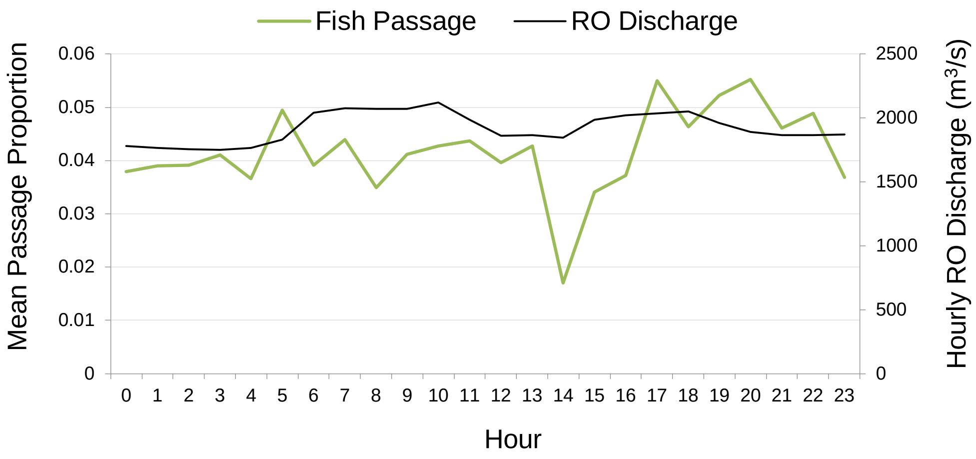

Figure 3.15. Diel Distribution of Smolt-Size Fish Passage at the RO During Periods When It Was Operated Throughout the Day and Fish Passed (November, 2011 and January, 2012). Green line represents fish data as the hourly proportions of total passage. Black line represents total hourly turbine discharge (m^3/s). Discharge data were obtained from the USACE WVP operations office

3.3.4 Relationships Between Fish Passage and Environmental Variables

The selected environmental variables were all significantly correlated with fish passage (Table 3.3). Many of the environmental variables were also significantly correlated with each other. This is to be expected for a storage reservoir where operations result in large changes in water volume, depth, etc. These changes also occur with an annual rhythm that approximates the natural seasonal changes, which can result in greater correlation among variables. For example, surface-water temperature was significantly correlated with all other variables in the list. Because temperature is highly seasonal, that result suggests that all of the variables must have a seasonal component.

Table 3.3. Correlations Among Passage and Environmental Variables. Red font indicates $P < 0.05$.

Means	DayHours	Forebay_Delta	Forebay_Elev	L_Tot_Discharge	Temp_0.5ft	Temp_180ft
L_Tot_Pass	-0.66	-0.19	-0.55	0.22	-0.43	-0.28
DayHours		0.38	0.92	-0.05	0.47	0.13
Forebay_Delta			0.44	0.04	0.10	-0.10
Forebay_Elev				0.01	0.55	0.16
L_Tot_Discharge					-0.24	-0.13
Temp_0.5ft						0.83

By plotting the variables against each other (Figure 3.16), it is possible to examine the nature of the correlations. The LOWESS fits (Statistica 11, www.statsoft.com) emphasize the trends in the data. While the fits for total passage and the other variables are not nearly straight, they generally illustrate a trend of increasing or decreasing passage as the other variable increases. Because there is no single variable that appears to explain a majority of the variation in passage, a multivariate approach may be useful in explaining some of the residual variation.

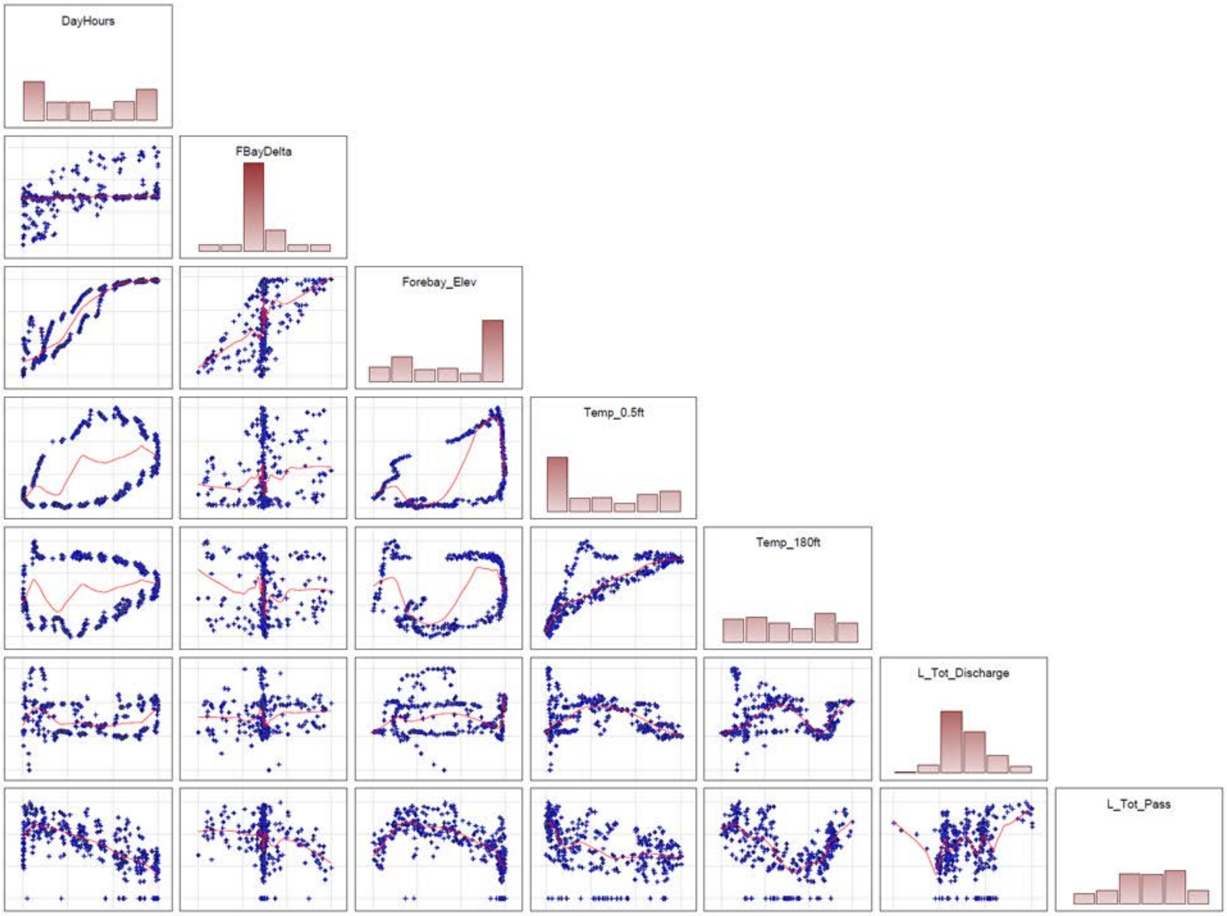

Figure 3.16. Matrix of Plots for Environmental and Passage Variables. Red line is a LOWESS fit to the data, included here to emphasize trends.

3.3.4.1 Multivariate Analysis

The 10 best regression models are included in Table 3.4, ranked by AIC score with the best scores at the top of the table. The best model included the forebay temperature at depth (Temp_180ft), forebay elevation (Forebay_Elev), total discharge (L_Tot_Discharge), hours of daylight (DayHours), and the operation period (OPS_Period). These variables capture the operational changes (OPS_Period, Forebay_Elev, L_Tot_Discharge), the seasonal changes within the reservoir (Temp_180ft), and the seasonal environment that would be correlated with fish life history (DayHours). The variables that were not selected into the model were the daily change in forebay elevation (FBayDelta), surface-water temperature (Temp_0.5ft), and a tabulation of whether peaking operations were in effect (Peaking). FBayDelta was correlated with Forebay_Elev, so models would likely need to include only one of the two variables. Temp_0.5ft was correlated with all other environmental variables, which suggests it offers little additional information. Peaking operations were common only in the Winter period, but information about peaking operations did not add useful information about fish passage to the model.

Table 3.4. Best Subsets Model Selection for Fish Passage as a Function of Environmental Variables at DET. The selected model is highlighted.

Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7	df	AIC	LRatioChi2	p
Temp_180ft	Forebay_Elev	L_Tot_Discharge	DayHours	OPS_Period			7	646.03	290.43	< 0.001
Temp_180ft	Forebay_Elev	L_Tot_Discharge	DayHours	OPS_Period	Peaking		8	647.77	290.69	< 0.001
Temp_180ft	Forebay_Elev	L_Tot_Discharge	DayHours	Temp_0.5ft	OPS_Period		8	647.89	290.57	< 0.001
Temp_180ft	Forebay_Elev	L_Tot_Discharge	DayHours	FBayDelta	OPS_Period		8	647.89	290.56	< 0.001
Temp_180ft	Forebay_Elev	L_Tot_Discharge	DayHours	FBayDelta	OPS_Period	Peaking	9	649.61	290.84	< 0.001
Temp_180ft	Forebay_Elev	L_Tot_Discharge	DayHours	Temp_0.5ft	OPS_Period	Peaking	9	649.61	290.84	< 0.001
Temp_180ft	Forebay_Elev	L_Tot_Discharge	DayHours	FBayDelta	Temp_0.5ft	OPS_Period	9	649.78	290.67	< 0.001
Temp_180ft	L_Tot_Discharge	DayHours	OPS_Period				6	650.18	284.27	< 0.001
Temp_180ft	L_Tot_Discharge	DayHours	Temp_0.5ft	OPS_Period			7	651.28	285.17	< 0.001
Temp_180ft	L_Tot_Discharge	DayHours	OPS_Period	Peaking			7	651.46	284.99	< 0.001

The equation for the selected model is as follows[1]:

Expected Fish Passage = exp[-0.1598
- 0.1999*DayHours
+ 0.0026*Forebay_Elev
- 0.1713*Temp_180ft
+ 0.2591*L_Tot_Discharge
+ 0.0814 (when Ops_Period = Conservation_Pool)
- 0.3014(when Ops_Period = Winter Pool)
+ 0.0016 (when Ops_Period = Refill)]

The selected model does not explain all variation in fish passage, but predicted values follow the trend of observed values well (Figure 3.17). There are several days when no fish were detected passing the dam. These appear out of place on the plot, but we had no justification for removing them from the analysis data set. Increased sampling effort might be able to better quantify passage when numbers approach zero, but the life history of the fish is also likely to drive whether fish are available to pass.

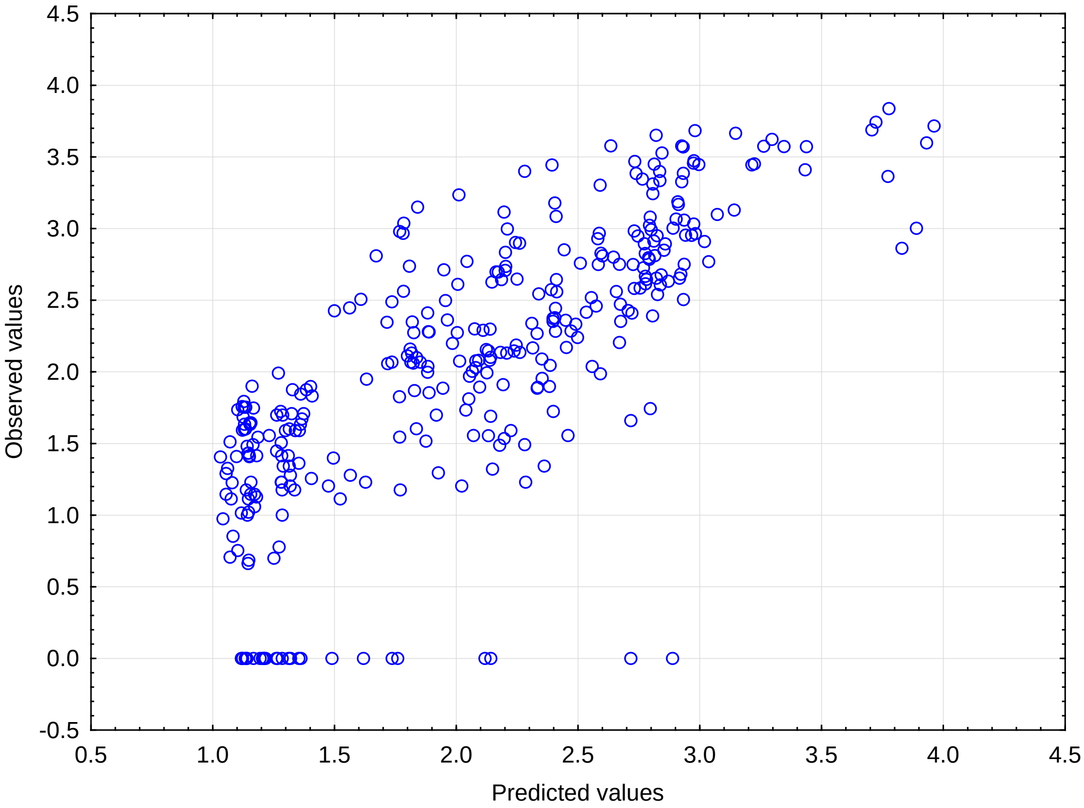

Figure 3.17. Residuals of Observed Versus Model Prediction Plotted Versus Predicted Values

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[1] The regression fitting routine has to select one category of categorical variables as the “Default”, and all other categories are compared to it. The Drawdown period was the default.

3.3.5 Vertical Distribution and Abundance Index

The vertical distribution of fish (grouped by daylight and nighttime hours) in the forebay near the face of the dam where the transducers sampled (Figure 3.1) showed fish were generally distributed throughout the water column during the four forebay pool elevation periods mentioned earlier (Figure 3.18). During the Refill and Conservation Pool periods, vertical distribution was bi-modal with surface-layer and mid-water modes. Patterns for day and night distributions were variable. Fish were distributed above and below the thermocline when it was present (Conservation Pool and Drawdown periods) (Figure 3.18). During Drawdown and Winter Pool, juvenile fish were distributed throughout the water column during daylight hours, however at night, these fish separated into two groups; with the division occurring at depths of approximately 40 m during Drawdown and 35 m during Winter Pool) (Figure 3.18).

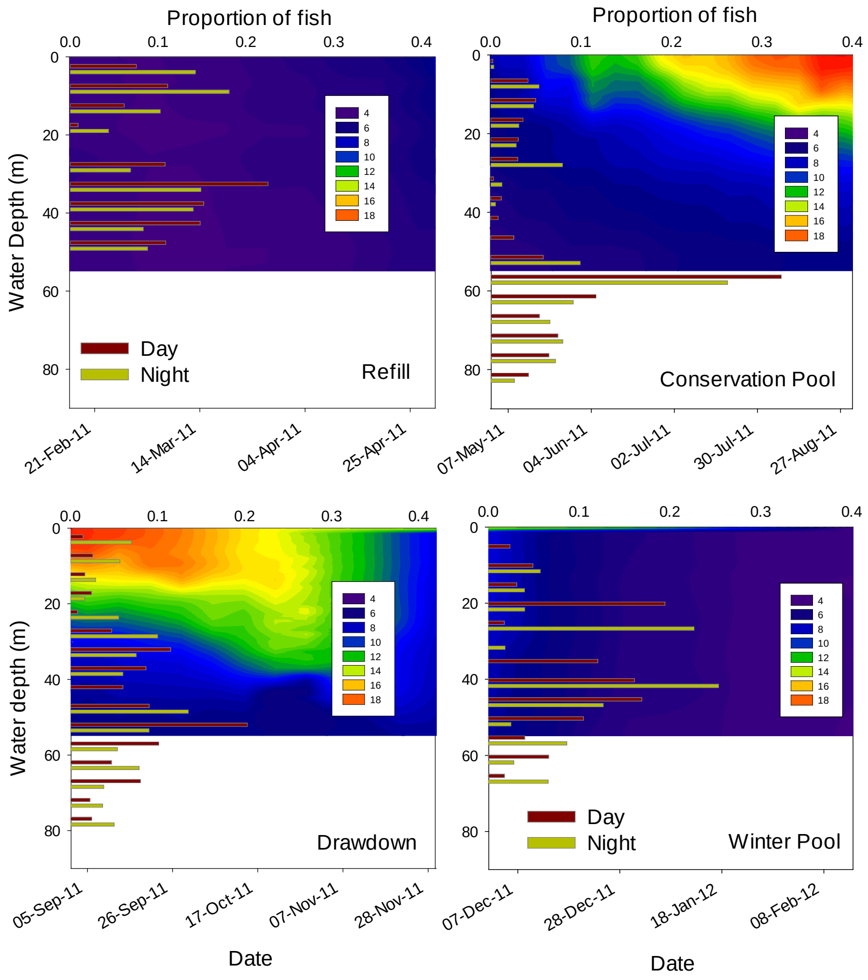

Figure 3.18. Vertical Distribution of Smolt-Size Fish and Forebay Water Temperature (ºC) at the Forebay Dam Face Presented Separately by The Four Distinct Pool Elevation Periods Mentioned Earlier. Red bars represent fish distributions during day time hours. Olive-colored bars represent fish distributions during night time hours. Water temperature data were obtained from the USACE Portland Office. No temperature data was logged deeper than 54.86 m.

The forebay abundance index derived from the vertical distribution data set indicates smolt-size fish were in the immediate forebay face of the dam between the turbines and spillway throughout the year (Figure 3.19). Forebay fish abundance was relatively uniform across the study year, with a distinct peak in mid-March. A smaller peak in the forebay abundance index occurred in mid-February. The forebay abundance index indicates the availability of fish to possibly pass the dam.

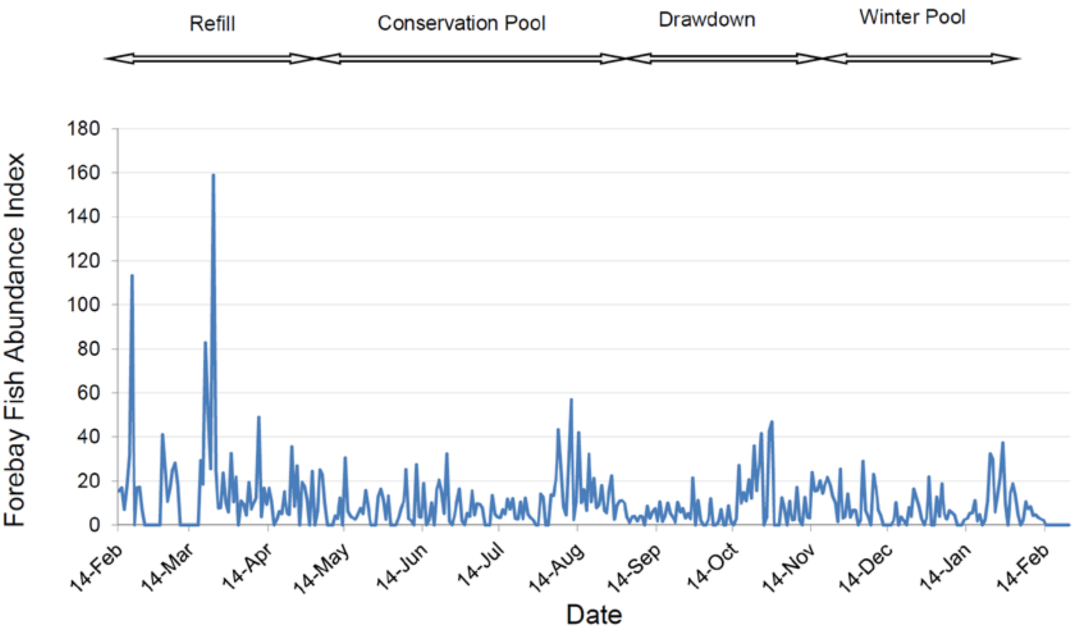

Figure 3.19. Forebay Abundance Index. These data are daily estimates of total fish estimates from the forebay vertical distribution transducers. Fish detections were extrapolated to an arbitrary width of 5 m for the purpose of the abundance index. Arrows at the top of Figure indicate the four forebay pool elevations periods mentioned earlier in this report.

3.3.6 Acoustic Size

The acoustic size (target strength) of fish at the turbines was fairly consistent at -50 dB among the passage peaks during the year-long study (Table 3.5). This corresponds to a fish length of about 100 mm[2]. Mean target strength for fish at the spillway during September was about 4 dB higher, indicating average fish length of about 150 mm[3]. For the two analysis periods for RO fish, mean target strength was relatively high at -45 dB during the November period (~105 mm[4]); it was comparable to turbine target strength during the January period. The target strength frequency distributions were mostly unimodal (Figure 3.20, Figure 3.21, and Figure 3.22).

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[2] Turbine -- assume sampling volume was dorsal, 45 deg off head aspect.

[3] Spillway – assumes sampling volume was ventral, 30 deg off vertical.

[4] RO – assume sampling volume was dorsal, 0-15 deg off vertical.

Table 3.5. Target Strengths (dB re: 1 µPa @ 1 m) by Analysis Period Corresponding to Passage Peaks (see Figure 3.7).

Analysis Period	Route	Dam Operations Period	n	mean	SD	SE	median
Feb 20 – 28, 2011	Turbines	Refill	213	-50.1	2.9	0.2	-50.6
Mar 23 – 31, 2011	Turbines	Refill	333	-49.7	2.7	0.2	-50.3
Apr 19 – 22, 2011	Turbines	Refill	49	-49.7	2.7	0.4	-50.1
May 05 – 07, 2011	Turbines	Conservation	27	-50.7	3.0	0.6	-52.1
Nov 22 – 28, 2011	Turbines	Winter	103	-48.6	3.7	0.4	-49.9
Jan 05 – 31, 2012	Turbines	Winter	2418	-50.4	2.6	0.1	-49.2
Feb 01 – 12, 2012	Turbines	Winter	762	-49.7	3.0	0.1	-50.2
Sept 01 – 23, 2011	Spillway	Drawdown	447	-46.0	3.8	0.2	-46.1
Nov 22 – 28, 2011	RO	Winter	578	-45.3	3.2	0.1	-45.1
Jan 02 – 30, 2012	RO	Winter	3428	-49.9	3.1	0.1	-50.7

SD = standard deviation; SE = standard error.

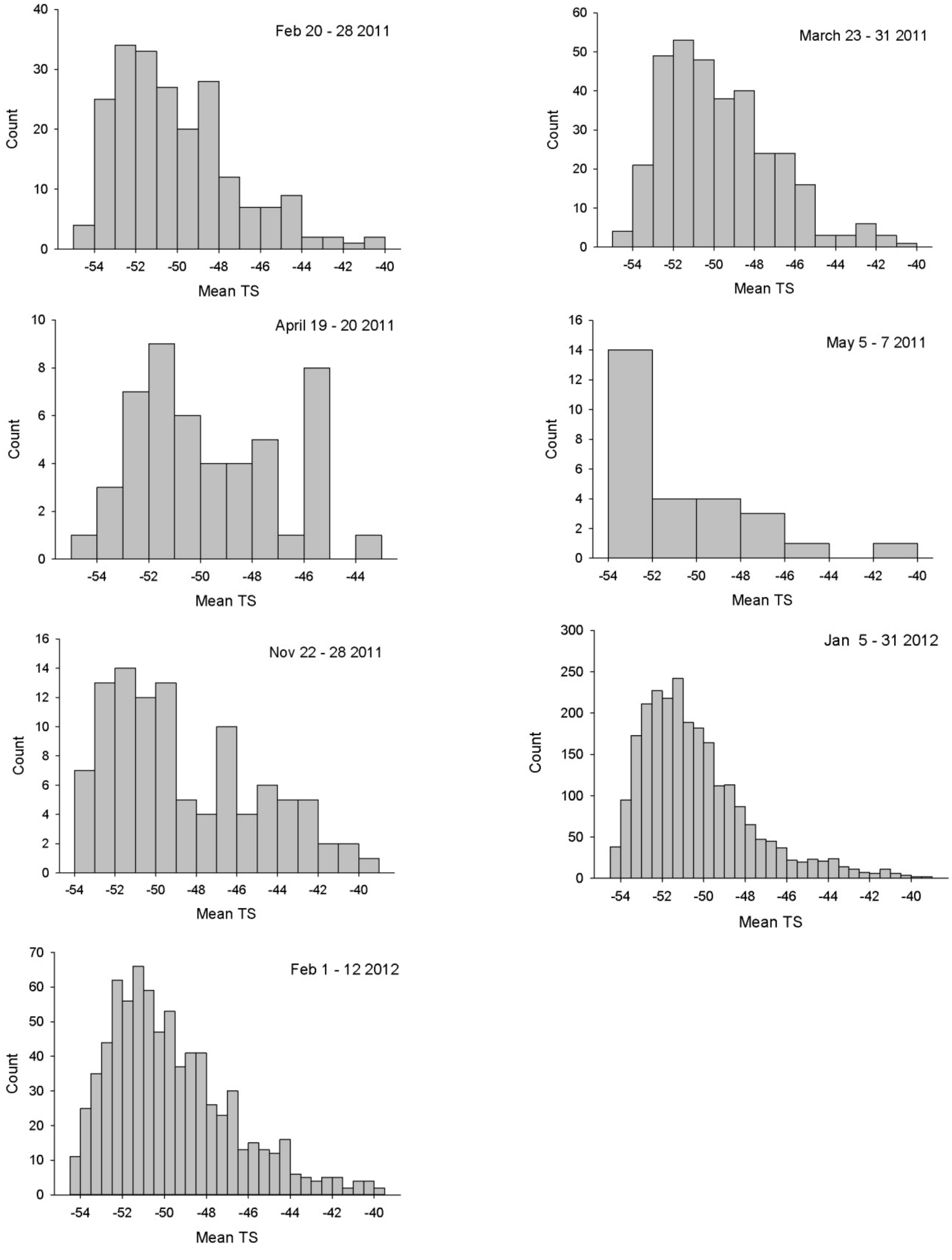

Figure 3.20. Frequency Distribution of Mean Target Strength (TS) for Individual Fish by Analysis Period for the Turbines

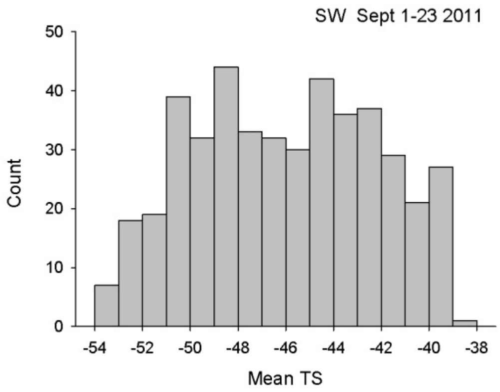

Figure 3.21. Frequency Distribution of Mean Target Strength (TS) for Individual Fish for the Spillway for September

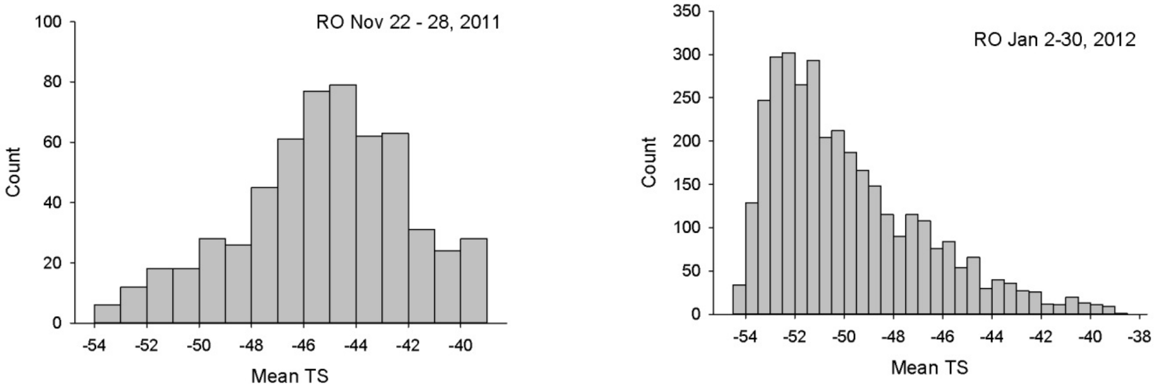

Figure 3.22. Frequency Distribution of Mean Target Strength (TS) for Individual Fish by Analysis Period for the RO for November, 2011 and January 2012

4.0 Discussion

The results of the 2011 hydroacoustic study of juvenile salmonid passage and distribution at DET on the North Santiam River provide new and, in some cases, first-ever passage estimates, run timing; relationships between passage and environmental variables, and horizontal, diel, and vertical distributions of fish at the dam. Findings from this one year of study should be applied carefully because annual variation can be expected due to the variability in adult salmon escapement, egg-to-fry and fry-to-smolt survival rates, reservoir rearing and predation, dam operations, weather, etc.

4.1 Comparison Between Hydroacoustic and Direct Capture Data

The hydroacoustic data likely included juvenile Chinook salmon, as well as kokanee (land-locked sockeye salmon), because both Chinook salmon and kokanee were captured in the ODFW tailrace screw trap when it was operated between April and December 2011 (Figure 4.1). Using periods when hydroacoustic and trap data were collected simultaneously, daily passage patterns (“run timing”) for Chinook salmon and kokanee were variable between the two methods during April through September, but were similar during October through December. Sampling techniques, gear bias, and trap efficiency should be considered when comparing hydroacoustic and direct capture data; however, the two data sets together provide a more complete depiction of dam passage than either alone.

Passage peaks for Chinook salmon captured in the trap during October through December matched those observed in the hydroacoustic data (Figure 4.2). For example, the trap data peaked during the last week of November and, similarly, the hydroacoustic data showed a distinct peak in turbine passage during the same week in November. In contrast, passage peaks in hydroacoustic data during April and May were not observed in the trap catch (Figure 4.1). Conversely, passage peaks of Chinook salmon from the trap during August and September were not observed in hydroacoustic data. One plausible explanation for not observing higher numbers of Chinook salmon in the hydroacoustics data during August and September is the rigorous filtering used during data analysis for that period, where “noisy” data were eliminated from the final dataset. Consequently, some acceptable fish tracks may have been sacrificed at the risk of retaining undesirable tracks. Direct capture numbers for kokanee peaked in early November, during RO operations, and a similar peak was observed in the hydroacoustic data during the same period (Figure 4.2).

During April and May, when the turbines were the only route for water and fish to pass the dam, the proportion of direct-captured juvenile salmon was approximately 80% kokanee and 20% Chinook salmon (data provided courtesy of ODFW). Between June and September, during turbine and spillway operations, a majority of direct-captured juvenile fish were Chinook salmon. For October and November, during turbine and RO operations, similar proportions of Chinook salmon and kokanee were captured in the trap. And, in December, most of the juvenile fish in the trap were Chinook salmon (85%). As a result, the direct capture data suggests a majority of fish represented in the hydroacoustic data may be kokanee during spring months and Chinook salmon in the summer, with similar proportions of Chinook salmon and kokanee during October and November, and Chinook salmon as the majority of fish in December.

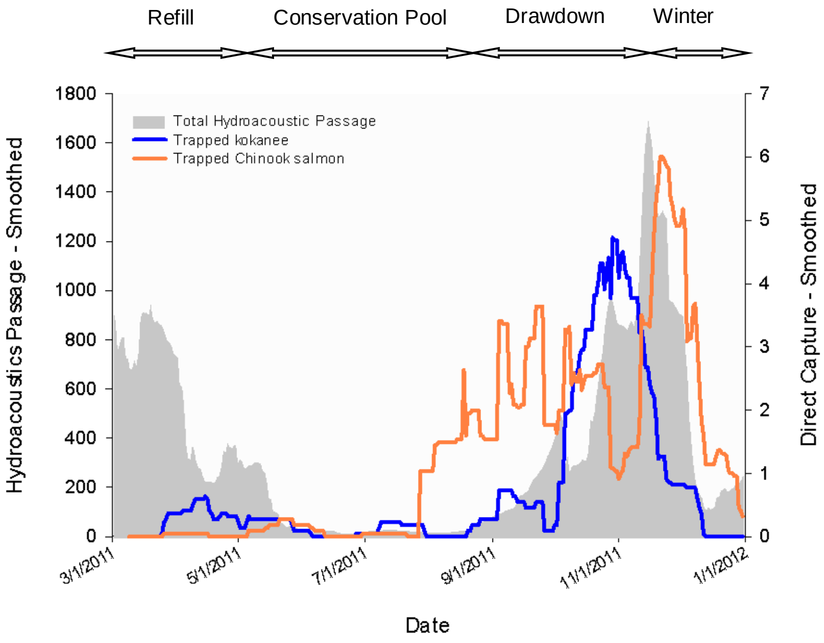

Figure 4.1. Smoothed Data (two-week running average) of Total Smolt-Size Fish Passage from Hydroacoustic Data (Shaded) and Direct Capture Numbers of Juvenile Chinook Salmon (Orange Line) and Kokanee (Blue Line) in the Tailrace of DET in 2011. Screw trap data were provided courtesy of ODFW. Arrows at the top of Figure indicate the four forebay pool elevations periods mentioned earlier in this report.

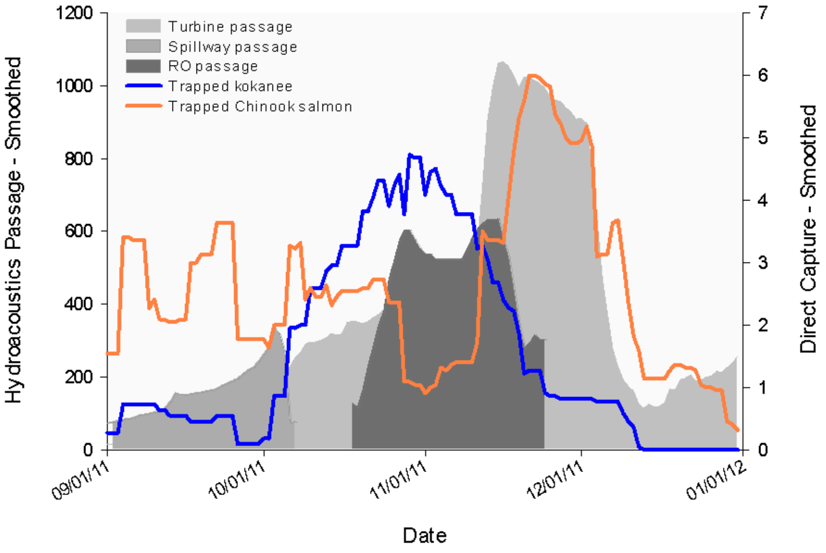

Figure 4.2. Smoothed Data (two-week running average) of Smolt-Size Fish Passage from Hydroacoustic Data for the Turbines, Spillway, and RO (Shaded) and Direct Capture Numbers of Juvenile Chinook Salmon (Orange Line) and Kokanee (Blue Line) in the Tailrace of DET During September Through December 2011. Screw trap data were provided courtesy of ODFW.

4.2 Passage, Environmental Variables, and Vertical Distribution

Fish passage occurred in varying amounts at all three routes of the dam (turbines, spillway, and RO) when they were operated. Recall, the turbines were the only route through the dam during spring (Refill period); the spillway was operated in the summer months (Conservation Pool) for downstream water temperature control; and, the RO was operated in the fall (Drawdown) for downstream water temperature control and during winter months (Winter Pool) to pass excess water. Run-timing peaks occurred during the Refill, Drawdown, and Winter Pool periods (Figure 3.7), whereas very few (<100 fish/d) smolt-size fish passed the dam during summer months (Conservation Pool). The noticeable passage peak in early spring as the reservoir was being refilled indicates a biological response, because fish were passing into the turbines even as the forebay deepened. During Conservation Pool, the low passage numbers observed at the spillway and turbines (Figure 3.7) and at the ODFW tailrace trap (May through July) (Figure 3.5) suggest fish do not have a proclivity to pass the dam during this period. We observed the highest passage rates during the Winter Pool period when forebay elevation was low, but variable, physically concentrating fish in a reduced water column. Similarly, Friesen et al. (2007) found the highest peaks of juvenile Chinook salmon in the lower Willamette River occurred during winter and spring months. The DET run-timing data reflect both operational and biological influences.

The multiple regression analysis also indicated that fish passage at DET was related to dam and reservoir operations, as well as biological factors. The key variables in the model of fish passage were forebay temperature at depth, forebay elevation, total discharge, hours of daylight, and the operation period. These variables reflect a mixture of physical and biological effects. The fact that no single environmental variable stood out demonstrates the complexity of downstream movement of juvenile salmonids at DET.

Opportunities to sample fish passage at the spillway and RO, separately, as the only route through the dam, presented themselves when the turbines were out of service for maintenance July 5 through 10 and November 1 through 8, respectively. During the turbine outage in July, the spillway was the only route for water and fish to pass the dam. As mentioned earlier, fish passage numbers were generally low during the summer months and, consistent with this pattern, we did not see an increase of passage via spill (Figure 3.7). However, during the turbine outage in November, and while fish passage was increasing after the summer's low passage rates, the RO was the only route for water and fish to pass the dam. Fish passage rates at the RO were comparable to those at turbines before they went offline and after they went back into service (Figure 3.7). Other research suggest juvenile salmonids are generally reluctant to sound to pass dams, but when surface outlets are not available, they will sound to pass through a relatively deep outlet (e.g., Andrew and Geen 1960; Johnson 1996; Moursund et al. 2004).

Generally, surface-oriented vertical distribution is a common behavior for juvenile salmonids (e.g., Johnson and Dauble 2006; Ploskey et al. 2007; Smith et al. 2009). In the DET forebay immediately in front of the dam face, however, juvenile fish were variably distributed throughout the water column during our year-long study (Figure 3.18). During Refill and Conservation Pool elevation periods, the distribution was bi-modal with surface-layer and mid-water modes. For the Drawdown and Winter Pool elevations, fish were uniformly distributed throughout the water column during daylight hours, but separated into two groups at night; one group was above approximately 40 m and the other below 45 m. Net sampling efforts by ODFW in the DET forebay between August and November, 2011, indicated most of the juvenile Chinook salmon captured were present between 4.6 and 13.7 m deep during August, at deeper depths (between18.2 and 27.4 m deep) during the Drawdown period, and near the surface again in

November (Monzyk et al 2012). We saw comparable distributions of fish targets in our hydroacoustic data during these periods (Figure 3.18). During Drawdown, a small proportion of fish were between 15 and 20 m deep, but most fish were deeper in the water column (between 30 and 70 m) during daylight hours and closer to the surface at night. Temperature data shows the water surface was still fairly warm in September and October (16 to 18°C) (Figure 3.18); therefore, these fish may be avoiding sunlight and warm temperatures during the day and only moving close to the surface at night to feed. Scheuerell and Schindler (2003) and Quinn (2005) describe diel vertical migration of sockeye salmon in lakes, where these fish would remain deep in a water column during daylight, especially during summer months, mainly for predator avoidance, and only move close to the surface at crepuscular hours for feeding.

Net sampling did not occur deeper than 27.4 m in the DET forebay in 2011 (personal communication, Fred Monzyk, ODFW); therefore, we were not able to ascribe fish species for hydroacoustic detections deeper in the water column (Figure 3.18). Our assumption, however, is that the fish deeper in the water column are likely kokanee based on knowledge of kokanee distribution and their known presence in DET reservoir. Kokanee occupy deep, cold waters in a lake and generally only move up close to the surface at dusk for feeding (Horak and Tanner 1964; Beauchamp et al 1997; Bevelhiemer and Adams 1993; Scheuerell and Schindler 2003; Quinn 2005). Furthermore, the Detroit reservoir is stocked annually with hatchery kokanee for a sport fishery (Monzyk et al 2012). In 2011, the Detroit reservoir was stocked with 55, 125 kokanee for sport fishery, which is less than half of the usual stocking amount due to low egg availability (personal communication with Doug Curtis, Wizard Falls Hatchery, Camp Sherman, Oregon). Consequently, kokanee are available to pass the dam if they happen to move into the DET forebay.

4.3 Implications for Collector Design

Bioengineers will need to consider fish behavior to develop design alternatives to collect juvenile salmon; such designs are currently being contemplated (AECOM and BioAnalysts 2010). Design of passage structures should incorporate debris load and its effect on fish passage at any new passage or collection structures, especially during winter months when high numbers of juvenile salmonids pass the dam (Figure 3.7; Keefer et al. 2011). Daily passage of thousands of juvenile salmonids (Figure 3.7) may be expected to enter surface collectors or passage devices.

The horizontal distribution of turbine passage was skewed to Unit 2, the turbine of which is closest to the north shore of the forebay. This is consistent with the general shoreline orientation of juvenile salmon in reservoirs (Smith et al. 2009). However, juvenile salmon may occupy deeper water as their size increases (Dauble et al. 1989; Tabor et al. 2011). Additionally, Dauble et al. (1989) found subyearling Chinook salmon were generally shoreline oriented, whereas yearling Chinook salmon were distributed in the main channel of a river. Therefore, placement of proposed surface collectors or passage devices should consider this horizontal distribution pattern.

Vertical distribution data are fundamental to designing structures for downstream fish passage or collection (Giorgi and Stevenson 1995; Sweeney et al. 2007). Distribution data are also used to aid in the design of project operations intended to increase fish passage survival. Vertical distribution of fish in the forebay near the face of DET during our study (February 2011through February 2012) was variable and likely included both kokanee and Chinook salmon, as mentioned above. Because vertical distribution of fish must be considered when designing a collector, more research on the vertical distribution, including species composition and spatially and temporally detailed data, would be useful at DET.

The “free flow” test of operating two spill bays (4 and 5) at the spillway during September 23−27, 2011, when the pool elevation was between 0.8 m and the spillway crest (1543 – 1541 ft), has important implications for surface collector design. The peak in fish passage at the spillway we observed during the test (Figure 3.11) indicates the potential for surface flow outlet or collector to pass (or collect) smolt-size fish at DET. In addition, the similar numbers of smolt-size fish that passed through both bays during the test indicate these fish would use any available surface route to pass the dam (Figure 3.12). Diel distribution shows a distinct peak in passage between mid-morning and mid-afternoon, which coincided with a peak in spillway discharge, and low passage at night (Figure 3.13). In their study of direct injury and survival at during July, Normandeau Associates, Inc. (2010) and Duncan and Carlson (2011) found high mortality and injury of fish (16% to 40% mortality; 50% injury) passing the spillway, and a higher gate opening (3.5 ft) was more detrimental to fish than a 1.5 ft gate opening. Further tests of spillway operations are warranted during peak fish passage from late fall through winter and early spring to aid in the design of a surface flow outlet or collector.

4.4 RO Operations

Dam operations at DET during 2011 involved opening the RO in late summer and fall for downstream water temperature control, and during winter to discharge excess water beyond turbine discharge capacity (Figure 3.2). RO fish passage rates were moderate and RO efficiency relative to the turbines was 0.33; both findings indicate the potential to pass fish through this non-turbine route. It should be noted that the RO can only be operated when the forebay pool elevation is lower than the spillway crest (El 469.7 m). Recent studies of direct injury and survival (Normandeau Associates, Inc. 2010; Duncan and Carlson 2011) suggest the RO with a five foot (5 ft) gate opening was the safest route for juvenile fish passage compared to the RO with a one foot (1 ft) gate opening, the turbines, or the spillway. The later three options were detrimental to fish survival through the dam (Normandeau Associates, Inc. 2010; Duncan and Carlson 2011).

The direct injury and survival studies (Normandeau Associates, Inc. 2010; Duncan and Carlson 2011) were conducted in early December when the forebay elevation was at low levels (Winter Pool). As mentioned above, our hydroacoustic data show high fish passage rates through the dam during late fall and winter months (Figure 3.7). Operations of the RO to protect Chinook salmon may also affect other species, such as kokanee, because kokanee were captured with Chinook salmon in the tailrace screw trap during fall of 2011 (data provided by ODFW). During the turbine outage in November (November 1 – 8), the RO was operated 24 h/d every day, with an average gate opening of 6.5 ft (ranged from 4.6 – 8.0 feet) (data provided by USACE WVP operations office). For this period, we saw an increase in fish passage through the RO in our hydroacoustic data (Figure 3.14; Figure 4.2). Additionally, direct-capture data for the same period show an increase in kokanee and a decrease in Chinook salmon numbers in the screw trap (Figure 4.2). In fact, the capture numbers during that week show approximately 91% of salmonids in the trap were kokanee (data provided ODFW). However, capture numbers for kokanee decreased by mid-November and no kokanee were captured for several days after RO operations ended on November 14, 2011. Furthermore, very few kokanee passed the dam from mid-November to the end of December, while at the same time Chinook salmon capture numbers increased (Figure 4.2). Therefore, it appears kokanee would readily use the RO, a deeper outlet, when it is operated in lieu of turbines to pass the dam, whereas Chinook salmon may prefer to pass through the turbines.

The results of the abovementioned studies suggest that managers consider additional evaluations of RO operations as a non-turbine route for fish passage (such as additional gate openings and different forebay pool elevations) because the direct injury and survival studies were conducted at only two gate openings (1 ft and 5 ft) and during a winter low forebay pool. During our hydroacoustic study, the gate opening for the RO in October and November, 2011, ranged from 3.2 – 8.0 feet and in January and February, 2012, ranged from 1.2 – 10.0 feet (data provided by USACE WVP operations office).

4.5 Comparison of Hydroacoustic Study Results at Detroit and Lookout Point Dams

Hydroacoustic studies at Lookout Point Dam (LOP) in 2010–2011 (Khan et al. 2012) and DET during 2011–2012 (this study) can be compared to identify similarities and dissimilarities in turbine passage and distribution patterns. While we recognize that the two reservoirs have different species composition and abundance, we make a preliminary comparison of data on total turbine passage estimates, run timing, and horizontal distribution to identify patterns in fish passage and distribution across multiple WVP dams.

- Khan et al. (2012) estimated 142,463 fish ± 4,444 (95% CI) smolt-size fish passed through turbines at LOP from March 2010 through January 2011. Estimated turbine fish passage at DET from February 2010 through February 2012 was 182,526 smolt-size fish (±4,660 fish). This finding implies comparable levels of juvenile salmon passage at the two WVP projects.
- At both dams, run timing peaked in late fall and winter (Figure 4.3). Similar trends were found in data from screw-trap sampling below Detroit, Cougar and Foster dams (Romer et al. 2012). We observed run-timing peaks in early spring at DET, but not at LOP. In contrast, Khan et al. (2012) reported peaks in late spring 2010 for LOP that were not evident at DET the next year.
- Horizontal distributions of juvenile fish at the turbine intakes of the two dams were similar; units closest to a shoreline passed the most fish.

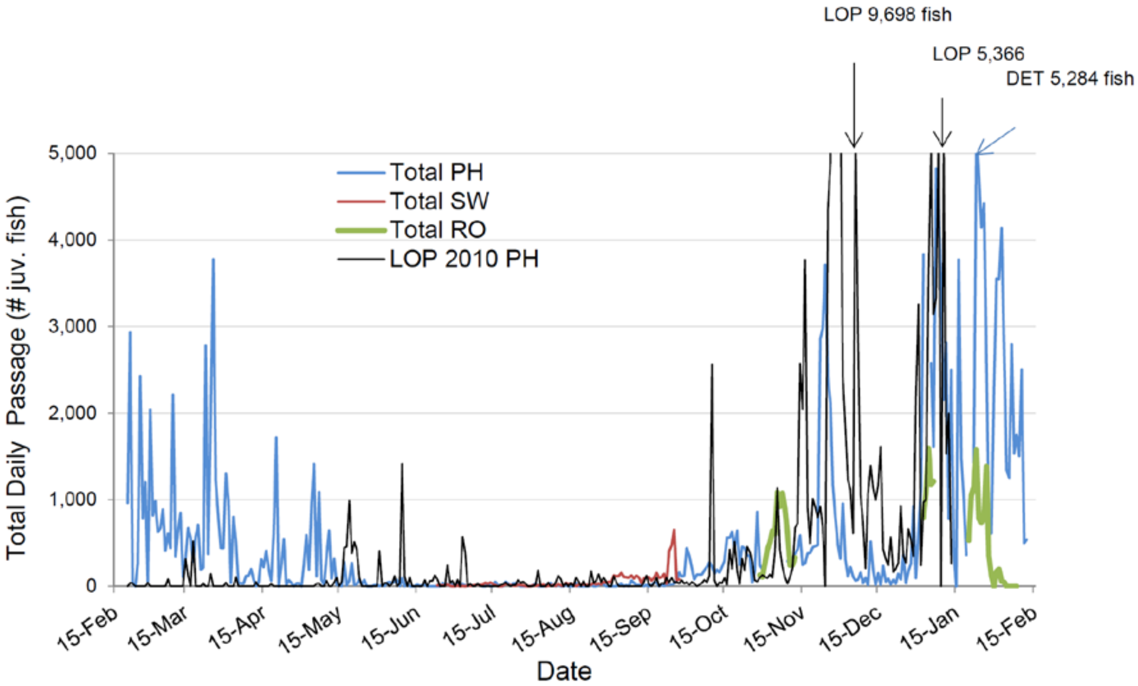

Figure 4.3. Total Daily Passage of Smolt-Size Fish and Run Timing from Hydroacoustic Studies at LOP (2010) and DET (2011). Blue line represents turbine passage at DET. Red line represents spillway passage at DET. Green line represents RO passage at DET. Black line represents turbine passage at LOP.

4.6 Conclusions and Recommendations

We draw the following conclusions from the hydroacoustic evaluation of juvenile salmonid passage and distribution at DET from February 2011 through February 2012:

- The non-obtrusive hydroacoustic data from this study are reliable because passage patterns were similar to those observed in the direct-capture data from the tailrace screw trap.
- The variable vertical distribution of fish we observed indicates the need for careful consideration of development of surface passage or collector devices.
- The horizontal distribution of turbine passage should be considered for placement of proposed surface collectors or passage devices.

We offer the following recommendations for future research at DET to support the design of fish passage or collection systems:

- Consider conducting a quick, focused test of surface spill to demonstrate whether juvenile salmonids will pass at a time of year when emigrants are typically migrating downstream.
- Consider additional evaluations of the RO (such as different gate openings and different forebay pool elevations, when the pool elevation is below the spillway crest) as a non-turbine route to pass juvenile salmonids.

- Collect additional data on vertical distribution, including species composition and spatially and temporally detailed data.
- Consider conducting mobile hydroacoustic surveys coupled with direct observations to provide estimates of juvenile salmonid distribution and abundance by fish size class in DET reservoir (e.g., Ploskey et al. 2012).

In closing, the spatially and temporally high-resolution data reported herein provide detailed estimates of vertical, horizontal, diel, daily, and seasonal passage and distributions and analyses of relationships between fish passage and environmental variables at DET from February 2011 through February 2012. This information is applicable to management decisions about the design and development of surface passage and collection devices to help restore Chinook salmon populations in the North Santiam River watershed above Detroit Dam.

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Appendix A

Hydroacoustic System Parameters

Appendix A - Hydroacoustic System Parameters

Legend for Table A.1 (next page)

A. System

B. Echo-sounder number

C. Channel

D. Transducer number and phase (if split beam)

E. Calibrated cable length (ft)

F. Source level (dB)

G. -6 dB

H. Maximum output voltage (dB)

I. G1 40 logR receiver sensitivity (dB)

J. Target strength of largest on-axis target of interest (dB)

K. Calculated receiver gain (dB)

L. Installed cable length (ft)

M. Difference in cable length between calibrated cable and installed cable (ft)

N. Receiver gain adjusted for difference in cable length (dB)

O. Source level adjusted for difference in cable length (dB)

P. Receiver sensitivity adjusted for difference in cable length (dB)

Q. Target strength of smallest on-axis target (dB)

R. Voltage of smallest on-axis target (dB); voltage of smallest on-axis target at 20 dB per volt (V)

Table A.1. Hydroacoustic System Parameters Used at DET, 2011-2012

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
H	8	0	28	485	214.16	80	-113.39	-26	5.23	485	0	5.23	214.16	-113.39	-56	50	2.50
H	8	1	29	485	214.16	80	-113.39	-26	5.23	485	0	5.23	214.16	-113.39	-56	50	2.50
Q	21		407 (x)	705	213.14	80	-111.18	-26	4.04	940	-235	6.14	212.24	-112.38	-56	50	2.50
Q	21		407 (y)	705	213.33	80	-111.10	-26	3.77	940	-235	5.87	212.43	-112.30	-56	50	2.50
Q	21	2	407	705	213.24	80	-111.14	-26	3.90	940	-235	6.01	212.33	-112.34	-56	50	2.50
U	1		425 (x)	705	216.62	90	-105.70	-26	5.08	783	-78	5.78	216.32	-106.10	-56	60	3.00
U	1		425 (y)	705	216.59	90	-105.96	-26	5.37	783	-78	6.07	216.29	-106.36	-56	60	3.00
U	1	0	425	705	216.61	90	-105.83	-26	5.22	783	-78	5.92	216.31	-106.23	-56	60	3.00
U	1		426 (x)	705	216.64	90	-105.82	-26	5.18	783	-78	5.88	216.34	-106.22	-56	60	3.00
U	1		426 (y)	705	216.58	90	-105.88	-26	5.30	783	-78	6.00	216.28	-106.28	-56	60	3.00
U	1	1	426	705	216.61	90	-105.85	-26	5.24	783	-78	5.94	216.31	-106.25	-56	60	3.00
Y	23		443 (x)	705	214.11	80	-111.50	-26	3.39	705	0	3.39	214.11	-111.50	-56	50	2.50
Y	23		443 (y)	705	214.11	80	-111.50	-26	3.39	705	0	3.39	214.11	-111.50	-56	50	2.50
Y	23	0	443	705	214.11	80	-111.50	-26	3.39	705	0	3.39	214.11	-111.50	-56	50	2.50
Y	23		444 (x)	705	214.11	80	-111.30	-26	3.19	705	0	3.19	214.11	-111.30	-56	50	2.50
Y	23		444 (y)	705	214.11	80	-111.24	-26	3.13	705	0	3.13	214.11	-111.24	-56	50	2.50
Y	23	1	444	705	214.11	80	-111.27	-26	3.16	705	0	3.16	214.11	-111.27	-56	50	2.50
Y	23		446 (x)	705	214.11	80	-111.54	-26	3.43	705	0	3.43	214.11	-111.54	-56	50	2.50
Y	23		446(y)	705	214.11	80	-111.36	-26	3.25	705	0	3.25	214.11	-111.36	-56	50	2.50
Y	23	2	446	705	214.11	80	-111.45	-26	3.34	705	0	3.34	214.11	-111.45	-56	50	2.50
Y	23		429 (x)	685	214.16	80	-111.24	-26	3.08	685	0	3.08	214.16	-111.24	-56	50	2.50
Y	23		429 (y)	685	214.18	80	-111.32	-26	3.14	685	0	3.14	214.18	-111.32	-56	50	2.50
Y	23	3	429	685	214.17	80	-111.28	-26	3.11	685	0	3.11	214.17	-111.28	-56	50	2.50

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