PNNL-36335

Evaluation of Foster Dam Spillway and Green Peter Dam Spillway and Regulating Outlet Operations for Juvenile Fish Passage: Year 2

Final Report

September 2024

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Prepared for the U.S. Department of Energy
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Preface

This study was funded by the U.S. Army Corps of Engineers (USACE) – Portland District. It was led by Stephanie Liss (509-375-2988) from Pacific Northwest National Laboratory. The USACE technical lead for the study was Fenton Khan (503-808-4777).

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Executive Summary

A juvenile fish passage and survival study was conducted at Green Peter Dam (Green Peter) and Foster Dam (Foster) from February 2023 through March 2024. Spillway operations were evaluated at Foster in spring and fall to understand if it was a safer and effective route for downstream salmonid passage compared to turbine passage. Regulating outlet (RO) operations were evaluated at Green Peter in the fall after a reservoir deep drawdown to understand if they provided a safe and effective route of downstream salmonid passage. Green Peter and Foster dams are located on the Middle and South Santiam rivers, respectively, and are both located near Sweet Home, Oregon. These 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. As a result, the 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) regarding the operation of dams in the Willamette River Basin, including Green Peter and Foster (NMFS 2008).

There were two efforts for this study. The first, to provide the U.S. Army Corps of Engineers – Portland District (USACE) biologists, engineers, resource managers, and regional decision makers with the efficiency and effectiveness, as well as survival, of the interim nighttime spillway operations at Foster during spring (February 1–June 15) and fall (October 1–December 15) months as a benefit for passing juvenile Chinook salmon and juvenile winter steelhead. The purpose was to determine if spillway passage was safer and more efficient than daytime turbine passage. The second, to provide an evaluation of spring spillway operations (March–April) and fall regulating outlet operations (October–December) at Green Peter for juvenile Chinook salmon passage. The purpose of the spring spillway operation was to evaluate two spill operations (continuous [24/7[spill or nighttime only spill) to determine if the spillway was a safe route for downstream juvenile fish passage. The purpose of the fall deep drawdown RO operation was to determine if the ROs were a safe route for downstream passage. The turbines at Green Peter were not operated during either the spillway nor the RO operation; thus, leaving the only routes of passage as the spillway (spring) or ROs (fall). The fall study was intended to evaluate passage efficiency and survival for only the ROs – e.g., for subyearling Chinook salmon emigrating from the Green Peter Reservoir after the reservoir elevation was drawn down below the turbine penstocks.

The radio telemetry (RT) system used for this study was designed to enable the detection of tagged fish at nine different locations through the Santiam and Willamette rivers. Unfortunately, in spring, yearling Chinook salmon became diseased and were unable to be utilized for any evaluations at Green Peter and unable to be used for evaluations after the first tagging event (Feb) at Foster. Therefore, evaluation of the spring spillway operations at Green Peter was not possible. For the spring study at Foster, yearling Chinook salmon (*n* = 175) and age-1 winter steelhead (*n* = 1,669) were double tagged with an RT tag and a passive integrated transponder (PIT) tag and released into the Foster Reservoir. Yearling Chinook salmon were only released during low pool; thereafter, the study fish were diseased and unable to be utilized. Age-1 steelhead were released into the Foster Reservoir during spring low pool (*n* = 749) and high pool (*n* = 920). In fall, subyearling Chinook salmon were double tagged with an RT and a PIT tag for the Green Peter study (*n* = 787) and released into the Green Peter Reservoir. Double tagged subyearling Chinook salmon (*n* = 166) and age-1+ winter steelhead (*n* = 1,578) were tagged and released into the Foster Reservoir for the Foster fall study. Green Peter is located geographically

upstream of Foster on the Santiam River and will be presented first throughout this Executive Summary and report.

Fall study results for the deep drawdown operation at Green Peter indicated dam passage survival was similar regardless of passage through the north or south RO (0.69 ± 0.05 [SE] and 0.73 ± 0.03, respectively), although the north RO was closed for the majority of the treatment period. Reach survival was also similar through the north and south ROs, and it was low (0.19 ± 0.04 and 0.23 ± 0.03, respectively). Diel behavior indicated more fish passed during the nighttime than during the daytime. Reservoir residency for daytime and nighttime passed fish was short overall, with fish moving out in a median of approximately 18 hours. This may have been because of the close proximity of the release locations as the season progressed and the boat could not travel as far upstream of the dam because the reservoir was smaller and shallower from the deep drawdown. Thereafter, travel times were fairly consistent for daytime and nighttime passed fish. Dam Passage Efficiency (DPE) was mostly efficient overall (0.89 ± 0.02 [SE]) and was more efficient for fish passing at night (0.76 ± 0.02) than during the day (0.14 ± 0.02). The south RO was mostly effective at passing subyearling Chinook salmon overall (0.70 ± 0.03) and for both daytime (0.65 ±0.07) and nighttime (0.71 ± 0.03) passage. The north RO was not as effective (0.30 ± 0.03 overall); however, this may have also been because it was closed for the majority of the season. Comparisons to previous study years could not be made, as this was the first year of the deep drawdown operation.

Study results at Foster for yearling and subyearling Chinook salmon age classes suggest that the majority of fish passed at night (>0.82). Nighttime spillway operations provided a safe route of passage for fish released in spring, as all fish passed via the spillway and had 0.80 ± 0.08 (SE) dam passage survival. No fish passed the turbines, so survival could not be compared. During fall, nighttime spillway operations provided a safe route of passage (0.90 ± 0.02) although fall daytime survival was similar to nighttime survival (0.87 ± 0.07 and 0.90 ± 0.02, respectively). For steelhead, results suggest that very low proportions (31.4%) of age-1+ (fall) and even lower proportions (7.1%) of age-1 (spring) steelhead passed the dam. Age-1 and age-1+ steelhead were likely to have remained in the reservoir or in the tributaries upstream of Foster because of the very low proportions of fish that emigrated from the reservoir. Thus, estimates of survival, which assume active migration, may be estimates of the joint probability of migration and survival. For those that did pass, the majority of fish passed at night (>82%, except for spring high pool when only 3 fish passed, and all did so via the turbines). Nighttime spillway operations provided a safer passage than daytime turbine operations as survival was higher for nighttime passed fish (> 0.25 ± 0.12 compared to daytime turbine survival that was unable to be estimated due to low sample sizes), even though it was still poor overall.

Foster spillway passage efficiency was higher for nighttime spillway operations than daytime for yearling and subyearling Chinook salmon, and age-1 and age-1+ steelhead, suggesting the spillway was an efficient route of passage. Overall, the spillway was also effective for both age classes of Chinook salmon and steelhead. No yearling Chinook salmon passed during the day in spring so nighttime spillway operations had a higher spillway effectiveness than daytime. Interestingly, spillway effectiveness was higher for the daytime turbine operations than nighttime spillway for subyearling Chinook salmon and age-1 and age-1+ steelhead, but this is likely because some fish passed via the spillway during the daytime when there was little discharge through the spillway.

Collectively, the results from the 2023 study support previous findings that Chinook salmon and steelhead pass the dam in greater proportions at night than during the day (Hughes et al. 2016, 2017; Liss et al. 2020, 2023). Results also support previous findings that the nighttime spillway operation is a safe and efficient route of passage for downstream-migrating Chinook salmon at Foster (Liss et al. 2023). In 2023, no evaluations of the spring spillway operations could be performed at Green Peter and the evaluations of the spring spillway operations for yearling Chinook salmon at Foster were limited due to fish disease. This was also the first year to evaluate fish passage and survival through the ROs at Green Peter in the fall after the deep drawdown. Results from this year suggest that the ROs were a safe and efficient route of passage for downstream migrating subyearling Chinook salmon.

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This project was a collaborative effort which would not have been possible without the help provided by several agencies. The teamwork, communication, and attention to detail were essential for the study to succeed. In particular, we thank the U.S. Army Corps of Engineers – Portland District Foster and Green Peter Dam Facility Operations staff and the Willamette Valley Project Office. These folks were instrumental in study design execution. We would like to acknowledge the following staff:

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PNNL's Institutional Animal Care and Use Committee approved the protocol governing the care and use of fish for this study (protocol number 2023-01).

Acronyms and Abbreviations

°C	degree(s) Celsius
AIC	Akaike's Information Criterion
ANOVA	analysis of variance
AT	acoustic telemetry
BiOp	Biological Opinion
cfs	cubic (foot) feet per second
CH0	subyearling Chinook salmon
CH1	yearling Chinook salmon
CJS	Cormack-Jolly-Seber
COP	Configuration and Operation Plan
d	day(s)
D	detection(s)
DPE	dam passage efficiency
el.	elevation
ESA	Endangered Species Act
FL	fork length
FPE	fish passage efficiency
ft	foot(feet)
fmsl	feet above mean sea level
FWE	fish weir efficiency
FWS	forebay water supply
g	gram(s)
h	hour(s)
HOR	head-of-reservoir
in.	inch(es)
km	kilometer(s)
L	liter(s)
LRT	likelihood ratio tests
m	meter(s)
MHz	megahertz
min	minute(s)
MITAS	Multiprotocol Integrated Telemetry Acquisition System
mg	milligram(s)
MLE	maximum likelihood estimation
mm	millimeter(s)
MOR	mid-of-reservoir
msl	mean sea level
MW	megawatt(s)

N	number (population size)
n	number (sample size)
N/A	not applicable
ND	no data
NF	near-forebay
NMFS	National Marine Fisheries Service
N_i	dam-passed fish
N_{spill}	spillway-passed fish
N_{tur}	turbine-passed fish
ODFW	Oregon Department of Fish and Wildlife
OSU	Oregon State University
PHT	powerhouse tailrace
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
psi	pound(s) per square inch
QA	quality assurance
QC	quality control
RNE	regulating outlet North efficiency
R	release
rkm	river kilometer(s)
RN	regulating outlet - North
RO	regulating outlet(s)
RPA	reasonable and prudent alternative
rpm	revolutions per minute
RSE	regulating outlet South efficiency
RS	regulating outlet - South
RT	radio telemetry
S_1	Foster-to-Primary Array survival (CJS estimates)
SBE	spill bay efficiency
S_D	Foster-to-Egress Array survival (ViRDCt estimates)
SE	standard error
sec or s	second(s)
SPE	spill passage efficiency
SPT	spillway tailrace
STH	juvenile steelhead
STH1	juvenile wild surrogate steelhead age-1 (spring released)
STH1+	juvenile wild surrogate steelhead age-1+ (fall released)
S-STH	juvenile hatchery summer steelhead
SURPH	Survival Under Proportional Hazards
TUR	turbine

USACE	U.S. Army Corps of Engineers
V	virtual release
ViRDCt	Virtual Release/Dead Fish Correction
WVP	Willamette Valley Project

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1.0 Introduction

The development and operation of hydroelectric and flood risk management dams have adversely affected salmon and steelhead populations in the Willamette River Basin. The Willamette Valley Project (WVP), a group of 13 dams in the basin, is owned and operated by the U.S. Army Corps of Engineers – Portland District (USACE). These 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) regarding the operation of the WVP in the Willamette River Basin (NMFS 2008). Two of the WVP dams, Foster Dam (Foster) and Green Peter Dam (Green Peter), were the focus of this study.

There were two efforts for this downstream fish passage and survival study. The first, to provide the USACE biologists, engineers, resource managers, and regional decision makers with the efficiency and effectiveness, as well as survival, of the nighttime spillway operations at Foster during spring (February 1–June 15) and fall (October 1–December 15) months as a benefit for passing juvenile Chinook salmon and juvenile winter steelhead. Results will inform the timing of operational adjustments for improved downstream fish passage at Foster.

The second, to provide a full-scale evaluation of spring spillway operations and fall regulating outlet (RO) operations at Green Peter for juvenile Chinook salmon passage. The spring spillway operation at Green Peter was intended to have two spill tests: nighttime only spill for two weeks and continuous spill for 24 hours a day, 7 days a week (24/7 spill) for two weeks, without turbine operation during either of the two spill tests. The fall deep drawdown RO operations began when the reservoir reached elevation 780 ft. (October 31) through December 15. The turbine penstocks were above water level, and turbines were not operated during this RO operation. Results were intended to inform the spring spillway and fall drawdown operations for the fish passage in 2024.

Spring tagging took place from February through June 2023. In March 2023, the yearling Chinook salmon exhibited bacterial kidney disease and furunculosis. They were treated with medicated feed on two separate occasions in an attempt to regain their health. However, it was not successful, and fish remained unhealthy and compromised for the rest of the spring season. They were not suitable to be tagged and released at Foster nor at Green Peter. As a result, a small number of Chinook salmon were tagged and released at Foster during the February tagging and no fish were tagged and released at Green Peter during the spring season.

This report will describe results for age-1 steelhead and the small number of yearling Chinook salmon released at Foster during the spring season. Fish health was not compromised during the fall; therefore, results for subyearling Chinook salmon released at both Foster and Green Peter, as well as age-1+ steelhead released only at Foster, will be described for the fall season. Green Peter is located geographically upstream of Foster on the Santiam River and will be presented first throughout this report.

1.1 Green Peter Dam

Green Peter is located on the Middle Santiam River near Sweet Home, Oregon. It is a high-head dam (300 feet [ft.] tall) with three routes for water and fish to pass: turbines (2), ROs (2), and spillway (1). The primary route for water to pass is through the two turbines or the two ROs. Until recently, the spillway was generally not used, except for emergencies during high water events to pass excess water as necessary. The spillway crest at Green Peter is at elevation 968.7 ft. above mean sea level (fmsl). Under normal operations, the reservoir elevation levels are below the spillway crest in winter months for water storage and flood risk reduction, typically from mid-October through early March (depending on winter and early spring precipitation). Reservoir refill under normal operations begins in February and the spillway is not typically available for operation until early to mid-March. The RO intake is at elevation 745 ft. Under normal operations, the reservoir elevation during fall months ranges from 964 ft. in November to 922 ft. in December, which is between 219 and 177 ft. above the RO intake during November and December, respectively. During fall 2023, the reservoir was drafted down to 780 ft. (approximately 35 ft. above the RO intake) for a deep drawdown and RO operation for fish passage. This elevation was below the turbine penstock intakes (elevation [el.] 817 ft); therefore, the turbine penstocks were above water levels, and the only available route of passage was through the ROs. Reservoir refill commenced on December 1 to refill the reservoir to the normal winter pool (el. 922 ft.). Turbine operation for power generation resumed on December 16.

Investigations of reintroducing Chinook salmon in the watershed above Green Peter commenced during 2022 with releasing (outplanting) adult Chinook salmon, captured at the Foster adult fish facility, into the watershed. This outplanting effort was conducted by Oregon Department of Fish and Wildlife (ODFW) staff. The expectation was that progeny of the outplanted adult salmon would migrate downstream in 2023 and following years. The spillway at Green Peter would be operated during spring months as soon as the reservoir elevation reached a few feet above spillway crest (el. 971 ft.) for at least 30 days to provide a non-turbine route for downstream migrating juvenile salmon. Additionally, the reservoir would be drafted to 780 ft. (deep drawdown) and the ROs would be operated during late fall for 30 days (approximately November 15–December 15) to provide a non-turbine route for downstream migrating juvenile salmon.

During spring, the spillway at Green Peter was expected to be an effective route for fish passage and survival; however, it was necessary to conduct a baseline evaluation of the spillway operations in 2022 on juvenile salmonid reservoir residence time; route of passage; and downstream survival to inform operations as a route for downstream fish passage (Liss et al. 2023). Results from that study indicated reservoir residence time to be 41 hours (median) for fish released during the nighttime spill treatment and 87 hours (median) for fish released during the 24/7 spill treatment. Nearly all fish passed via the spillway, regardless of treatment. Dam passage survival was estimated to be 69.1% (SE: 3.2%) and reach survival was estimated to be 32.1% (SE: 3.1%). A full-scale study to evaluate the same metrics at Green Peter is essential to understand if the spillway is an effective route for fish passage.

Fall fish passage and survival through the ROs had not been evaluated prior to this study. A full-scale study to evaluate fish passage and survival was essential to understand if the ROs are an effective route for fish passage.

There were two operations intended to be evaluated for the Green Peter task, depending on the season (spring or fall). However, fish health compromised the spring study, and no fish were tagged and released for the spring spillway operation. As such, it will not be discussed further.

<u>Fall Regulating Outlet Operation</u>

The purpose of the fall (October 31–December 15) deep drawdown RO operation was to determine if the ROs are a safe route for downstream juvenile fish passage for subyearling Chinook salmon (or appropriate surrogates). The turbines were not operated during the RO operation.

The objectives were to evaluate the RO operation using the following metrics:

I. Seasonal and diel behavior of juvenile fish to document and quantify timing of downstream passage (reservoir residency time, route distribution, migration travel times).

II. Seasonal and diel survival (reservoir, route specific, dam passage, and reach).

   a. Dam passage survival was measured to the first detection array downstream of Green Peter (Sunnyside Array), located approximately 5 rkm downstream.

   b. Reach survival was measured from the time of Green Peter passage to the confluence of the Santiam River with the mainstem Willamette River (I-5 Santiam Rest Stop Array), located approximately 81 rkm downstream.

III. Efficiency and effectiveness of dam passage.

1.2 Foster Dam

Foster is a re-regulating, multiuse dam located on the South Santiam River also near Sweet Home, Oregon, and approximately 11.5 river kilometers (rkm) downstream of Green Peter (~7.2 rkm from Green Peter to the Foster Reservoir). Construction of Foster was completed in 1953. The dam structure is 4,565 ft. wide and 126 ft. high and is comprised of a powerhouse with two turbines and a spillway with four spill bays. There are no ROs. The turbines and spillway provide routes for water and fish to pass the dam. Typically, reservoir drawdown begins in September and refill commences in February. However, in recent years (starting in 2013 to date) during spring the reservoir was held at minimum (low) pool elevation until April or May (delayed refill) before refilling to maximum (full) pool as an interim operation for downstream fish passage. For the purposes of this report, basic features of the dam include:

- Maximum pool elevation = 641 fmsl
- Minimum conservation pool elevation = 613 fmsl
- Minimum pool elevation = 609 fmsl
- Penstock centerline elevation = 590 fmsl
- Spill bay invert elevation (crest) = 597 fmsl

The turbines and spillway provide routes for water and fish to pass the dam. Multiyear studies were conducted to inform regional decision-makers of structural or operational alternatives for improving downstream fish passage at Foster. Results from screw-trap studies in the Foster Reservoir and tailrace by the Oregon Department of Fish and Wildlife (ODFW; Romer et al. 2014, 2015, 2016; Monzyk et al. 2017), as well as fish passage and survival studies by PNNL using hydroacoustic technology and RT (Hughes et al. 2014, 2016, 2017), found that large numbers of juvenile Chinook salmon and winter steelhead present in the reservoir pass the dam during both periods of low pool (fall, winter, spring) and high pool (May–June). When the reservoir was at full pool elevation during the summer months, few fish passed the dam. These studies also indicated the original fish weir was not an effective route for passing Chinook salmon as most fish passed the dam either through the turbines or spillway when the spillway was operated to pass excess water (Hughes et al. 2016, 2017, 2021). The fish weir was effective, however, at passing age-2 steelhead, particularly at high pool. Another RT study conducted in 2018 indicated most spring migrants (88.5%) and fall migrants (92.7%) passed Foster at night (Hughes et al. 2016, 2017; Liss et al. 2020).

Research to evaluate the effects of Foster operations on the total dissolved gas (TDG) levels on the river environment and fish habitat downstream of the dam was also performed in 2016 through 2017 (Arntzen et al. 2018). Results showed TDG levels exceeding 110% saturation for short durations did not appear to affect adult and juvenile salmon in the river (Arntzen et al. 2018). Both life stages can seek refuge in deeper pools during periods of high TDG levels (Arntzen et al. 2018). The operations that could support reduced TDG (i.e., that would ensure a short duration of 110% or greater saturation) occurred when one turbine unit was operated for Station Service only (one turbine unit operating at approximately 200 cfs flow).

The cumulative results of the RT and TDG studies informed the current nighttime spillway operations during fall and spring months for downstream fish passage. The 2022 and 2023 delayed refill (maintain the reservoir at low pool elevation until May 15 before refilling to full pool) and nighttime spillway operations were conducted in conjunction with turbine operations for Station Service to reduce TDG levels in the river downstream of the dam. The turbines were operated for power generation during daylight hours and the spillway was not operated unless required to pass excess water. The timing and periods of the nighttime spill operation schedule were conducted annually and were evaluated for effectiveness in safely passing downstream migrating salmon and steelhead for the purposes of this study, are (dates and times are approximate):

- Dusk (20:00) to dawn (06:00) during February 1–June 15
- Dusk (one hour before sunset) to dawn (one half hour after sunrise) during October 1–December 15

The objectives of the Foster task were to determine if the nighttime spillway operations provided a safer and more efficient passage route compared to daytime turbine operations for subyearling and yearling Chinook salmon and age-1 and age-1+ winter steelhead using the following metrics:

I. Seasonal and diel behavior of juvenile fish to document timing of downstream passage (reservoir residency time, route distribution, migration travel times).
II. Seasonal and diel survival (reservoir, route specific, dam passage, and reach).
    i. Dam passage survival was measured to the first detection array downstream of Foster (Egress Array), located approximately 3 rkm downstream.
    ii. Reach survival was measured to the confluence of the Santiam River with the mainstem Willamette River (I-5 Santiam Rest Stop Array), located approximately 69 rkm downstream.
III. Efficiency and effectiveness of dam passage, and the nighttime spillway operation compared to the daytime turbine operation.

2.0 Methods

2.1 Receiver Deployment

The RT arrays utilized in this study were installed with a signal amplifier and connected via LMR200 or LMR400 coaxial cable (Times Microwave Systems, Wallingford, CT) to an individual Orion receiver (Sigma Eight Inc., Newmarket, Ontario, Canada). The Orion receiver located at each antenna processed each tag frequency and code transmission, and stored detection data locally on the receiver unit. The detection zones at Green Peter and Foster used a mix of underwater loop-vee and aerial corner reflector antennas. At each downstream detection array a mix of 3-element, 6-element and/or corner reflector aerial Yagi antennas were installed to detect fish at each receiving array location (Table 2-1).

All RT arrays at the dams and downstream were tested and calibrated prior to the start of the study to ensure that the detection zones (i.e., a specific area where an RT tag will be identified or detected on an antenna) enabled a high probability of detecting tagged fish at all arrays. Antenna ranges not meeting the study objectives were adjusted accordingly by increasing or decreasing signal attenuation (i.e., increasing or decreasing reception ranges) or by modifying the deployment type, configuration, and/or orientation of the individual RT antennas. Beacon tags were also installed near each receiver so that RT array performance could be evaluated continuously during the season. Beacons were programmed to transmit once every 5 seconds for a 1-minute duration each hour of the study period. The presence and strength of beacon detections by each antenna were reviewed daily to ensure that signal strength remained constant over time and that all RT system components were functioning correctly to meet the study objectives.

Table 2-1. Green Peter (GPR) and Foster (FOS) radio telemetry array location, antenna type, distance (rkm) downstream from the dams, reservoir elevation (where appropriate) and study purpose.

Location	Antenna Type	Rkm below Green Peter / Foster	Elevation (ft. msl)	Study Purpose
GPR Forebay	Corner Reflector Dipole	–	–	Forebay Delineation
GPR Spill Bays	Underwater Loop-Vee[(a)]	–	968.5	Route Specific (spring)
GPR Regulating Outlets	Underwater Loop-Vee[(a)]	–	745	Route Specific (fall)
GPR Tailrace	6-Element Yagi	0.1	–	Tailrace Delineation
Sunnyside Array	3-Element Yagi	5.4	–	Project Egress/ViRDCt survival
FOS Extended Forebay	Corner Reflector Dipole	11.2	–	Extended Forebay Delineation
FOS Near Forebay	3-Element Yagi	11.7	–	Near Forebay (< 100 m) Delineation (i.e., additional dam coverage)
FOS Spill Bays 1−4	Underwater Loop-Vee[(a)]	11.7	610[(b)] & 629[(c)]	Route Specific
FOS Turbine Units 1–2	Underwater Loop-Vee[(a)]	11.7	597	Route Specific
FOS Spillway Tailrace	Corner Reflector Dipole	11.8 / 0.1	–	Dam Passage
FOS Powerhouse Tailrace	Corner Reflector Dipole	11.8 / 0.1	–	Dam Passage
Egress Array	Corner Reflector Dipole	15.4 / 3.7	–	Project Egress/Reservoir Survival (ViRDCt)
Waterloo Array	2 × 6-Element Yagi	30.7 / 19.0	–	Survival – Foster Cross-Years Comparison
Lebanon Dam Array	2 × Corner Reflector Dipole	38.8 / 27.1	–	Downstream Migration
I-5 Santiam Rest Stop Array	6-Element Yagi	80.8 / 69.1		Primary Reach Survival Array
Cole Island Array	6-Element Yagi	85.5 / 73.8		Secondary Reach Survival Array
Willamette Falls Dam Array	6-Element Yagi	221.7 / 210	–	Downstream migration

2.1.1 Green Peter Dam

Fall 2023 was the first time RT-tagged study fish were released in the reservoir and tracked in the forebay and through Green Peter after the reservoir drawdown (deep drawdown to el. 780 ft.). Detection zones monitored approach and passage of RT-tagged juvenile Chinook salmon through the ROs, which had two passage routes (north RO (RN) and south RO (RS); Figure 2-1).

Downstream of Green Peter, nine additional RT arrays were used to detect fish moving through the study area at Foster and downstream to the confluence of the Santiam and Willamette rivers (Table 2-1; Figure 2-2; Figure 2-3). The Sunnyside Array was successfully used as a tailrace detection array during 2016 and 2017 (Liss et al. 2017, 2018) and in 2022 and 2023 was used for project egress to calculate survival using the virtual release/dead fish correction (ViRDCt) model (Harnish et al. 2020). Most of the other arrays for the Green Peter task were also part of the Foster task (Table 2-1).

Figure 2-1. Radio telemetry detection locations to assess survival of juvenile Chinook salmon at Green Peter during the fall study season. The yellow boxes depict the approximate range of the regulating outlet (RO) antennas, which are referred to as the north RO (RN) and south RO (RS) throughout the report. The blue triangle depicts the approximate range of the forebay antenna, and the orange triangle depicts the approximate range of the tailrace antenna.

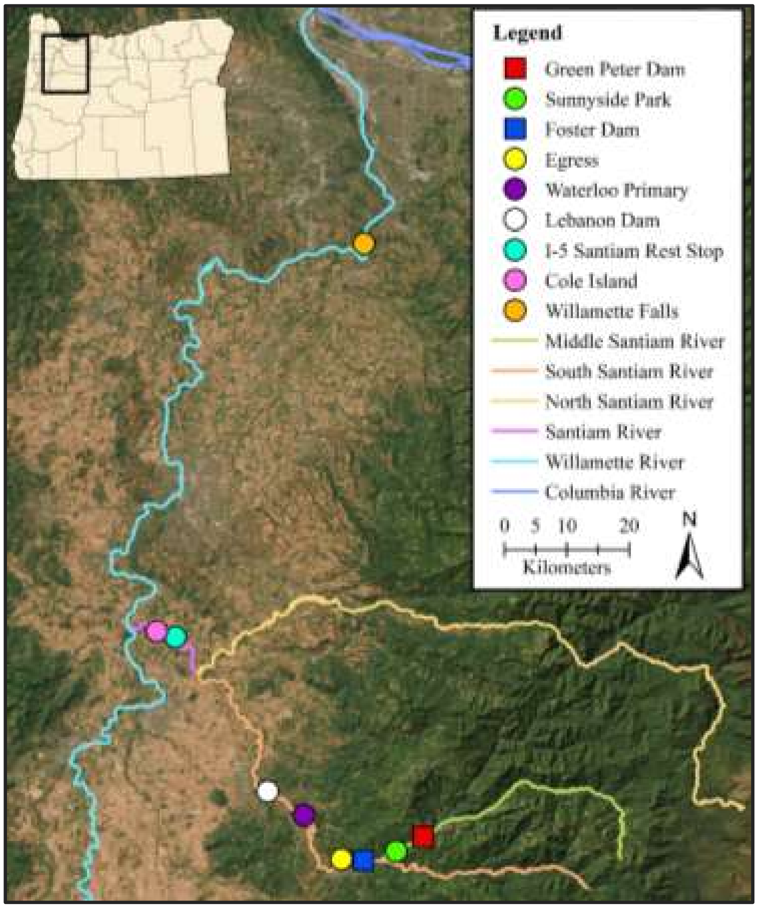

Figure 2-2. Map of the Green Peter/Foster study area with the locations of radio telemetry (RT) detection arrays deployed to evaluate juvenile fish migration behavior and passage through Green Peter Reservoir, dam, tailwaters, Foster Reservoir, dam, and tailwaters. Downstream arrays (Sunnyside, Egress, Waterloo, Lebanon Dam, I-5, Cole Island, and Willamette Falls) had a single detection array, whereas the Green Peter and Foster dams had multiple detection arrays. The Santiam rivers flow east to west into the Willamette River, which flows from south to north into the Columbia River and the Pacific Ocean.

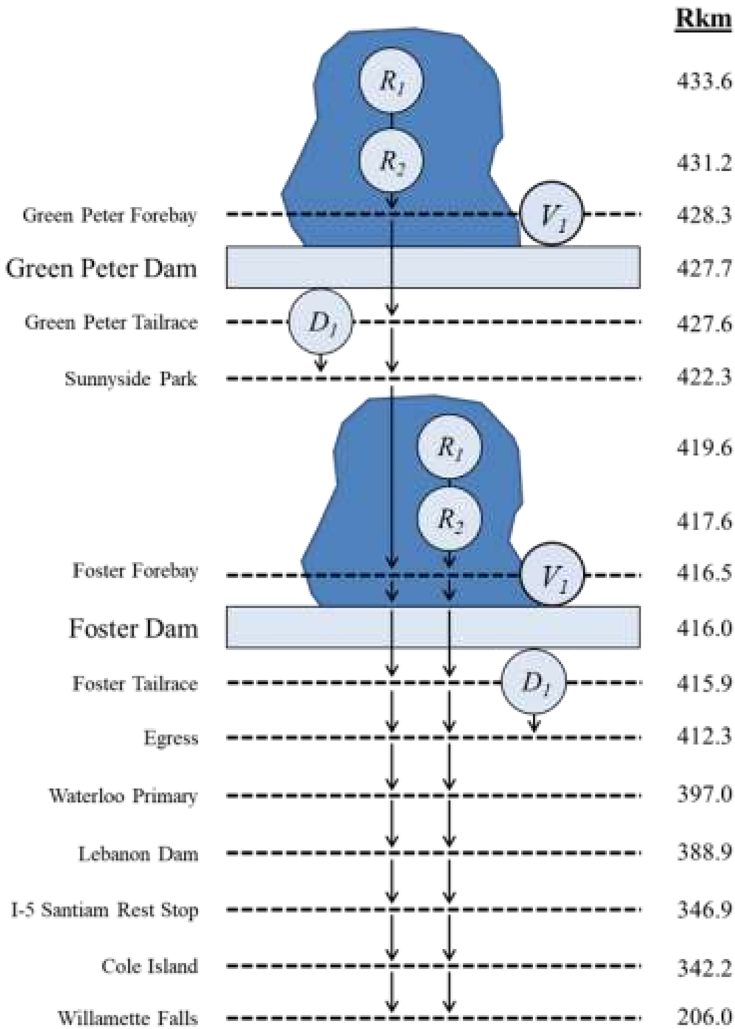

Figure 2-3. Schematic of the study design for Green Peter and Foster releases and approximate locations of detection arrays. R_1 and R_2 represent the head-of-reservoir and mid-of-reservoir release locations, respectively, for both Green Peter and Foster reservoirs. V_1 represents the virtual release group of fish detected passing the dams (i.e., fish used for analyses). D_1 represents the release of dead tagged fish in the tailrace of both dams. Detection arrays are indicated by the dashed lines.

2.1.2 Foster Dam

Detection zones at Foster monitored route-specific passage of RT-tagged juvenile salmon and steelhead through a total of six passage routes (2 turbines and 4 spill bays; Table 2-1; Figure 2-4). Previous studies also evaluated two freshwater supply intakes: the auxiliary water supply for the fish ladder, and the hatchery water supply (Hughes et al. 2016, 2017). However, few or no fish were detected through those routes in those study years, and they were not evaluated in 2018 (Liss et al. 2020) or 2022 (Liss et al. 2023). As such, they were not evaluated in 2023.

Downstream of Foster, six RT arrays detected fish moving through the study area (Figure 2-2 and Figure 2-3). This downstream array configuration allowed for a cross-years comparison of dam passage survival to 2018 and 2022 (i.e., to the Egress Array) and reach survival to 2015, 2016, and 2018 (i.e., to the Waterloo Array; Figure 2-3) as well as a new reach survival estimate (e.g., to the I-5 Santiam Rest Stop Array; Figure 2-3).

Figure 2-4. Radio telemetry detection locations to assess route-specific survival and behavior of juvenile Chinook salmon and steelhead at Foster. NF = near forebay, PHT = powerhouse tailrace, SB = spill bay, SP = spillway, SPT = spillway tailrace, TUR = turbine, W = weir. Red squares represent passage routes, green squares are tailwater antennas, and yellow squares and the red circle represent antenna locations used monitor fish approach and behavior to aid in identifying a route of passage.

2.2 Radio Telemetry Tag Specifications and Frequencies

The RT tags used for this study were NTFD-2-1 from the NanoTag series (Lotek, Newmarket, Ontario, Canada; 0.4 g in air). Burst rates of the RT tags were distributed from 4.5–5.2 sec and staggered across a 1.0 MHz bandwidth from 166.550–167.500. Using the 2003 Lotek RT tag “code set”, up to 512 unique coded RT tags could be detectable on a single frequency. However, ten different frequencies were used to allow for the potential simultaneous detection of multiple tags: 166.620, 166.689, 166.740, 166.766, 167.340, 167.380, 167.420, 167.440, 167.460, and 167.480 MHz. The RT tag codes near the ‘tails’ of the unique coded range (e.g., numbers ~1–50 and ~460–512) were more prone to false-positive detections and if possible, were not used. The number of RT tags assigned to each frequency were approximately equally distributed. When combined with the release strategy, the approximately equal distribution of frequencies will be used to minimize the chance of code collision—when too many fish are located in one detection zone at the same time, which can reduce detection efficiency.

2.3 Data Collection

All data for Green Peter and Foster were acquired using an RT system composed of a Multiprotocol Integrated Telemetry Acquisition System (MITAS) Cloud software (Sigma Eight Inc., Newmarket, Ontario, Canada) server controlling individual autonomous Orion receivers. The MITAS and Orion receivers are both programmable and can detect RT tags manufactured by other companies (e.g., Lotek). The MITAS and Orion receivers also allow simultaneous scanning of multiple frequencies, resulting in high detection probabilities.

All antennas with paired Orion receivers and networking units transmitted data (wirelessly or were routed to a central network router system) to a centrally located 4G-capable networking unit. Digital signals on the Orion (converted from analog signals received by the antennas) were routed or transmitted wirelessly and streamed to the cloud-based MITAS software. The MITAS Cloud software was used to analyze and monitor the system of connected receivers in real time and to time-sync all receivers and therefore unique tag detections.

The Orion receivers had redundant storage capabilities. The data was stored internally in each receiver, using swappable flash media devices, and was remotely sent to the cloud-based MITAS via the 4G capable networking unit. Data on the Orion receivers at Green Peter and Foster was collected manually approximately biweekly. Data was saved in at least two separate locations to minimize the chance of data loss.

2.4 Fish Source and Tagging

The Oregon State University (OSU) Wild Fish Surrogate Program provided juvenile Chinook salmon for the Green Peter and Foster studies and winter steelhead for the Foster study. Fish age class and timing of tagging and releases coincided with natural migration run timing, and Chinook salmon and winter steelhead were reared to the approximate size of wild juveniles migrating through the South Santiam River (Romer et al. 2016; Monzyk et al. 2017). The Foster spring yearling Chinook salmon size ranged from 108-150 mm FL (Table 2-2). Spring-released Foster juvenile winter steelhead (age-1) ranged from 105 to 165 mm FL (Table 2-2). Fall released subyearling Chinook salmon at Green Peter ranged from 109 to 188 mm FL and at Foster from 108 to 150 mm FL (Table 2-2). Although age-1 and age-1+ steelhead do not typically migrate from the South Santiam River (Romer et al. 2016; Monzyk et al. 2017), this study included age-1 steelhead in the overall passage and survival evaluation in spring and age-1+ in fall.

Study fish for the Green Peter and Foster releases were surgically implanted with both an RT tag and a PIT tag. Few PIT tag arrays existed in the Willamette River Basin (e.g., Lebanon Dam, Willamette Falls). The Lebanon Dam PIT tag array was re-installed in 2022; however, several antennas were damaged during winter 2022 and 2023 and repaired. If the antennas are functioning, they may be used as a secondary identification tool to the RT arrays. Similarly, if the Willamette Falls PIT tag arrays are functioning and reporting data, they too may be used as a secondary identification tool to the RT arrays. Tagged fish were larger than 95 mm FL, which is the recommended minimum length for surgical implantation of tags in juvenile salmon to minimize tag burden (i.e., the weight of the tag relative to the weight of the fish), as tag presence may adversely affect survival in fish smaller than 95 mm FL (Geist et al. 2018). The majority of fish tagged for live fish releases in 2023 (92.3%) had a tag burden between 1.0 and 4.0%. The greatest tag burden observed was 4.5%.

Table 2-2. General information about the fish releases and sizes for yearling Chinook salmon (CH1), age-1 winter steelhead (STH1), subyearling Chinook salmon (CH0), and age-1+ winter steelhead (STH1+) released at Green Peter and Foster dams.

Dam	Season	Pool elevation	Species	Treatment	Released alive (*n*)	Fork length mean and range (mm)	Weight mean and range (g)	Head-of-Reservoir release (*n*)	Mid-of-Reservoir release (*n*)
Green Peter	Fall	Deep Drawdown Oct 1 – Dec 16	CH0	RO 24/7 Operation	738	158 (109-188)	40.1 (13.0–69.3)	371	367
Foster	Spring	Low Feb 1– May 15	CH1	Nighttime Spill (20:00–05:59) and Daytime Turbines (06:00–19:59)	149	132 (108-150)	22.5 (13.9-32.2)	75	74
			STH1		671	125 (111-165)	17.2 (13.0-34.4)	335	336
		High May 21– June 16	STH1	Nighttime Spill (20:00–05:59) and Daytime Turbines (06:00–19:59)	832	119 (105-152)	15.5 (11.0-34.1)	419	413
Foster	Fall	Low Oct 1– Dec 16	CH0	Nighttime Spill (one hour before sunset to one ½ hour after sunrise) and Daytime Turbines	120	154 (111-179)	38.8 (15.6–67.7)	60	60
			STH1+		1527	144 (109-191)	30.7 (13.0-78.7)	763	764

Surgical procedures and fish handling for the Green Peter and Foster tagging were the same. Fish were placed in an anesthetic water bath of AQUI-S®, containing approximately 35 mg/L of the active ingredient eugenol. After losing equilibrium, fish were weighed (g), measured (mm FL), and assigned to a pre-determined transport bucket and reservoir release location. Fish were also assigned an RT tag (unique frequency and code) and a PIT tag (both tag types disinfected in 70% ethanol for 10 minutes and rinsed with sterile water prior to use). Tagging information was added automatically to the tagging database using “P4” software from the PIT Tag Information System (PTAGIS; Pacific States Marine Fisheries Commission, Portland, OR). Finally, fish were transferred to their assigned surgeons for tag implantation.

Trained surgeons used a shielded-needle surgical technique for implanting the RT tags, modified from Adams et al. (1998) and Hockersmith et al. (2003). During surgery, each fish was placed ventral side up and a gravity-fed supply of fresh water was provided through tubing into the fish’s mouth. As necessary, a “maintenance” anesthetic (up to 15 mg/L of eugenol) was administered through the same gravity-fed supply line. Using a stainless-steel surgical blade, an incision approximately 5–7 mm long was made on the linea alba (e.g., midline of the fish) 5 to 10 mm anterior of the pelvic girdle. A hollow 19-gauge stainless steel needle, sheathed with 16-gauge stainless steel tubing (catheter), was inserted into the incision to make a small hole through the body wall near the distal end of the pelvic fin. The hollow needle was used as a conduit to insert the antenna of the RT tag through the body wall. Then the body of the RT tag (with the antenna protruding posteriorly through the body wall) and a PIT tag were inserted into the body cavity of the fish. The incision was closed with two interrupted stitches using Ethicon Monocryl® monofilament sutures with a reverse cutting needle. Stitches were secured with a knot consisting of four single wrap throws in alternating directions (Deters et al. 2012). Post-surgery, the fish were allowed to recover in transport buckets and held overnight in holding tanks with flow-through water to ensure the short-term effects of the surgical process dissipated prior to releases.

All metal surgical tools (catheters, needles, needle holders, and forceps) were autoclaved prior to the start of each tagging day. After using the surgical tools on a single fish, the tools were disinfected or autoclaved prior to reuse. Needle holders and forceps were disinfected in a hot bead sterilizer for 30 seconds, whereas suture material and needles were disinfected with ultraviolet light for 2 minutes (Walker et al. 2013). Blades were disinfected with ultraviolet light for 5 minutes. An adequate supply of sterile catheters and needles allowed for the tagging of all fish before needing to be autoclaved at the end of the day.

2.5 Fish Releases

On the day of fish releases for both Green Peter and Foster, transport buckets were removed from the holding tanks and placed into transportation totes on the bed of a truck. The truck also held a supplemental source of oxygen to deliver to the totes as needed. A YSI meter (YSI Incorporated, Yellow Springs, OH) was used to monitor dissolved oxygen concentrations and water temperatures in the totes before, during, and at the end of transport to ensure that those parameters remained within acceptable limits (80–110% for dissolved oxygen, ± 2 °C for water temperature). If measurements approached unacceptable limits, staff adjusted the flow of oxygen from the tanks to increase dissolved oxygen levels or tempered the water temperature.

For both Green Peter and Foster, fish were released at one of two transect locations within the reservoir, each with three release points: head-of-reservoir (HOR) and middle-of-reservoir (MOR; Figure 2-5). The release locations within Green Peter reservoir were intended to represent potential juvenile salmonid migration from the Middle Santiam into Green Peter Reservoir (HOR) or potential juvenile salmonids rearing in the Green Peter Reservoir (MOR). Release locations within Foster Reservoir represented juvenile salmonids that reared and migrated from the South Fork South Santiam River into Foster Reservoir (HOR), as well as the juveniles that reared and migrated from the Foster Reservoir (MOR).

In addition to live fish tagging and releases at Green Peter and Foster, fish for a dead fish release (DFR) group were also tagged and released in conjunction with live fish release groups at each reservoir. The DFR groups allowed for the single-release dam passage survival of the virtual release group (e.g., ViRDCt survival) to be adjusted for the bias that occurs from misidentifying dead fish as alive at the Sunnyside Array for Green Peter fish, and at the Egress Array for Foster fish. The methods of tagging the DFR group were the same as for live fish, including overnight recovery; however, fish designated for DFR were euthanized before release via an overdose of MS-222 and were pithed prior to release. Dead fish were released just downstream of each dam (Figure 2-5), with an even distribution of fish being released between the powerhouse and RO tailrace (Green Peter) and the powerhouse and spillway tailrace (Foster).

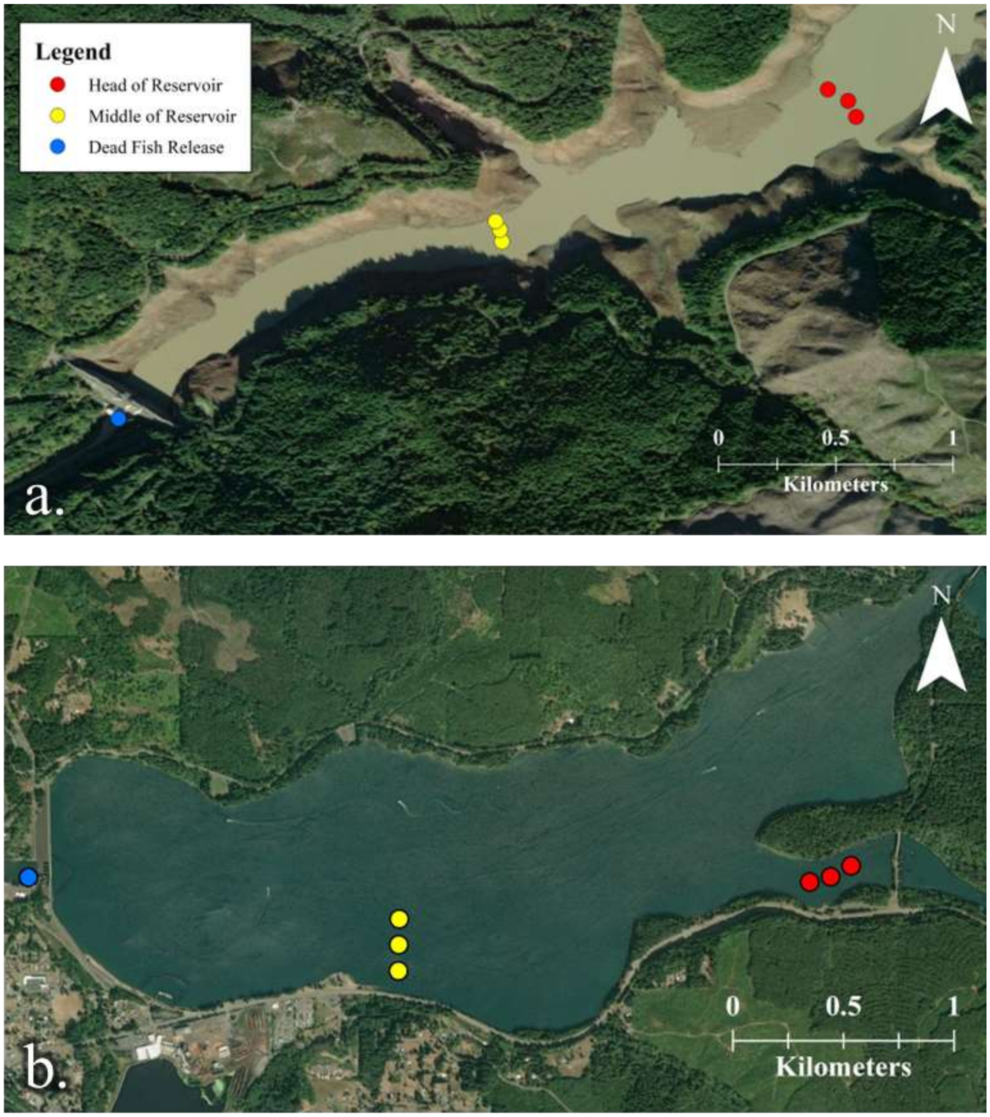

Figure 2-5. Map of reservoir release sites within (a.) Green Peter and (b.) Foster. Red circles indicate release sites located at the head-of-reservoir, furthest upstream of the dams, and the yellow circles indicate sites located at the mid-of-reservoir. Dead fish were released in the tailwaters of each dam, signified by blue circles.

2.6 Statistical Methods

Statistical methods used for this investigation are summarized in the following sections. For the purposes of this report, the Green Peter deep drawdown RO treatment operations began October 31 at 07:00 hours and ended on December 16, 2023, at 08:10 hours. The reservoir began to refill on December 3 due to storm events and a winter flood and could not be held at an elevation of 780 ft.; however, the operational treatment (RO operation only, no turbines) continued. Turbine and RO operation began on December 16, 2023, at 08:11 hours and the ROs remained in operation until December 29 at 16:00 hours. Beginning December 29 at 16:01 hours, operations switch to turbine only operation and the turbines became available as a passage route. Starting on December 29 at 16:01 hours, the ROs remined closed for all winter and spring.

At Foster, the spring low and high pool daytime turbine operations occurred from 06:00 hours to 19:59 hours, and the nighttime spillway operations occurred from 20:00 hours to 05:59 hours. Low pool began on February 1, 2023, at 06:00 hours and ended on May 15, 2023, at 05:59 hours. High pool began on May 21, 2023, at 06:00 hours after the reservoir was filled to summer elevation and ended on June 16, 2023, at 06:00 hours. The spring study period (based on the tag [battery] life of the tags) went through August 21, 2023, at 16:25 hours.

The fall daytime turbine operations occurred from one half hour after sunrise to one hour before sunset. Nighttime spillway operations occurred from one hour before sunset to one half hour after sunrise. Throughout fall there was one pool elevation: low pool. The operational treatments began on October 1, 2023, at 07:00 hours and went through December 16, 2023, at 08:10 hours. The study period (based on tag life) lasted until March 2, 2024, at 12:00 hours.

2.6.1 Estimation of Survival

2.6.1.1 Design Concepts

A representative subsample of 60 RT tags were randomly sampled from the production lot and retained each season for an assessment of operational life (i.e., tag life). In spring there was only one lot of tags so 60 RT tags were evaluated for spring tag life. In fall there were two lots of tags, so 120 tags were evaluated for the fall tag life. Tags were monitored continuously from activation until failure. Failure times from each tag life study were fit to Weibull 2-parameter (Lawless 1982; Lee 1992), Weibull 3-parameter (Elandt-Johnson and Johnson 1980), and the 4-parameter vitality model (Li and Anderson 2009). The best-fitting model was used to estimate tag life probabilities at each detection array. Estimated tag life probabilities were used to adjust reach survival estimates for the probability of tag failure.

Reach survivals were estimated separately for fish released in Green Peter and Foster reservoirs; however, fish released at Green Peter were also included in estimations of survival at Foster and downstream. Survival was estimated from release in the reservoir to the dam. Fish that were detected passing the dam were formed into a virtual release group, which is a grouping of fish based on detections at an array independent of when or where those fish were released (Buchanan et al. 1993; Skalski 2009). Survival of the virtual release group was estimated from the dam (upstream side, not the tailrace) to each downstream detection array. These downstream detection arrays included Sunnyside, Egress, Waterloo Primary, Lebanon Dam, I-5 Santiam Rest Stop, Cole Island, and Willamette Falls. Fish that were not detected were only included in the estimation of survival from release to dam passage. These fish may have experienced one of several possible outcomes. Fish may have been caught by fishermen, remained in the reservoir for additional rearing, moved into a tributary, or experienced post-tagging mortality. However, a non-detected fish does not automatically indicate the fish died.

At Green Peter, survival was estimated for all tagged fish detected passing the dam and by RO (north RO and south RO). At Foster, reach survivals were estimated for each species, stock, and pool level, and by operations (i.e., night spill and daytime turbine) period of passage. When sample sizes allowed, reach survivals were also estimated by route of dam passage. All reach survival estimates were calculated using the single-release-recapture model (Skalski et al. 1998). When sufficient numbers of fish from the virtual release groups were detected at downstream arrays, survival estimates were adjusted for the probability of tag failure using the methods of Townsend et al. (2006), results from tag life studies, and program ATLAS (Acoustic Tag Life-Adjusted Survival; Columbia Basin Research, University of Washington).

In past studies conducted at Foster in 2015, 2016, and 2018, reach survival was not estimated to the confluence of the Santiam River (i.e., I-5 Santiam Rest Stop Array). However, dam + tailwater survival was estimated to the Waterloo Primary Array in all three years and dam passage survival was estimated to the Egress Array using the virtual release/dead fish correction (ViRDCt) model (Harnish et al. 2020) in 2018 and in 2022. Therefore, comparisons of past and 2023 survival estimates for Foster were limited to the reaches evaluated during past studies.

Survival estimates were compared among years using model selection criteria, such as Akaike's Information Criterion (AIC) and Likelihood Ratio Tests (LRT). First, it was determined whether or not it was appropriate to pool detection data from past years. To do this, a full model, in which survival and detection probabilities differed among years, was fit. Parsimony was then achieved by fitting a reduced (i.e., nested) model in which survival was equal between years. AIC was used to identify the best-fitting model. If the reduced model provided the best fit, survival was determined to be similar between years and the data were pooled. If the full model provided the best fit, LRTs were used to determine if the full model differed significantly (α = 0.05) from the reduced model. If no significant difference was observed, the reduced (i.e., more parsimonious) model was selected, indicating similar survival between years and the data were pooled. If a significant difference was observed between the full and reduced models, the full model was retained, indicating survival differed between years and data were not pooled.

A similar approach was used to determine whether 2023 survival estimates differed from those of past studies (2015, 2016, 2018, 2022). A full model, in which survival differed between 2023 and past years (either pooled or individually), was fit, and compared to a reduced model in which survival was equal between 2023 and past years using AIC and LRTs.

Because reach survival estimates include mortality that occurs well downstream of the dams, the ViRDCt model (Harnish et al. 2020) was used to isolate dam passage survival of virtual release groups to a shorter river reach. At Green Peter, the ViRDCt model was used to estimate survival from dam passage to the Sunnyside Array, which is located approximately 5 rkm downstream of Green Peter (Figure 2-3). At Foster, the ViRDCt model was used to estimate survival from dam passage to the tailrace Egress Array, which is located approximately 3 rkm downstream of Foster (Figure 2-3). Estimating survival over a shorter reach allows for more meaningful comparisons between passage routes, diel passage periods (defined by operational diel periods), and operations that are less influenced by environmental conditions (e.g., discharge, temperature, predation) that may cause mortality downstream of the dams that are unrelated to dam passage conditions.

Because the Sunnyside and Egress Arrays were located in close proximity to the dams, fish that died during dam passage could drift far enough downstream to be detected. Therefore, the ViRDCt model utilized releases of dead-tagged fish from the dam and detections of these fish on downstream arrays were used to correct the bias that occurs from detecting fish from the virtual release groups that died during dam passage. Two alternative ViRDCt maximum likelihood estimation models were available for use. The first model was a full model that allowed for detection of dead-released fish on two downstream arrays. The second model, which provided greater precision when valid, was a reduced model that allowed for detection of dead-released fish on only one downstream array.

For the full model, with possible dead-fish detections at two downstream arrays, the likelihood can be written as follows:

$$L = \binom{V_1}{\vec{n}} (S_D p_0 \lambda + (1 - S_D)\omega p_D \Psi)^{n_{11}}$$

$$\cdot (S_D(1-p_0)\lambda + (1-S_D)\omega(1-p_D)\Psi)^{n_{01}}$$

$$\cdot \left(S_D p_0(1-\lambda) + (1-S_D)\omega p_D(1-\Psi)\right)^{n_{10}}$$

$$\cdot \left[S_D(1-p_0)(1-\lambda) + (1-S_D)\left((1-\omega) + \omega(1-p_D)(1-\Psi)\right)\right]^{n_{00}}$$

$$\cdot \binom{D_1}{\vec{d}} (\omega p_D \Psi)^{d_{11}} (\omega(1-p_D)\Psi)^{d_{01}}$$

$$\cdot \left(\omega p_D(1-\Psi)\right)^{d_{10}} \left((1-\omega) + \omega(1-p_D)(1-\Psi)\right)^{d_{00}}.$$

Where

V_1 = number of alive fish in the virtual release at the upstream dam face,

D_1 = number of dead-tagged fish released at the dam,

n_{ij} = number of V_1 fish with capture history ij ($i = 0$ or 1 for detection at the tailrace array, $j = 0$ or 1 for detection at the tailwater array,

d_{ij} = number of dead-released fish (D_1) with capture history ij ($i = 0$ or 1 for detection at the tailrace array, $j = 0$ or 1 for detection at the tailwater array,

S_D = dam passage survival,

p_0 = probability of an alive V_1 fish being detected at the tailrace array,

λ = joint probability of survival between the tailrace array and the tailwater array, and being detected at the tailwater array,

ω = probability of a dead fish from D_1 arriving at the tailrace array,

p_D = probability of detecting a dead fish at the tailrace array, and

Ψ = joint probability that a dead fish is washed down to the tailwater array from the tailrace array and is detected at the tailwater array.

The model has six parameters and six minimum sufficient statistics. Program USER (http://www.cbr.washington.edu/analysis/apps/user) was used to estimate the model parameters and associated variances. No attempt was made to adjust for tag life because travel times were short.

For the reduced ViRDCt model with dead-released fish detected only at the Tailrace Array, the joint likelihood model can be written as follows:

$$L = \binom{V_1}{\vec{n}} (S_D p_0 \lambda)^{n_{11}} [S_D(1-p_0)\lambda]^{n_{01}}$$

$$\cdot [S_D p_0(1-\lambda) + (1-S_D)\phi]^{n_{10}}$$

$$\cdot [S_D(1-p_0)(1-\lambda) + (1-S_D)(1-\phi)]^{n_{00}}$$

$$\cdot \binom{D_1}{\vec{d}} \phi^d (1-\phi)^{D-d}$$

where

ϕ = joint probability of a dead-released fish (D_1) arriving at the Tailrace Array and being detected at that array, and

d = number of dead-released fish detected at the Tailrace Array.

The reduced model has four parameters and four minimum sufficient statistics. This reduced model has the same basic assumptions as its full model counterpart, except the additional assumption that dead-released fish do not drift as far downstream as the tailwaters arrays (Sunnyside Array for Green Peter and Egress Array for Foster). A sufficient sample size of dead-released fish is necessary to help ensure that this additional model assumption is correct. Releasing just a small group of dead tagged fish and not observing any detections downstream is no guarantee of assumption compliance. On the other hand, if 50 dead tagged fish are released and none is detected downstream at an array having a detection probability p of 1.0, then you can be 95% certain that the actual drift probability is no greater than 0.05 (i.e., $P\ [\omega \leq 0.05] = 0.95$; Skalski 1981). At Green Peter, 49 dead-tagged subyearling Chinook salmon were released from the dam during the fall. At Foster, 26 dead-tagged yearling Chinook salmon were released during spring low pool, 78 dead-tagged steelhead were released during spring low pool, 88 dead-tagged steelhead were released during spring high pool, 51 dead-tagged steelhead were released during fall, and 46 dead-tagged subyearling Chinook salmon were released during the fall study.

The ViRDCt model has the following assumptions (Harnish et al. 2020):

1. The virtual release group is composed of fish known to have arrived alive and passed through the dam.
2. The virtual release group has a dam passage distribution representative of run-of-river (i.e., salmon out-migrating during the natural migration period) fish.
3. The tagged fish are representative of the population of inference.
4. All tagged fish act independently.
5. Fish within a release have homogenous survival and detection processes.
6. No tag loss or failure.
7. The probabilities of dead-released fish arriving at the Tailrace Array (ω) and being detected (p_D) are representative of the probabilities of arrival and detection of fish from the virtual release group that die during dam passage.

The receiver arrays deployed at Green Peter and Foster dams were used to track RT-tagged fish to their ultimate passage, ensuring the virtual release groups were comprised of alive fish that passed the dams. Releases of fish used to construct the virtual release groups were released a sufficient distance upstream of the dams in order to provide tagged fish the opportunity to redistribute themselves within the flow as other in river migrants, and as such, arrive at the dam face in similar distribution. The next three assumptions are necessary for statistical estimates and inference to in-river fish. If nonhomogeneous survival between fish occurs, point estimates remain unbiased, but variance estimates from the maximum likelihood model will be inflated (Feller 1968). The final assumption of no tag loss or tag failure can be accounted for by proper tagging procedures (e.g., Adams et al. 1998 and Hockersmith et al. 2003), monitoring for tag loss prior to release, and evaluating tag failure by conducting a concurrent tag life study. Assumption 7 was addressed by releasing dead-tagged fish at both dams downstream of the spillways during the day and night on each day of live fish releases.

The representativeness of the dead-tagged fish releases was tested by comparing the temporal distribution of dead-released fish to the temporal distribution of fish from the virtual release groups that were not detected downstream of the Sunnyside Array (for estimates of Green Peter passage) or downstream of the Egress Array (for estimates of Foster passage). Temporal distributions were evaluated using the Log-Rank and Wilcoxon group homogeneity tests (α = 0.05) (Cox and Oakes 1984) to compare the timing of the dead-tagged fish releases and the observed dam passage timing of virtual release group mortalities.

2.6.2 Estimation of Reservoir Residency and Migration Travel Times

Reservoir (forebay) residence time was calculated for each RT-tagged fish detected passing Green Peter and Foster by subtracting the date and time of dam passage from the date and time of release. Dam passage was identified by detections in zones established to monitor passage of RT-tagged juveniles through the two ROs at Green Peter and six passage routes at Foster (i.e., 2 penstocks and 4 spill bays) using MITAS (Sigma Eight Inc., Newmarket, Ontario, Canada).

At Green Peter, reservoir residence and travel times of RT-tagged fish were compared by release location but there was only one treatment to evaluate in fall (RO operation) and 2023 was the first study year so data were not compared to other treatments nor previous study years. Reservoir residence and travel times of RT-tagged fish that passed Foster in 2023 were compared to those from past study years. Because fish travel time data are often right-skewed, the Mann-Whitney-Wilcoxon test (α = 0.05) was used for comparisons. Residence times from 2015, 2016, 2018, and 2022 were first compared for each species/stock/pool level to determine whether or not it was appropriate to pool data from multiple past years. Next, residence times from 2015, 2016, 2018, and 2022 (either pooled or individually) were compared to residence times from the 2023 study to evaluate the effect of nighttime spillway operations on reservoir residence times.

Median travel times were calculated and reported. Project egress time was measured from the last detection on the dam-face array at both Green Peter and Foster to the last detection on the Sunnyside Array or Egress Array below each dam, respectively. Travel time within each river reach was calculated as the difference between the time of the last detection event on the upstream array (or time of release for reservoir residency) and last detection event at the downstream array. Travel times were calculated from the dams to each downstream detection array and between each detection array. Only fish known to have passed the dams alive were used in the travel time calculations. Because the travel time data was not normally distributed, medians are presented and nonparametric statistics (i.e., Mann-Whitney-Wilcoxon, Kruskal-Wallis tests) were used for comparisons.

2.6.3 Estimation of Passage Distributions

Route-specific passage proportions were calculated for each RT-tagged fish detected passing Green Peter and Foster in 2023. Proportions (P_i), which are the proportion of fish from the virtual release group passing each individual route relative to total project passage, were estimated by

$$P_i = \frac{N_i}{N_{spill} + N_{tur}}$$

where N_i is the total number of tagged fish that passed the dam via a given route, N_{spill} is the number of fish that passed through the ROs at Green Peter and Spill Bays 1–4 at Foster, and N_{tur} is the number of fish that passed via turbines (Green Peter [when it became an available route] and Foster).

In spring at Foster, study fish were grouped by passage pool elevation and not by release pool elevation due to some fish remaining in the reservoir during spring refill and passing during summer high pool. In fall there was only one pool elevation (low pool). All study fish that passed Green Peter and Foster were assigned a specific passage route except for a few fish that did not have detections on the dam face. In these instances, the last detection of the fish in the forebay was matched with the first detection in the tailrace at either the powerhouse or spillway tailrace. Based on first detection in the tailrace and hourly dam operations a general route of assignment was given (Dam-Turbine, Dam-RO [Green Peter], Dam-Spillway [Foster], Dam-No Route). These fish were also included in the passage proportions.

Once passage proportions were calculated, the time of passage was used to split between daytime turbine and nighttime spill to determine when study fish were actively passing both Green Peter and Foster. In spring at Foster, daytime began at 06:00 hours and lasted until 19:59 hours. Nighttime began at 20:00 hours and lasted until 05:59 hours. In fall, daytime began one half hour after sunrise to one hour before sunset and nighttime began one hour before sunset to one half hour after sunrise.

Predation occurred throughout the study area in 2023. Predation can be difficult to verify; however, several events were considered evidence that predation occurred. Events presumed to be predation included fish traveling downstream between detection arrays at a rate beyond which is physically possible (i.e., less than 20 minutes), a fish passing a dam and subsequently returning upstream into the forebay, a fish moving between downstream and upstream detection sites multiple times at a rapid rate, or if fish skip (i.e., are not detected on) multiple detection sites but are detected further downstream. Any study fish that exhibited one of these behaviors were censored from the last feasible downstream detection and were used to calculate project metrics until predation occurred. A fish denoted as "no route-predation" was never detected on any dam-face array at Green Peter or Foster after release but had events that were presumptive of predation, as described above. These fish had no useable data other than indication of predation. A fish denoted as "predated after detection" was detected on at least one of the dam-face arrays at Green Peter or Foster after release (or further downstream), before predation occurred. These fish had useable data up to the point of predation.

2.6.4 Estimation of Efficiency and Effectiveness

Passage routes were identified by detections in the ROs at Green Peter and the penstock and spill bays at Foster. The proportion of fish that passed through each of these routes was calculated for each species, stock, and treatment or pool level, if applicable. Efficiency metrics were calculated based on the numbers of fish passing the dam overall and the number passing through each specific route.

Dam passage efficiency (DPE), the proportion of total fish passing the dam through any route (Spill = spillway [Foster] or RO [Green Peter], TUR = turbine) relative to the number of total fish detected in the near forebay of the dam (Near Forebay) and therefore available to pass. Additionally, day and nighttime DPE were calculated in a similar manner, as the proportion of total fish passing the dam during either day or night relative to the total number of fish detected during day or night in the Near Forebay. The formula for estimating DPE was:

$$DPE = \frac{\widehat{N}_{Spill\ or\ RO} + \widehat{N}_{TUR}}{\widehat{N}_{NearForebay}}$$

Regulating outlet passage efficiency for the two ROs (north – RNE; and south – RSE) was only calculated for Green Peter and it is the proportion of fish passing via one of the ROs i (RN or RS) relative to the total number of fish passing through the dam. Additionally, day and nighttime passage efficiency were estimated by using only fish passing through RO_i (RN or RS) during day or nighttime relative to the total number of fish passing during day or nighttime. Overall, day and nighttime RO_iE were estimated by the fraction:

$$RO_iE = \frac{\widehat{N}_{RO_i}}{\widehat{N}_{RN} + \widehat{N}_{RS}}$$

Effectiveness of regulating outlets was calculated by dividing RO_iE by the proportion of total dam discharge (disch.) that passed through that same route. This was only calculated at Green Peter and results in a unitless measure of effectiveness. Also, day and nighttime effectiveness by RO was calculated using the day and nighttime RO_iE relative the proportion of total dam discharge (disch.) that passed through that same route during day or nighttime. An effectiveness value ≥ 1.0 is considered an effective route, whereas a value < 1.0 is not effective. Overall, day and nighttime (by RO) was estimated by the fraction:

$$RO_i\ Effect = \frac{RO_iE}{RO_i\ disch. \div Total\ disch.}$$

Fish passage efficiency (FPE) was only calculated for Foster, and it is the proportion of fish passing via a non-turbine route (i.e., spillway [Spill]) relative to the number of total fish in the near forebay and available to pass (Near Forebay). Additionally, day and nighttime FPE was calculated using the proportion of fish passing via a non-turbine route during day or nighttime relative to the total number of fish in the Near Forebay, both were estimated by the fraction:

$$FPE = \frac{\widehat{N}_{Spill}}{\widehat{N}_{NearForebay}}$$

Estimates of DPE and FPE at Foster in 2023 were compared to those from past study years. First, species-, stock-, and pool level-specific estimates of DPE and FPE from 2015, 2016, 2018, and 2022 were compared to determine if the observed proportions were similar enough between years to be pooled. These comparisons were conducted using the tabular passage data and Fisher's exact tests ($\alpha = 0.05$). If these comparisons revealed no significant differences, data from 2015, 2016, 2018, and 2022 were pooled for comparison to 2023 estimates. If differences were detected between past study years, 2023 estimates were compared to past years individually. Comparisons to past years (either pooled or individually) were also performed using the tabular passage data and Fisher's exact tests. Because we expected DPE and FPE to increase in response to nighttime spillway operations, one-sided tests were used to test for these changes.

Spillway passage efficiency (SPE) was only calculated for Foster, and it is the proportion of fish passaging through the non-turbine route (i.e., spillway) relative to the number of total fish passing the dam via any route. It was estimated by the fraction:

$$SPE = \frac{\widehat{N}_{Spill}}{\widehat{N}_{Spill} + \widehat{N}_{TUR}}$$

Effectiveness of the spillway (Spill Effect) was calculated for Spill Bays 1-4 at Foster by dividing the SPE by the proportion of the total dam discharge (disch.) that passed through that same route for the study period, resulting in a unitless measure of effectiveness. An effectiveness value ≥ 1.0 is considered an effective route, whereas a value < 1.0 is not effective.

$$Spill\ Effect\ = \frac{SPE}{(Spill\ disch. \div\ Total\ disch.)}$$

Comparisons of efficiency and effectiveness metrics at Foster by daytime turbine and nighttime spill operations for each species and season were performed using a comparison of proportions test (z-test). Where applicable, comparisons across study years were also performed.

3.0 Results

3.1 Spring Tag Life Study

Tags retained for the spring study assessment of operational tag life had a mean life of 71.2 d (range: 58.6 – 86.9 d). The Weibull three parameter model provided the best fit to the observed tag life data (Figure 3-1).

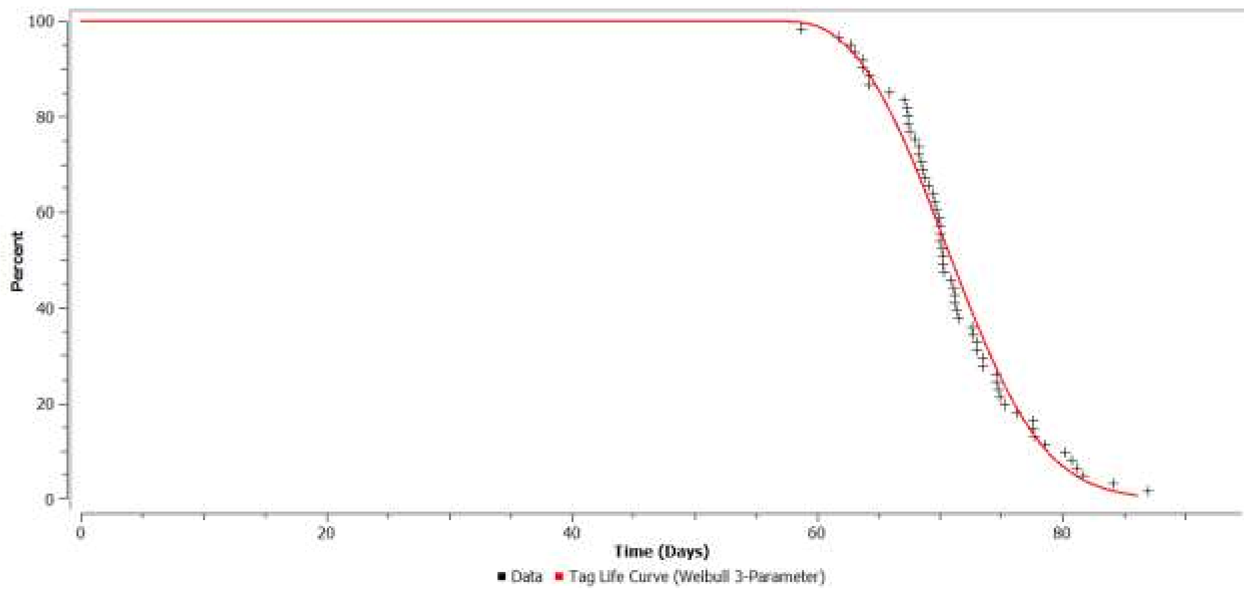

Figure 3-1. Weibull three parameter model fit to the observed tag life of radio tags used during the spring survival study conducted at Foster, 2023.

3.2 Fall Tag Life Study

As mentioned previously, two tag lots were used for the fall studies conducted at Green Peter and Foster. Tags retained from lots 1 and 2 had mean operational tag lives of 72.1 d (range: 54.7–92.7 d) and 72.2 d (range: 51.2–85.5 d), respectively (Figure 3-2). Because tag life was statistically similar between tag lots (Log-Rank test: χ^2 = 0.085, P = 0.771; Wilcoxon group homogeneity test: χ^2 = 0.527, P = 0.468), they were combined, and a single tag life probability curve was used for survival estimation (Figure 3-3).

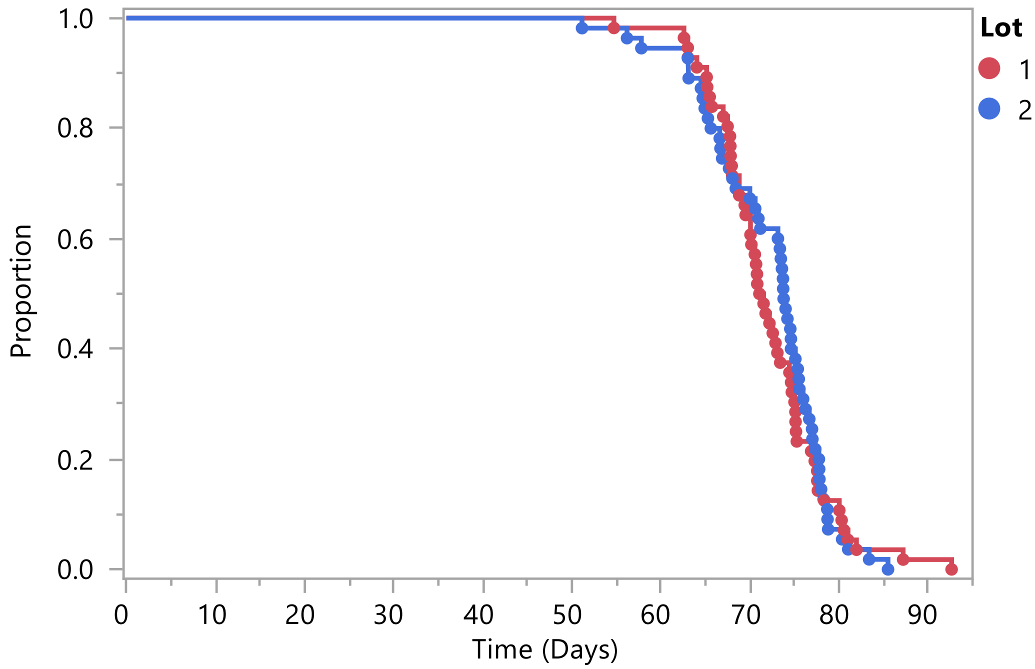

Figure 3-2. Observed tag life of radio tag lots used during the fall survival study conducted at Green Peter and Foster, 2023.

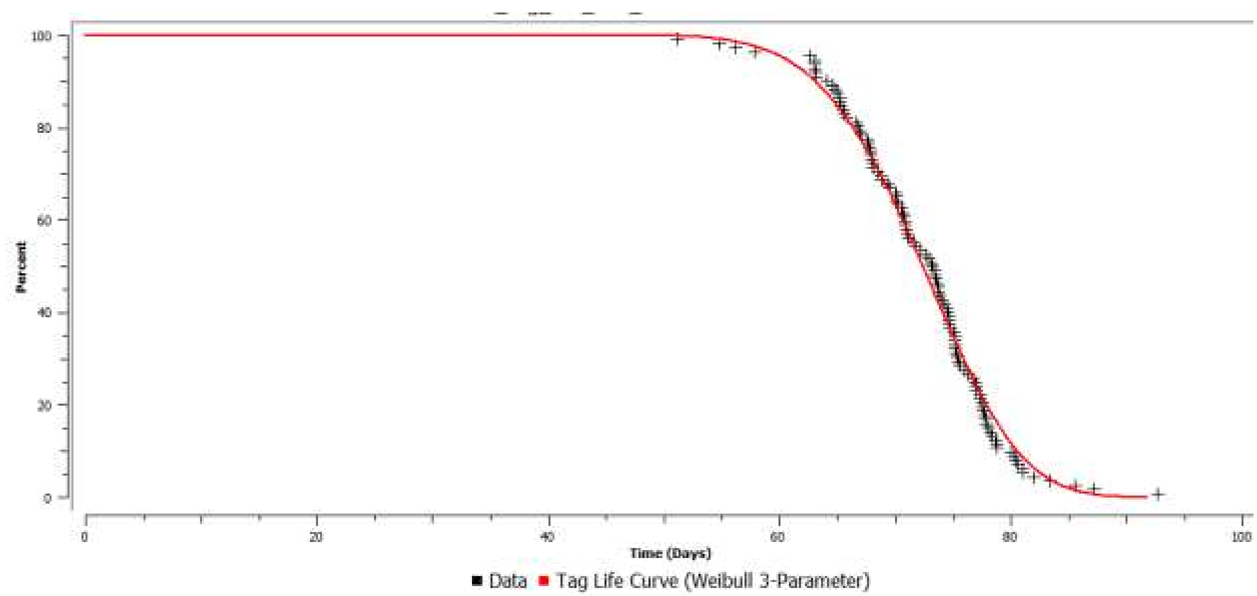

Figure 3-3. Weibull three parameter model fit to the observed tag life of radio tags used during the fall survival study conducted at Green Peter and Foster, 2023.

3.3 Green Peter Dam

Results for Chinook salmon released at Green Peter are only presented for the fall 2023 study season. In spring 2023, yearling Chinook salmon health was compromised, so no fish were tagged and released during that season.

Fish tagging and releases of subyearling Chinook salmon occurred from Nov 1 through Dec 2, 2023, over four trips. Fish were released two weeks prior to the start and end of the RO operation period (Nov 15–Dec 16) to maximize the likelihood of fish migrating to the dam to be available for dam passage during the treatment period.

3.3.1 Fall – Environmental Conditions

3.3.1.1 Temperature

Data collected on environmental conditions included forebay elevation by seasonal periods and forebay temperature. Temperature data was provided courtesy of the USACE operations office, and the elevation data was gathered from the USGS Water Data for the Nation website.

The Green Peter forebay elevation follows a “rule curve” managed by the USACE Water Management Reservoir Regulators. The rule curve dictates lowering the forebay pool elevation in fall to prepare for storage and flood control during winter months. Generally, the fall pool drawdown begins on or after October 1 and refill begins on or around February 1. Green Peter is also used to release cool water in the summer and refill the Foster Reservoir in the spring. Any deviations in the timing of refill and drawdown periods were coordinated through the Reservoir Regulators and local stakeholders.

A deep drawdown occurred in fall 2023 and the pool was held at el. 780 ft. from October 31 to December 3, 2023, to reduce the forebay for low pool and increase the potential for fish passage through the ROs. During this deep drawdown, the ROs operated 24/7, while the turbines did not operate. The forebay elevation lowered to 772 ft.; however, it returned to 900 ft. by December 3, 2023 (Figure 3-4), likely due to a high water event from storm events. The RO deep drawdown operational treatment period (i.e., ROs only, no turbines) occurred from October 31 to December 16 at 08:10. From the end of the RO operational treatment period through March 2 at 12:00, no set treatments occurred. The ROs were in operation until December 29 at 16:00. During this time, the reservoir refilled to approximately 974 ft., was slightly reduced to 950 ft., and refilled back to 970 ft. (Figure 3-4). Throughout December, the turbines were rarely operated.

Forebay temperature data was obtained from a temperature string that recorded hourly temperatures at depths ranging from 0.5-200 ft. (Figure 3-4). No temperature data was captured at 60-200 ft. from October 1, 2023 to January 23, 2024, which spanned throughout all of the low pool/RO treatment and part of the no treatment period. During the drawdown, the temperature was the warmest in the fall, decreased to be average temperature of 12.1 °C in the winter, and ranged from 3.7–21.1 °C for the season. The temperature data collected after the drawdown or during the no treatment period had an average temperature of 6.9 °C and ranged from 3.9–9.4 °C. The water column appears stratified at the beginning of the data collection when temperature was the warmest in October 2023 ($\bar{x}$ = 17.8 °C; range; 11.5–21.1 °C) but could not be confirmed due to the missing data. At the end of the no treatment period, from February to March 2024, the water column became more isothermal ($\bar{x}$ = 6.8 °C; range: 5.8-11.2 °C; Figure 3-4).

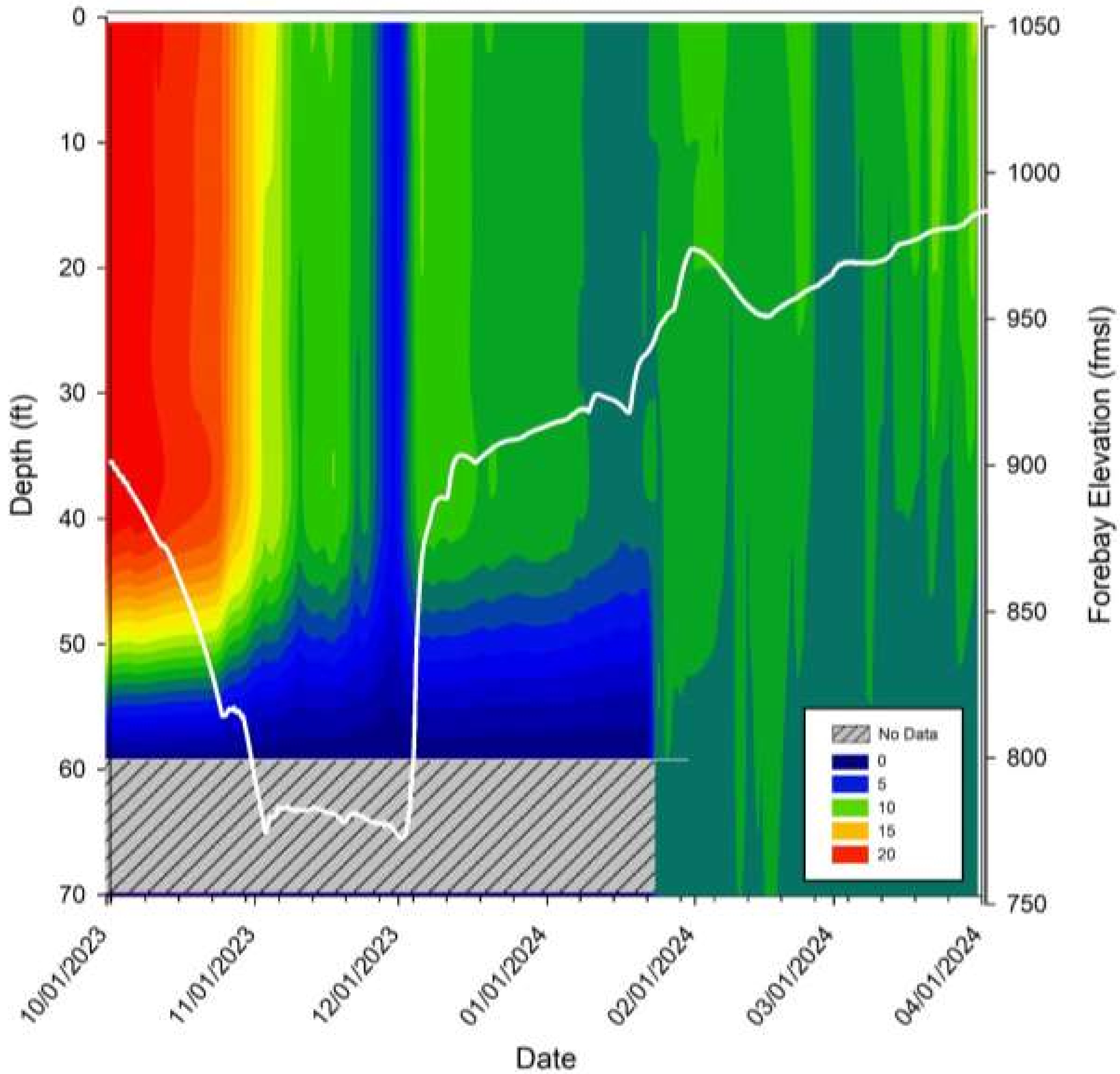

Figure 3-4. Daily average forebay elevation (solid white line; right axis) and temperature (°C) at depth (contour plot; left axis) in the Green Peter Forebay from October 1, 2023, through March 31, 2024.

3.3.1.2 Discharge

The mean daily discharge through the ROs at Green Peter during November 1-December 16 was 1,672 cfs and approximately equal by diel period (daytime: 1,649 cfs; nighttime: 1,676 cfs). The mean daily discharge during the treatment period through the RN was 1,602 cfs (excluding the period it was closed) and the mean daily discharge through the RS was 1,070 cfs. Discharges through each RO were also approximately equal by diel period. Discharge proportion by route (RN = 36%, RS = 64%) was relatively close to passage proportion by route (RN = 30%, RS = 70%). The mean daily discharge range for the season was 0-1,963 cfs.

3.3.2 Fall – Subyearling Chinook Salmon

The following sections describe reservoir, dam passage and reach survival; reservoir residency and migration travel times; passage route distributions; and efficiency and effectiveness results from the fall 2023 study period for subyearling Chinook salmon released at Green Peter.

3.3.2.1 Tagging

Fish tagging and releases occurred from Nov 1 through Dec 2, 2023. Approximately equal numbers of subyearling Chinook salmon were released at the HOR and MOR (Table 3-1). Releases at the HOR and MOR at the beginning of the fall season were further upstream of the dam than at the end of the season due to the lowered elevation of the reservoir and the inability of the boat to navigate the shallower waters. As a result, fish could be detected in the Green Peter forebay immediately upon release.

Table 3-1. Release location, sample sizes, fork lengths, weights, and standard errors (SE) of subyearling Chinook salmon released at Green Peter in fall 2023. HOR = head-of-reservoir; MOR = mid-of-reservoir; DFR = dead fish release.

Release Location	*n*	Length (mm; mean)	SE	Weight (g; mean)	SE
HOR	371	159.81	0.60	40.68	0.47
MOR	367	156.80	0.73	39.42	0.50
DFR	49	153.86	2.24	37.33	1.57
Total	787	158.04	0.47	39.88	0.34

3.3.2.2 Survival

Reservoir Survival

The 371 RT-tagged subyearling Chinook salmon released at Green Peter HOR had an estimated survival probability of 0.3962 (standard error estimate [$\widehat{SE}$] = 0.0254) from release to Green Peter passage. The 367 fish released at Green Peter MOR had an estimated survival probability of 0.4850 (0.0261) from release to Green Peter passage. The reservoir survival estimations represent a worst-case scenario and should be interpreted with caution, as there are no detection arrays within the reservoirs and the fate of fish that are not detected after release is unknown. It is possible they died, were predated, remained in the river for the duration of their tag life, moved into a different tributary, or had another fate. Reservoir survival is also limited to the battery life of the RT tags, which may not be representative of fish that rear in the reservoir over longer periods.

Dam Passage and Reach Survival

Dead tagged fish were released on the same days live tagged fish were released. Although the passage of live released fish continued after the last dead tagged fish release, the temporal distribution of dead tagged fish releases did not differ significantly from that of live released subyearling Chinook salmon mortality at Green Peter (Log-Rank test: χ^2 = 0.940, P = 0.332; Wilcoxon group homogeneity test: χ^2 = 0.036, P = 0.851; Figure 3-5). Of the 49 dead tagged fish released at Green Peter, three (6.1%) were detected at the Sunnyside Array.

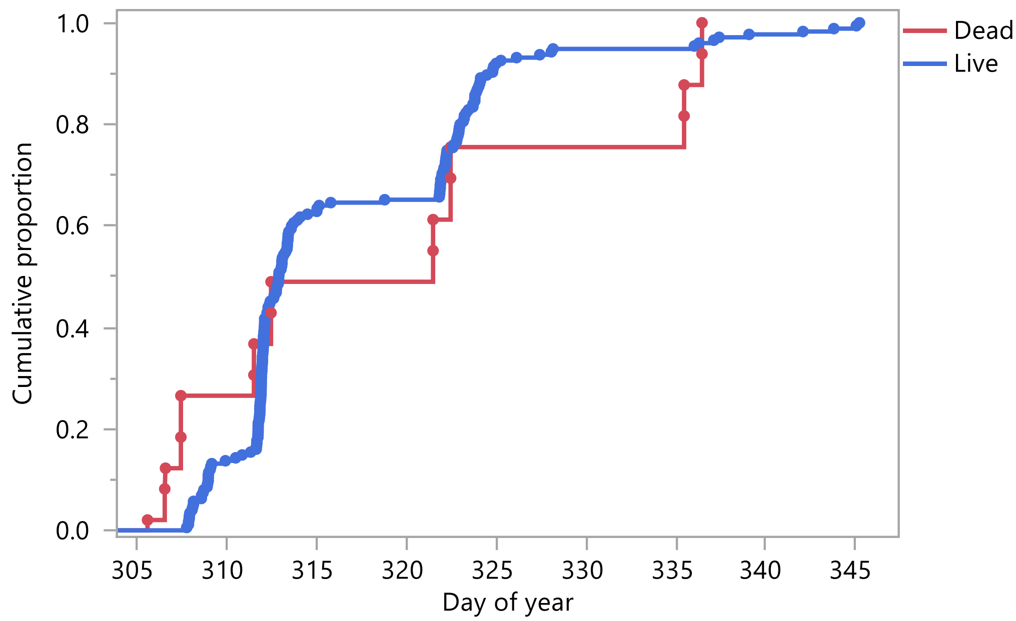

Figure 3-5. Cumulative proportions of live released RT-tagged subyearling Chinook salmon mortality (blue) and dead tagged fish releases (red) at Green Peter during fall, 2023.

Four tagged fish were detected passing Green Peter after the ROs were closed and five tagged fish were captured in the screw trap located immediately downstream of Green Peter. These fish were censored from the dam passage and reach survival estimation. The remaining 319 RT-tagged subyearling Chinook salmon that were detected passing Green Peter when the ROs were open had an estimated dam passage survival probability of 0.7268 (0.0284) to the Sunnyside Array (Table 3-2). Estimated dam passage survival probability was similar for fish that passed Green Peter through the north ($\hat{S}_D$ = 0.6979; $\widehat{SE}$ = 0.0535) and south ($\hat{S}_D$ = 0.7339; $\widehat{SE}$ = 0.0328) ROs (Table 3-2).

The majority of RT-tagged subyearling Chinook salmon passed through the study area when the probability of tag failure was low (Figure 3-6). The probabilities of tags being active at downstream detection sites were estimated to be ≥ 0.9964 (Table 3-2). Therefore, tag life adjustments to the survival estimates were small.

The 319 tagged subyearling Chinook salmon that passed Green Peter when the ROs were operating had an estimated reach survival probability of 0.2268 (0.0235) to the Santiam Rest Stop Array (Table 3-2). Reach survival was similar for tagged subyearling Chinook salmon that passed Green Peter through the north ($\hat{S}$ = 0.1964; $\widehat{SE}$ = 0.0415) and south ($\hat{S}$ = 0.2399; $\widehat{SE}$ = 0.0288) ROs (Table 3-2).

Undetected fish had unknown fates. It is possible they died, were predated, remained in the river for the duration of their tag life, moved into a different tributary, or had another fate as the reach survival encompasses approximately 81 rkm downstream of Green Peter.

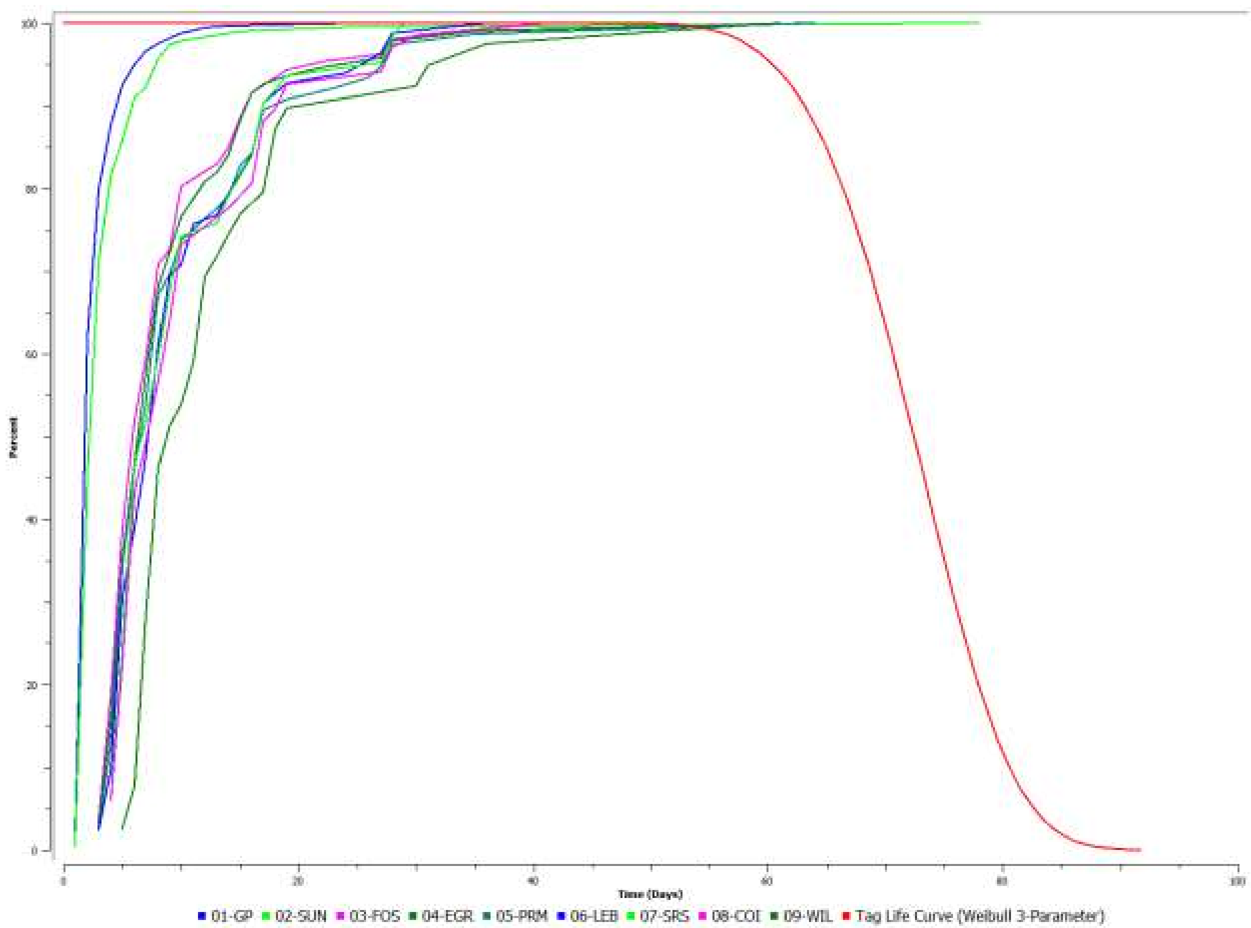

Figure 3-6. Fitted tag life curve (red) and cumulative arrival distributions of RT-tagged subyearling Chinook salmon at detection sites used in the estimation of survival. GP = Green Peter, SUN = Sunnyside Array, FOS = Foster Dam Array, PRM = Waterloo Primary Array, LEB = Lebanon Dam Array, SRS = I-5 Santiam Rest Stop Array, COI = Cole Island Array, WIL = Willamette Falls Array.

Table 3-2. Tag life, detection, and survival probability estimates for RT-tagged subyearling Chinook salmon (CH0) that passed Green Peter (GPR) during fall, 2023. Standard error estimates ($\widehat{SE}$) are shown in parentheses. SUN = Sunnyside Array, FOS = Foster Dam Array, PRM = Waterloo Primary Array, LEB = Lebanon Dam Array, SRS = I-5 Santiam Rest Stop Array, COI = Cole Island Array. Note: four fish that passed after the ROs were closed and two fish caught in the screw trap downstream of GPR were excluded. Five CH0 detected passing FOS could not be assigned to a specific RO.

Reach	Tag life prob. ($\widehat{SE}$)	Det. Prob. ($\widehat{SE}$)	Survival ($\widehat{SE}$)
North and South ROs (N = 319)			
GPR – SUN[1]	0.9964 (0.0006)	0.9862 (0.0097)	0.7268 (0.0284)
GPR – FOS	0.9987 (0.0003)	0.9896 (0.0104)	0.3362 (0.0265)
GPR – PRM	0.9986 (0.0004)	0.8690 (0.0368)	0.2746 (0.0251)
GPR – LEB	0.9982 (0.0007)	0.9722 (0.0194)	0.2644 (0.0248)
GPR – SRS[2]	1.0000 (0.0000)	0.8569 (0.0418)	0.2268 (0.0235)
GPR – COI	1.0000 (0.0000)	0.9260 (0.0318)	0.2268 (0.0235)
North RO (N = 92)			
GPR – SUN[1]	1.0000 (0.0000)	0.9714 (0.0282)	0.6970 (0.0535)
GPR – FOS	1.0000 (0.0000)	1.0000 (0.0000)	0.3370 (0.0493)
GPR – PRM	1.0000 (0.0000)	0.7809 (0.0865)	0.2505 (0.0452)
GPR – LEB	1.0000 (0.0000)	0.9544 (0.0445)	0.2505 (0.0452)
GPR – SRS[2]	1.0000 (0.0000)	0.8856 (0.0760)	0.1964 (0.0415)
GPR – COI	1.0000 (0.0000)	0.8856 (0.0760)	0.1964 (0.0415)
South RO (N = 222)			
GPR – SUN[1]	0.9949 (0.0009)	0.9905 (0.0095)	0.7339 (0.0328)
GPR – FOS	0.9981 (0.0005)	0.9851 (0.0148)	0.3253 (0.0315)
GPR – PRM	0.9976 (0.0009)	0.9153 (0.0363)	0.2812 (0.0303)
GPR – LEB	1.0000 (0.0000)	0.9811 (0.0187)	0.2663 (0.0297)
GPR – SRS[2]	1.0000 (0.0000)	0.8449 (0.0503)	0.2399 (0.0288)
GPR – COI	1.0000 (0.0000)	0.9388 (0.0342)	0.2399 (0.0288)

[1]Dam passage survival
[2]Reach survival

3.3.2.3 Reservoir Residency and Migration Travel Times

Five fish were caught in the screw trap in the Green Peter tailrace. Travel times for these fish were valid up until detections at that array (i.e., Reservoir Residence and HOR or MOR residence time; Figure 3-7). Thereafter, travel times for these fish were removed from further analyses as these individuals would be delayed and could bias the results.

Subyearling Chinook salmon that passed Green Peter during the day spent significantly more time in the reservoir than fish that passed Green Peter at night (Mann-Whitney-Wilcoxon test: $W = 8262$; $P \leq 0.002$). Fish spent a median of 27.4 hours in the reservoir before passing Green Peter during the day compared to the 16.4 hours that fish spent in the reservoir before passing the dam at night (Figure 3-7). The reservoir residence times were significantly different between diel periods for subyearling Chinook salmon released at the HOR (Mann-Whitney-Wilcoxon test: W =

1924; P = 0.036) but not for fish released at the MOR (Mann-Whitney-Wilcoxon test: W = 1951; P = 0.141).

A total of 229 fish passed Green Peter and were detected at the ViRDCt survival array at Sunnyside and had a median travel time of about 5 h (Table 3-3; Figure 3-7). Of those 229 fish, 102 continued to travel downstream and were detected passing Foster as well (Table 3-3). The fish that passed Green Peter during the day had a median travel time of 89.8 h (n = 14) from Green Peter to Foster, while the fish that passed Green Peter at night had a median travel time of 142.8 h (n = 88; Table 3-3). Sixty-two fish traveled downstream from Green Peter to the Santiam Rest Stop Array and had significantly different median travel times (Mann-Whitney-Wilcoxon test: W = 121; P = 0.019) of 66.6 h (n = 9) for fish that passed Green Peter during daytime and 116.4 h (n = 53) for fish that passed at nighttime (Table 3-3; Figure 3-7). Thirty-four fish were detected at the furthest downstream array, Willamette Falls, and had median travel times of 135.0 h (n = 4) for fish that passed Green Peter during the day and 136.4 (n = 30) for fish that passed Green Peter at night (Table 3-3; Figure 3-7).

Table 3-3. Travel time summary for subyearling Chinook salmon from Green Peter Dam to the downstream arrays during RO treatment in fall 2023.

		Daytime			Nighttime		
Treatment	**Reach**	**Median hours (SE)**	**Mean hours (SE)**	***n***	**Median hours (SE)**	**Mean hours (SE)**	***n***
RO Operation	GPR – SUN	5.4 (7.8)	17.4 (6.2)	33	5.2 (20.7)	46.1 (16.5)	196
	GPR – FOS[1]	67.5 (16.1)	83.6 (12.9)	19	86.0 (20.6)	142.1 (16.4)	121
	GPR – FOS[2]	89.8 (16.7)	69.8 (20.9)	14	142.8 (21.0)	85.2 (26.3)	88
	GPR – EGR	60.8 (21.3)	81.3 (17.0)	12	92.1 (29.1)	151.1 (23.2)	78
	GPR – PRM	64.0 (22.0)	79.4 (17.5)	11	101.6 (35.5)	176.5 (28.3)	64
	GPR – LEB	69.4 (24.8)	102.4 (19.8)	13	113.3 (23.8)	163.8 (19.0)	68
	GPR – SRS	66.6 (22.9)	83.5 (18.2)	9	116.4 (23.6)	163.2 (18.8)	53
	GPR – COI	67.7 (22.8)	84.4 (18.2)	9	117.4 (28.4)	180.4 (22.7)	57
	GPR – WIL	135.0 (20.2)	131.3 (16.2)	4	136.4 (59.8)	228.1 (47.7)	30

[1]Difference in time from last detection at GPR to first detection in Foster forebay
[2]Difference in time from last detection at GPR to last detection at Foster Dam

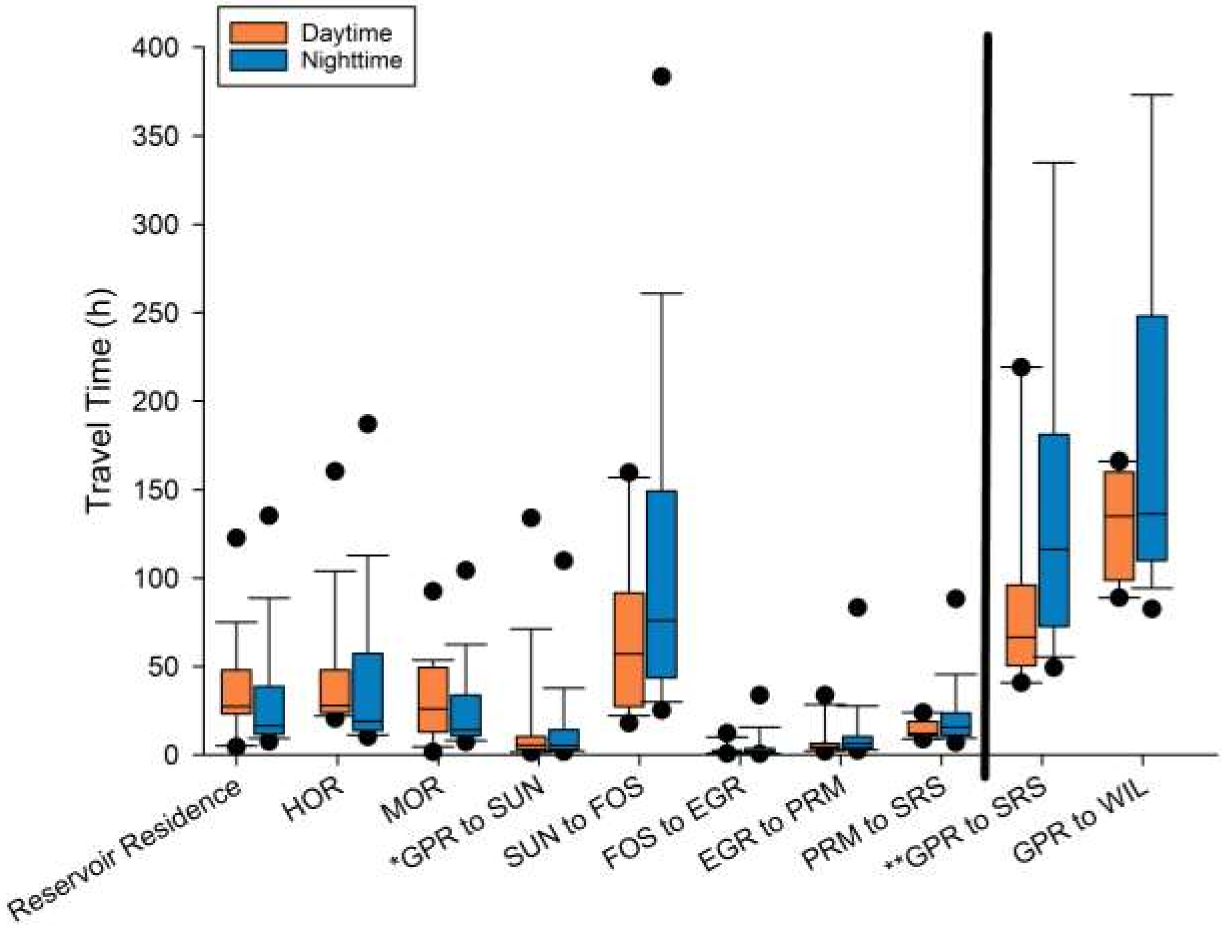

Figure 3-7. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir; MOR = mid-of-reservoir), and travel times between reaches for subyearling Chinook salmon released at Green Peter in fall 2023 (GPR; SUN = Sunnyside, FOS = Foster, EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). Daytime classification indicates fish with last detections at Green Peter Dam during the day, while nighttime fish had last detections occurring at night (indicating time of passage). Lines within the boxes represent medians, box boundaries indicate the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. The * indicates ViRDCt survival array and the ** indicates the reach survival array. The solid vertical line is a delineator to show the travel time from Green Peter through all the reaches and directly to the reach survival array and to the furthest downstream array at Willamette Falls. Two outliers are not depicted to manage the scale of the y-axis: 567 h from GPR to SRS and 1043 h from GPR to WIL under nighttime passage.

3.3.2.4 Passage Distributions

Of the 738 live fish released during the fall, 611 were detected after release and used for analyses (Table 3-4; Table 3-5). The remaining 127 fish had unknown fates (i.e., could have been predated, moved upstream, died, etc.). A few fish (*n* = 15) were never detected at Green Peter but were detected on other RT arrays downstream, potentially indicating no route predation (i.e., never detected at Green Peter after release; Table 3-4).

It should be noted that as the reservoir was drawn down, mid-of-reservoir and head-of-reservoir release locations moved, with fish were being released closer to the Green Peter forebay antenna as the season progressed. This likely lead to a higher number of fish being detected immediately after release as the drawdown occurred.

Of those fish detected after release, 53.2% (*n* = 325) passed Green Peter (Table 3-4). Approximately 6.5% of fish available to pass (*n* = 40; i.e., detected at the near forebay) never passed the dam (Table 3-4). Out of the 321 fish that passed downstream of Green Peter through the ROs, 84.8% passed during the night and 15.2% passed during the day (Table 3-5). Separated by RO, 29.7% of fish (*n* = 94) passed via the RN and 70.3% of fish (*n* = 222) passed via the RS. However, the RN was closed from November 11–December 6 (Table 3-5). Five fish (1.6%) passed through the ROs but were unable to be assigned a north or south route (Table 3-5). Additionally, there were four fish that passed through the turbines during no treatment operations (i.e., after December 16), one during the day (25%), and three during the night (75%; Table 3-5).

Fish passed Green Peter in greater numbers when the forebay elevation was lower (Figure 3-8). Due to winter floods and a high water event, the forebay elevation rose quickly in the beginning of December. The final cohort of Chinook salmon were released December 1 and 2, and these fish passed through the ROs in much lower numbers than all previous release groups. Of the 187 fish released, 13 fish passed the dam (Figure 3-8).

Fish may have also been detected at Green Peter (or downstream) and subsequently predated. A total of 596 fish were detected in the Green Peter forebay or downstream (excluding no route predation fish), and 63 of those fish (10.6%) were detected and presumed to be predated either in the Green Peter tailwaters or farther downstream (Table 3-4). The number of predated fish is likely a minimum estimate, as the fates of undetected fish are unknown, and it is possible that they were also predated.

Table 3-4. Movement summary (proportions [prop.] and sample sizes) of subyearling Chinook salmon released at Green Peter (GPR).

Treatment	Detected After Release (*n*)	No Route – Predation		Extended Forebay Detection – Never Passed		Near Forebay Detection – Never Passed		Downstream Passage		Presumed Predation between GPR Forebay and Sunnyside[1]		Presumed Predation downstream of Sunnyside[1]	
		Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Sub Prop.	*n*	Sub Prop.	*n*
RO Operation	611	0.025	15	0.378	231	0.065	40	0.532	325	0.091	54	0.015	9

[1] Predation as summarized is presumed, based on assumptions outlined in the methods.
Note: This table is based on the pool elevation during which fish were released. Fish that did not have an assigned route of passage (i.e., Route = Dam; Table 3-5) were excluded.

Table 3-5. Passage proportions by route of passage for RT-tagged Chinook salmon released at Green Peter Dam by operational treatment. A Dam – No Route indicates a specific route (turbines or spillway) could not be determined.

Treatment	Route	Overall Proportion	Overall *n*	Daytime Proportion	Daytime *n*	Nighttime Proportion	Nighttime *n*
RO Operation	**ROs**	**0.984**	**316**	**0.152**	**48**	**0.848**	**268**
	RN – North	0.297	94	0.181	17	0.819	77
	RS – South	0.703	222	0.140	31	0.860	191
	Dam – ROs	**0.016**	**5**	**0.200**	**1**	**0.800**	**4**
	Overall		**321**	**0.153**	**49**	**0.847**	**272**
No Treatment	**Dam**	**0.000**	**4**	**0.250**	**1**	**0.750**	**3**
	No Route	0.000	0	0.000	0	0.000	0
	Turbines	0.000	4	0.250	1	0.750	3
	Overall		**4**	**0.250**	**1**	**0.750**	**3**

Note: Fish that passed during RO Operation (10/1/23–12/16/23) could only have passed through the ROs, as the turbines were not open. Fish that passed after 12/29/23 at 16:00 could only have passed through the turbines.

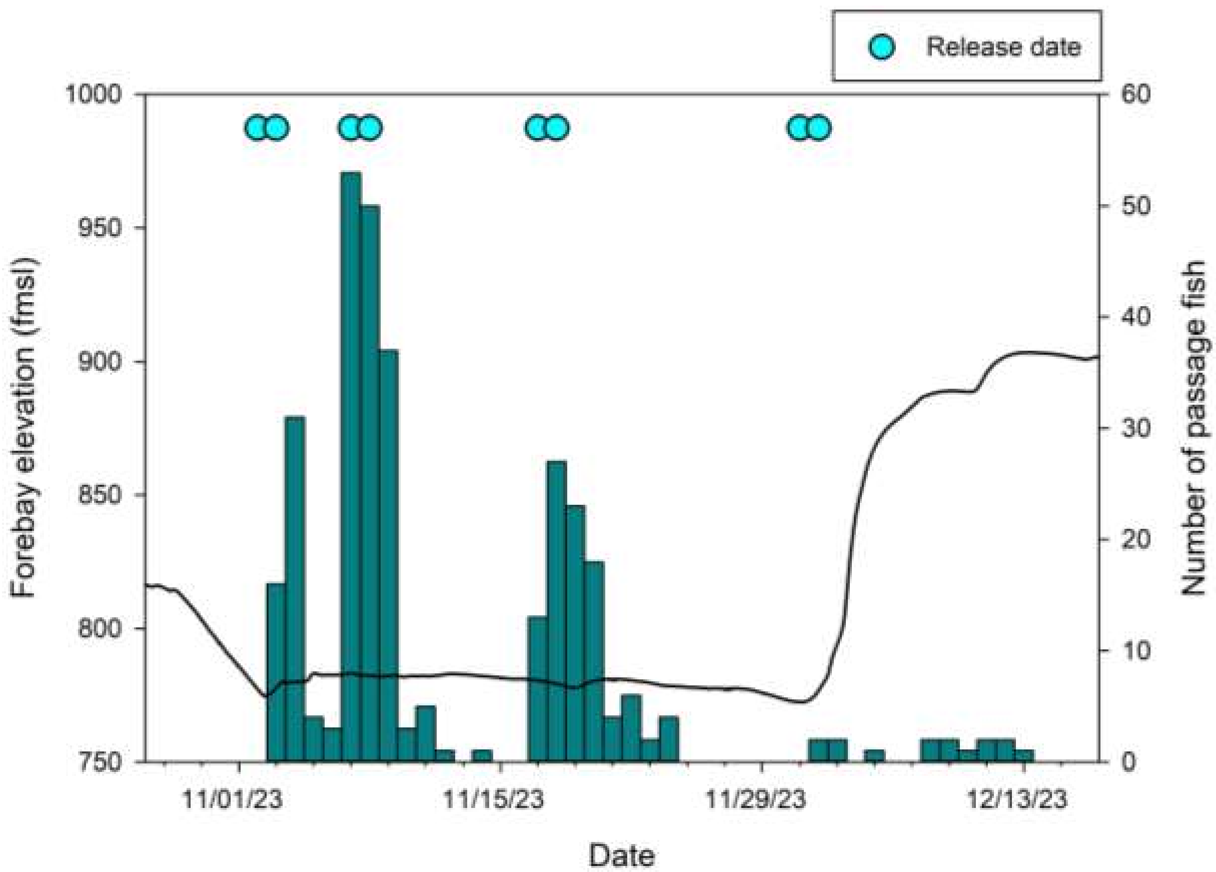

Figure 3-8. Forebay elevation (solid black line; left y-axis) as compared to number of passed fish (bar plot; right y-axis) at Green Peter. Circle symbols indicate the dates of fish releases. Fish were detected passing Green Peter during fall low pool from November 3 to December 13.

3.3.2.5 Efficiency and Effectiveness

The turbines were not operated during the treatment period (November 15–December 15) when the ROs were in operation. Thus, the north and south ROs (RN and RS, respectively) were the only routes of passage available for fish. No route fish were included in the DPE estimates as their route of passage had to be through one of the ROs.

The overall DPE was 0.892 and was significantly higher during nighttime passage than daytime passage (0.756 and 0.136 respectively; z-test; Z = 8.196, P < 0.001; Table 3-6; Figure 3-9). Most fish passed through the ROs during the night (n = 268) compared to the day (n = 48). Over the course of the treatment period, the proportion of discharge was higher through the RS (0.639) than the RN (0.361) and contributed to the differences observed in the RO passage efficiencies. Additionally, the RN was not open from November 11–December 6, influencing total passage by route. The overall RNE was 0.298 while overall RSE was 0.703 (Table 3-4; Figure 3-9). Daytime RNE was higher than nighttime RNE by approximately 7.0% but not significantly different (z-test; Z = 0.275, P = 0.783; Table 3-6; Figure 3-9). Conversely, nighttime RSE was higher than daytime RSE by approximately 7.0% and not significantly different (z-test; Z = 0.576, P = 0.564; Table 3-6; Figure 3-9).

Route specific effectiveness accounts for discharge rates. The overall RN effectiveness was 0.824 while the overall RS effectiveness was 1.099, indicating RS was more effective at passing subyearling Chinook salmon (Table 3-6; Figure 3-9). Daytime RN effectiveness was higher than RN nighttime (0.978 and 0.796, respectively), while RS nighttime effectiveness was similar to RS daytime effectiveness (1.115 and 1.012, respectively; Table 3-6; Figure 3-9).

Table 3-6. Passage efficiencies for subyearling Chinook salmon at Green Peter in fall 2023. Dam Passage Efficiency (DPE) is calculated relative to the number of fish detected in the near forebay, and RO North Passage Efficiency (RNE), and RO South Passage Efficiency (RSE) are calculated relative to the total fish passing dam. Effectiveness (RNE/RSE) are calculated relative to the proportion of discharge through the same route. Standard errors (SE) are also provided.

	Overall		Daytime		Nighttime	
Metric	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
DPE	**0.892**	**0.016**	**0.136**	**0.018**	**0.756**	**0.023**
RNE	**0.298**	**0.026**	**0.354**	**0.069**	**0.287**	**0.028**
RSE	**0.703**	**0.026**	**0.646**	**0.069**	**0.713**	**0.028**
RN Effectiveness	0.824	0.071	0.978	0.191	0.796	0.077
RS Effectiveness	1.099	0.040	1.012	0.108	1.115	0.043

DPE = dam passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).
RNE = RO North passage efficiency; proportion of fish passing via the north RO relative to total dam passage.
RSE = RO South passage efficiency; proportion of fish passing via the south RO relative to total dam passage.
RN/RS Effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.

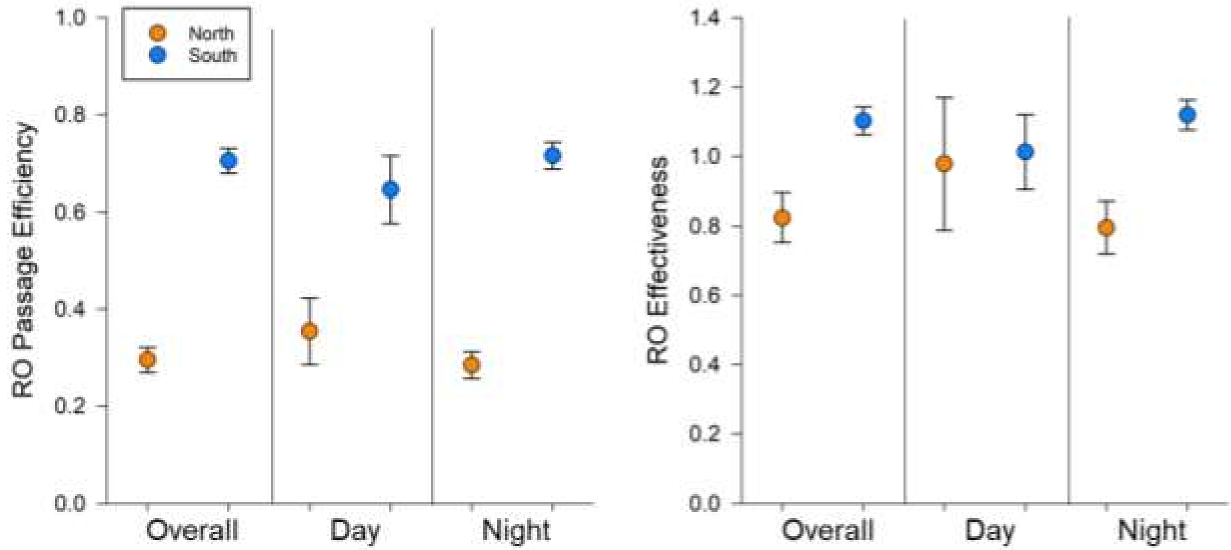

Figure 3-9. Passage efficiencies and effectiveness for subyearling Chinook salmon at Green Peter in fall 2023. RO Passage Efficiency (RNE and RSE) are calculated relative to the total number of fish passing through the dam. RO (RN and RS). Effectiveness are calculated as the proportion of fish passing through the route relative to the proportion of discharge through the same route. Standard error bars are also depicted.

3.4 Foster Dam

Results for the Foster study are first presented for the spring study season, then by species (yearling Chinook salmon results are presented first, Section 3.4.1.2; followed by age-1 winter steelhead, Section 3.4.3). The fall study season is described first by subyearling Chinook salmon (Section 3.4.4.2) and then age-1+ winter steelhead (Section 3.4.6).

Spring fish tagging and releases for yearling Chinook salmon and age-1 winter steelhead occurred from Feb 2 through Apr 30, 2023, for low pool (delayed refill) reservoir elevation and from May 20 through June 3, 2023, for high pool reservoir elevation. Fish were released two weeks prior to the start of the reservoir refill (May 15) and two weeks prior to the end of the high pool treatment period (June 16) during high pool to maximize the likelihood of fish migrating to the dam to be available for dam passage during the treatment operational periods.

Fall fish tagging and releases for subyearling Chinook salmon and age-1+ winter steelhead occurred from Oct 2 through Nov 30, 2023, over four trips. There was only one pool elevation, low pool during the fall study. Fish were released two weeks prior to the end of the treatment operation period (Dec 16) to maximize the likelihood of fish migrating to the dam to be available for dam passage during the treatment period.

3.4.1 Spring – Environmental Conditions

3.4.1.1 Temperature and Forebay Elevation

Data collected on environmental conditions included forebay elevation by seasonal periods and forebay temperature. Temperature data was provided courtesy of the USACE operations office, and the elevation data was gathered from the USGS Water Data for the Nation website.

The Foster forebay elevation also follows a “rule curve” managed by the USACE Water Management Reservoir Regulators. The rule curve dictates lowering the forebay pool elevation in fall to prepare for storage and flood control during winter months. Generally, spring refill begins on or around February 1. Any deviations in the timing of refill were coordinated through the Reservoir Regulators and local stakeholders.

During the low pool season of spring 2023 (February 1 – May 15), the forebay elevation ranged from 611–620 ft. Instead of refilling per the rule curve on February 1, the reservoir was kept at low pool (613 ft) for the spring delayed refill study. Refill began on May 15 (Figure 3-10) and high pool (635 ft) was achieved by May 21 for the high pool study. The reservoir remained at high pool until mid-September, when the fall drawdown reduced the forebay for the fall low pool study.

Forebay temperature data was obtained from a temperature string that recorded hourly temperatures at depths ranging from 0.5-80 ft. (Figure 3-10). From February 1-March 31, the temperature averaged 5.4 °C throughout the water column, ranging from 4.4–7.4 °C. April had an increase in both the average temperature and the range of temperatures observed throughout the water column (Figure 3-10). The average temperature in April was 6.9 °C, with a range of 5.6–12.2 °C. Data collected in May suggested that the water column began to stratify ($\bar{x}$ = 10.2 °C; range: 7.2-17.4 °C). By the beginning of high pool on May 21, the water column was clearly stratified, with a thermocline at approximately 10 ft. (Figure 3-10). Throughout the month of June, the upper water column averaged 17.9 °C and the lower averaged 10.2 °C.

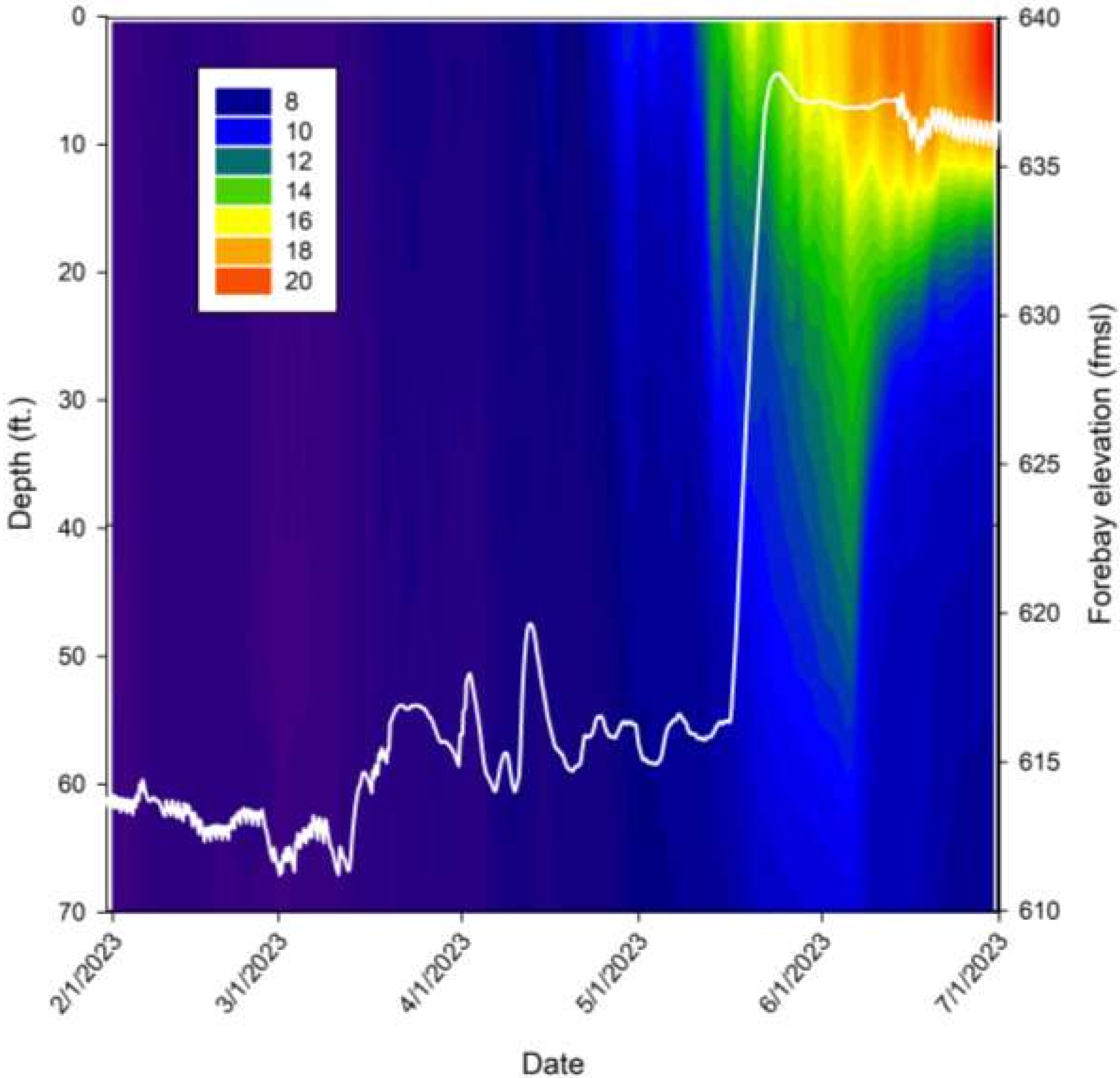

Figure 3-10. Daily average forebay elevation (solid white line; right axis) and temperature (°C) at depth (contour plot; left axis) in the Foster Forebay from February 1 through June 30, 2023.

3.4.1.2 Discharge

During the spring season at Foster, discharge was similar for low and high pool elevations. The mean daily discharge during low pool was 2,129 cfs (daytime: 2,103 cfs; nighttime: 2,165 cfs). The mean daily discharge during high pool was 2,051 cfs (daytime: 2,048 cfs; nighttime: 2,056 cfs), which was only pertinent to the age-1 winter steelhead as no Chinook salmon were released during spring high pool. The mean daily discharge range for the season was 0-1,799 cfs.

3.4.2 Spring – Yearling Chinook Salmon

The following sections describe reservoir, dam passage, and reach survival; reservoir residency and migration travel times; passage route distributions; and efficiency and effectiveness results from the spring 2023 study period for yearling Chinook salmon released at Foster. The sample size is small as fish health was compromised after the first tagging trip; therefore, no additional fish were tagged and released. Although the planned treatments were daytime turbines from 06:00–19:59 and nighttime spill from 20:00–05:59 each day, the operations data did not always match the planned treatment timing. As a result, the survival estimates, reservoir residency, travel time, passage distributions, and efficiency and effectiveness were based on the operations data at the time of passage.

3.4.2.1 Tagging

Tagging and releasing of yearling Chinook salmon occurred from Feb 2–3, 2023, during low pool only. Fish health was compromised after the first tagging trip in February. Thus, no additional yearling Chinook salmon were tagged and released for the remainder of the low pool elevation and no fish were tagged and released during high pool. Approximately equal numbers of yearling Chinook salmon were released at the HOR and MOR for the one trip during low pool (Table 3-7).

Table 3-7. Release location, sample sizes, fork lengths, weights, and standard errors (SE) of yearling Chinook salmon released at Foster in spring 2023. HOR = head-of-reservoir; MOR = mid-of-reservoir; DFR = dead fish release.

Pool Elevation	Release Location	*n*	Length (mm; mean)	SE	Weight (g; mean)	SE
Low	HOR	75	130.41	1.06	21.81	0.46
	MOR	74	132.74	1.04	23.13	0.52
	DFR	26	127.50	2.06	20.84	0.85
Total		175	130.97	0.71	22.22	0.33

3.4.2.2 Survival

Reservoir Survival

The 75 RT-tagged yearling Chinook salmon released at the HOR had an estimated survival probability of 0.2000 (0.0462) from release to Foster. The 74 RT-tagged yearling Chinook salmon released at the MOR had an estimated survival probability of 0.2568 (0.0508) from release to Foster.

Dam Passage and Reach Survival

Twenty-six dead tagged yearling Chinook salmon were released from Foster on 3 and 4, February. None of those fish was detected at the Egress Array. Therefore, the estimated probability of detecting dead fish at the Egress Array was 0.0. However, the live tagged yearling Chinook salmon released on these same dates passed Foster from February 3 through February 26. Therefore, the timing of dead tagged fish releases did not match the timing of Foster passage mortality (Log-Rank test: χ^2 = 24.621, P < 0.001; Wilcoxon group homogeneity test: χ^2 = 19.486, P < 0.001; Figure 3-11). As such, the primary assumption of the ViRDCt model, which states that the dead tagged fish releases are representative of live released fish that died during passage, may have been violated. Because no dead tagged fish were detected at the Egress

Array, the single-release Foster-to-Egress Array survival estimate was used as the Foster dam passage survival estimate for the yearling Chinook salmon released in February 2023. However, this estimate should be viewed with caution due to the potential survival model assumption violation.

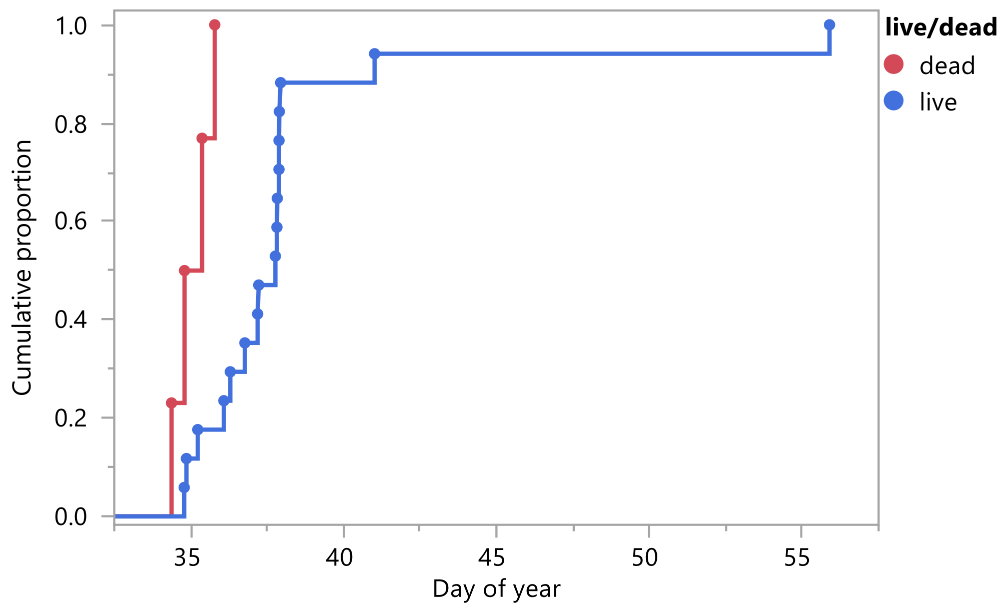

Figure 3-11. Cumulative proportions of live released RT-tagged yearling Chinook salmon mortality (blue) and all dead tagged fish releases (red) at Foster during February 2023.

The 34 yearling Chinook salmon that were that were detected passing Foster after release in early February 2023 all passed through the spillway during night spill operations. These fish had an estimated survival probability of 0.8000 (0.0812) to the Egress Array, 0.5294 (0.0943) to the Primary Array, and 0.3123 (0.0990) to the Santiam Rest Stop Array (Table 3-8). No adjustments for tag life were necessary because the tags had an estimated failure probability of 0.00 at each downstream array (Table 3-8). Survival estimates did not differ from those obtained from past studies conducted at Foster when survival was estimated to be 0.8665 (0.0188) to the Egress Array (2018 and 2022), 0.6250 (0.0145) to the Primary Array (2015, 2016, 2018, and 2022 pooled), and 0.4220 (0.0379) to the Santiam Rest Stop Array. The small number of yearling Chinook salmon that passed Foster during low pool in 2023 resulted in relatively low power to detect differences from past years.

Undetected fish had unknown fates. It is possible they died, were predated, remained in the river for the duration of their tag life, moved into a different tributary, or had another fate as the reach survival encompasses approximately 77 rkm downstream of Foster.

Table 3-8. Tag life, detection, and survival probability estimates for RT-tagged yearling Chinook salmon that passed Foster (FOS) during February 2023. Standard error estimates ($\widehat{SE}$) are shown in parentheses. EGR = Egress Array, PRM = Waterloo Primary Array, LEB = Lebanon Dam Array, SRS = I-5 Santiam Rest Stop Array, COI = Cole Island Array. nan = insufficient detections for estimation. NA = not estimable due to zero sample size.

Reach	Tag life prob. ($\widehat{SE}$)	Det. Prob. ($\widehat{SE}$)	Survival ($\widehat{SE}$)
All Routes and Operations (N = 34)			
FOS – EGR[1]	1.0000 (0.0000)	0.8824 (0.0781)	0.8000 (0.0812)
FOS – PRM	1.0000 (0.0000)	0.6667 (0.1217)	0.5294 (0.0943)
FOS – LEB	1.0000 (0.0000)	1.0000 (0.0000)	0.4412 (0.0852)
FOS – SRS[2]	1.0000 (nan)	0.6593 (0.1916)	0.3123 (0.0990)
FOS – COI	1.0000 (nan)	0.2825 (0.1482)	0.3123 (0.0990)
Spillway (N = 34)			
FOS – EGR[1]	1.0000 (0.0000)	0.8824 (0.0781)	0.8000 (0.0812)
FOS – PRM	1.0000 (0.0000)	0.6667 (0.1217)	0.5294 (0.0943)
FOS – LEB	1.0000 (0.0000)	1.0000 (0.0000)	0.4412 (0.0852)
FOS – SRS[2]	1.0000 (nan)	0.6593 (0.1916)	0.3123 (0.0990)
FOS – COI	1.0000 (nan)	0.2825 (0.1482)	0.3123 (0.0990)
Turbine (N = 0)			
FOS – EGR[1]	NA	NA	NA
FOS – PRM	NA	NA	NA
FOS – LEB	NA	NA	NA
FOS – SRS[2]	NA	NA	NA
FOS – COI	NA	NA	NA
Nighttime Spill (N = 34)			
FOS – EGR[1]	1.0000 (0.0000)	0.8824 (0.0781)	0.8000 (0.0812)
FOS – PRM	1.0000 (0.0000)	0.6667 (0.1217)	0.5294 (0.0943)
FOS – LEB	1.0000 (0.0000)	1.0000 (0.0000)	0.4412 (0.0852)
FOS – SRS[2]	1.0000 (nan)	0.6593 (0.1916)	0.3123 (0.0990)
FOS – COI	1.0000 (nan)	0.2825 (0.1482)	0.3123 (0.0990)
Daytime Turbines (N = 0)			
FOS – EGR[1]	NA	NA	NA
FOS – PRM	NA	NA	NA
FOS – LEB	NA	NA	NA
FOS – SRS[2]	NA	NA	NA
FOS – COI	NA	NA	NA

[1]Dam passage survival
[2]Reach survival

3.4.2.3 Reservoir Residency and Migration Travel Times

Tagged fish released during low pool had a median reservoir residence time of 40 h when they passed Foster at night (Figure 3-12). No fish passed Foster during the day (Table 3-9). The fish released at the head of the reservoir (HOR) had a median reservoir residence time of 36 h, and the fish released in the middle of the reservoir (MOR) had a reservoir residence time of 43 h. Of the thirty-four fish that passed Foster, twenty-four were detected at the Egress array after a median time of 7.4 h (Table 3-9). Seven fish traveled downstream from Foster and were detected at the Santiam Rest Stop Array with a median travel time of 52.8 h (Table 3-9). Only four fish were detected at the farthest downstream site, Willamette Falls. Median travel time for these fish from Foster to Willamette Falls was 317.4 h (Table 3-9).

Reservoir residence times were similar for tagged yearling Chinook salmon released during spring low pool in 2022 and 2023 (Mann-Whitney-Wilcoxon test: W = 2609; *P* = 0.346). Travel times were also found to be similar between the Egress Array and the Primary Array (Mann-Whitney-Wilcoxon test: W = 439; *P* = 0.118) and between the Primary Array and the Santiam Rest Stop Array (W = 131; *P* = 0.163). There was a difference between years in the travel time from Foster to Egress Array (Mann-Whitney-Wilcoxon test: W = 1212; *P* = 0.022). The travel time from Foster to Willamette Falls was significantly longer in 2023 than 2022 (Mann-Whitney-Wilcoxon test: W = 11; *P* = 0.005), but the travel time from Foster to Santiam Rest Stop was found to be similar (W = 143; *P* = 0.085).

Table 3-9. Travel time summary for yearling Chinook salmon from Foster Dam to the downstream arrays during spring low pool in 2023. nan = could not be calculated due to no fish passing the dam during that diel period.

		Daytime Turbines			Nighttime Spill		
Pool Elevation	**Reach**	**Median hours (SE)**	**Mean hours (SE)**	***n***	**Median hours (SE)**	**Mean hours (SE)**	***n***
Low	FOS – EGR	nan	nan	0	7.4 (1.6)	8.7 (1.3)	24
	FOS – PRM	nan	nan	0	24.6 (58.3)	70.7 (46.5)	11
	FOS – LEB	nan	nan	0	28.3 (43.6)	64.6 (34.8)	15
	FOS – SRS	nan	nan	0	52.8 (265.7)	338.4 (212.0)	7
	FOS – COI	nan	nan	0	98.9 (210.7)	241.1 (168.1)	3
	FOS – WIL	nan	nan	0	317.4 (116.9)	347.3 (93.2)	4

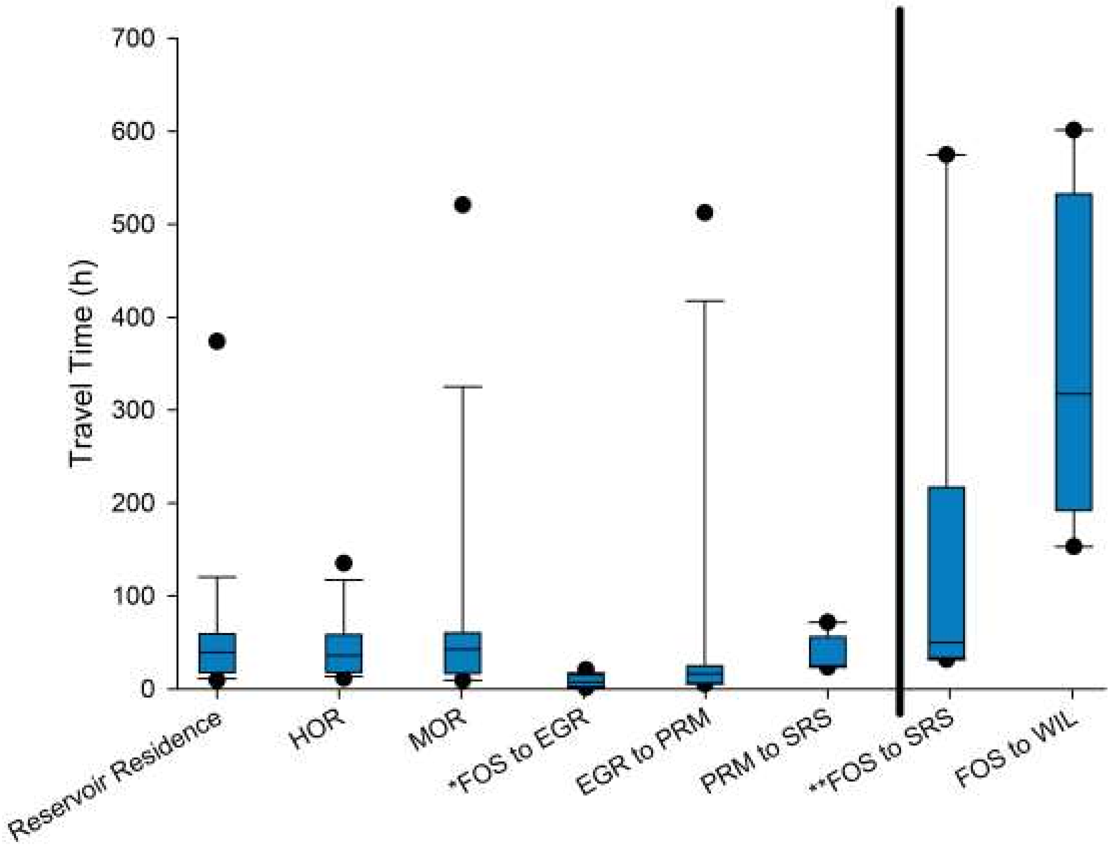

Figure 3-12. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir, MOR = mid-of-reservoir), and travel times between reaches for yearling Chinook salmon released at Foster in spring 2023 (FOS; EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). All yearling Chinook salmon passed Foster at night. Lines within the boxes represent medians, box boundaries indicate the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. The * indicates ViRDCt survival array and the ** indicates the reach survival array. The solid vertical line is a delineator to show the travel time from Foster through all the reaches and directly to the reach survival array and to the furthest downstream array at Willamette Falls. Two outliers from one fish are not depicted to manage the scale of the y-axis: 1517 h for PRM to SRS and 1530 h for FOS to SRS.

3.4.2.4 Passage Distributions

Out of the 149 live yearling Chinook salmon released in the spring during low pool, 69 were detected post-release and included in the analyses conducted to summarize movements of detected fish (Table 3-10; Table 3-11). This resulted in 80 fish with unknown outcomes (e.g., predation, upstream movement, mortality, etc.). Six fish were not detected by any receivers at Foster but appeared on other RT arrays downstream, suggesting no route predation (i.e., never detected at Foster after release; Table 3-10).

Among the detected fish, nearly half (49.3%) were detected passing Foster (Table 3-10). Approximately 40.6% (n = 28) of the yearling Chinook salmon detected in the near forebay and available to pass did not pass the dam (Table 3-10). Of the 34 fish that passed Foster, all 34 passed through a spillway, specifically, Spill Bay 4, during the nighttime spill operation (Table 3-11; Figure 3-13). No Chinook salmon passed through the turbines during low pool in the spring (Table 3-11). For those Chinook salmon that passed Foster, they appeared to move out of the reservoir quickly (Figure 3-14).

Some detected yearling Chinook salmon were presumably predated (i.e., detected after release and before predation, thus having usable data up until the point of predation). Of the 63 fish detected in the extended forebay, near forebay, or passed downstream, about 19% (*n* = 12) were predated either in the forebay of Foster or farther downstream (Table 3-10). This proportion of fish predated could be driven by the large number of fish (*n* = 28) detected at the near forebay (i.e., dam face) but never passed (Table 3-10). Cormorants are often observed at the dam face and frequently contribute to predation. This number likely underestimates the total predation, as the fate of undetected fish may have also been predation.

Table 3-10. Movement summary (proportions [prop.] and sample sizes) of yearling Chinook salmon released in Foster Reservoir for one release during low pool.

Pool Elevation	Detected After Release (*n*)	No Route Predation		Final Detection at Sunnyside – Never Passed		Extended Forebay Detection – Never Passed		Near Forebay Detection – Never Passed		Downstream Passage		Presumed Predation after any Forebay or Downstream Detection[1]	
		Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Sub Prop.	*n*
Low	69	0.087	6	0	0	0.014	1	0.406	28	0.493	34	0.190	12

[1] Predation as summarized is presumed, based on assumptions outlined in the methods.
Note: This table is based on the pool elevation during which fish were released. Fish that did not have an assigned route of passage (i.e., Route = Dam; Table 3-11) were excluded.

Table 3-11. Passage proportions by route of passage for RT-tagged yearling Chinook salmon detected passing Foster Dam by pool elevation. A "Dam" route indicates a specific route (turbines or spillway; unit 1 or 2; or spill bay 1–4) could not be determined.

Pool Elevation	Route	Overall		Daytime Turbines		Nighttime Spill	
		Proportion	*n*	Proportion	*n*	Proportion	*n*
Low	**Turbines**	**0.000**	**0**	**0.000**	**0**	**0.000**	**0**
	Unit 1	0.000	0	0.000	0	0.000	0
	Unit 2	0.000	0	0.000	0	0.000	0
	Spillway	**1.000**	**34**	**0.000**	**0**	**1.000**	**34**
	Spill Bay 1	0.000	0	0.000	0	0.000	0
	Spill Bay 2	0.000	0	0.000	0	0.000	0
	Spill Bay 3	0.000	0	0.000	0	0.000	0
	Spill Bay 4	1.000	34	0.000	0	1.000	34
	Dam	**0.000**	**0**	**0.000**	**0**	**0.000**	**0**
	No Route	0.000	0	0.000	0	0.000	0
	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	0.000	0	0.000	0	0.000	0
	Overall		**34**	**0.000**	**0**	**1.000**	**34**

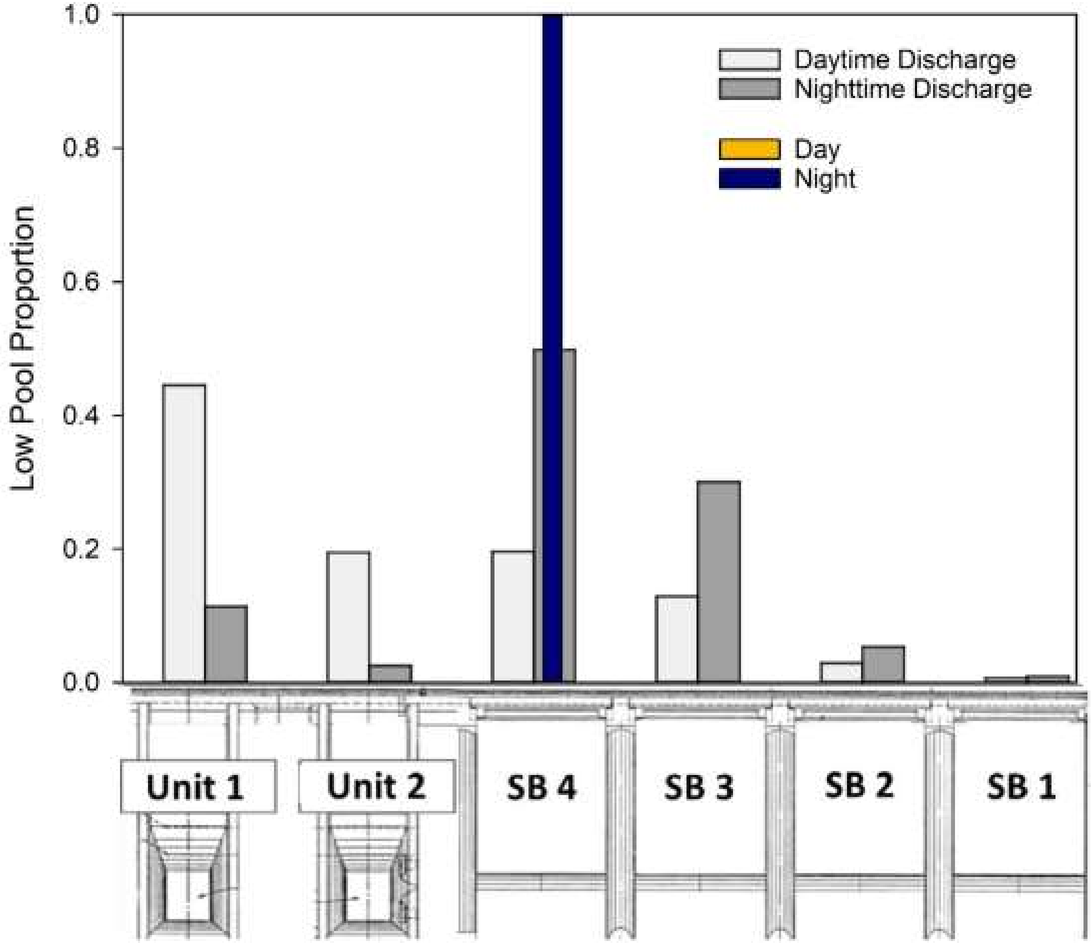

Figure 3-13. Diel passage proportions for yearling Chinook salmon passed during spring low pool at Foster compared to the amount of discharge through the same route (SB = Spill Bay). The view of passage routes is looking downstream from the reservoir. All yearling Chinook salmon passed at night.

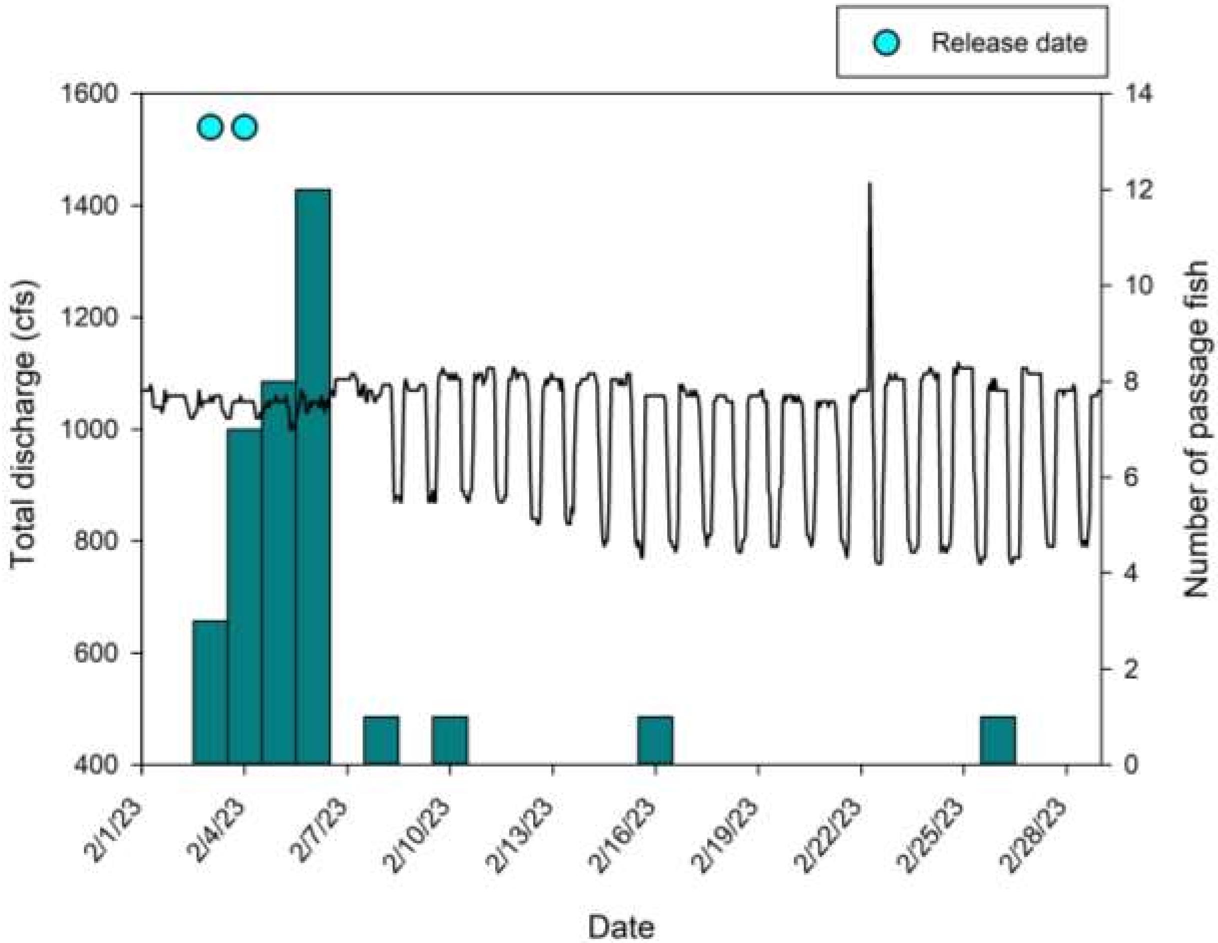

Figure 3-14. Total discharge (solid black line; left y-axis) as compared to number of passed yearling Chinook salmon (bar plot; right y-axis) at Foster. Circle symbols indicate the dates of fish releases. Fish were detected passing Foster during spring low pool from February 3 to February 26.

3.4.2.5 Efficiency and Effectiveness

Yearling Chinook salmon had an overall DPE of 54.8%. Nighttime spill passage DPE was also 54.8% as no fish passed Foster during the day (Figure 3-15). It should be noted that the sample size was low as only 34 fish passed the dam. Fish passage efficiency was equal to DPE because all fish passed via the spillway (specifically Spill Bay 4; Figure 3-13). Additionally, nighttime spill SPE was equal to 1.0 as it was the only route of passage used during the spring low pool. Finally, overall effectiveness was high, as it was greater than 1.16 for nighttime spill and overall (Table 3-12; Figure 3-15). No yearling Chinook salmon passed the dam during high pool.

Table 3-12. Passage efficiencies and effectiveness for yearling Chinook salmon at Foster in spring 2022 and 2023. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while the Spillway Passage Efficiency (SPE) is relative to the total number of fish that passed the dam (as indicated by "|| Dam"). Effectiveness is based on the SPE and the total dam discharge through those routes. Standard errors are in parentheses and nan = unable to calculate due to no daytime fish passage.

Metric	Low Pool Overall	Low Pool Daytime Turbines	Low Pool Nighttime Spill
DPE	**0.548 (0.063)**	**0.000 (0.000)**	**0.548 (0.063)**
FPE	**0.548 (0.063)**	**0.000 (0.000)**	**0.548 (0.063)**
SPE || Dam	1.000 (0.000)	nan	1.000 (0.000)
Spillway Effect.	1.746 (0.000)	nan	1.161 (0.000)

DPE = dam passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).
FPE = fish passage efficiency; proportion of fish passing via a non-turbine route relative to the number detected in the near forebay (< 100 m from dam-face).
SPE = spillway passage efficiency; proportion of fish that passed Foster through Spill Bays 1–4.
Spillway Effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.

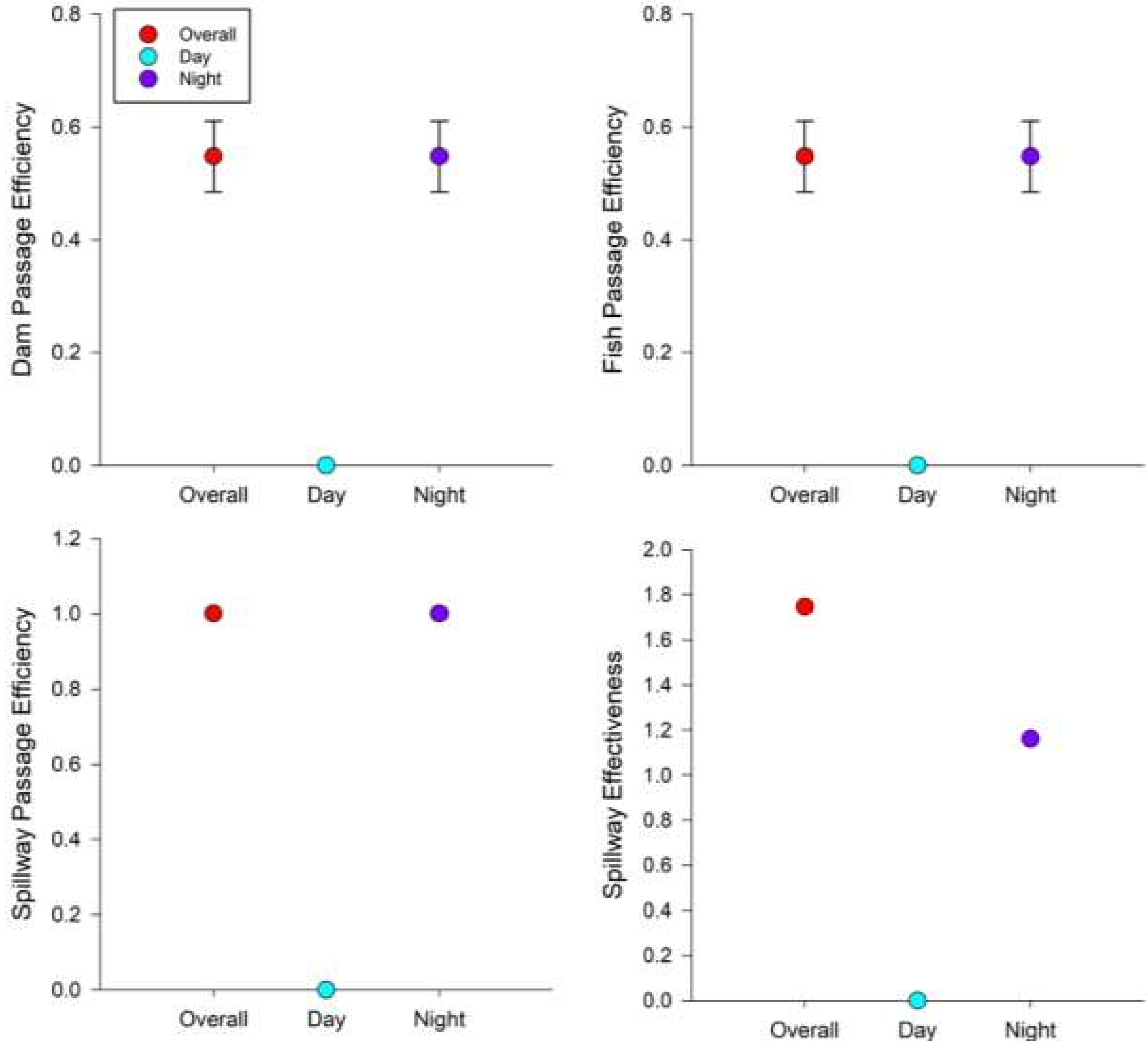

Figure 3-15. Dam passage efficiency, fish passage efficiency, spillway passage efficiency, and effectiveness of yearling Chinook salmon released at Foster in spring of 2023. Error bars represent standard errors (SE) of the mean. A lack of error bars indicates the SE was 0.000.

3.4.3 Spring – Age-1 Winter Steelhead

The following sections describe reservoir, dam passage, and reach survival; reservoir residency and migration travel times; passage route distributions; and efficiency and effectiveness results from the spring 2023 study period for age-1 winter steelhead released at Foster. Although the planned treatments were daytime turbines from 06:00–19:59 and nighttime spill from 20:00–05:59 each day, the operations data did not always match the planned treatment timing. As a result, the survival estimates, reservoir residency, travel time, passage distributions, and efficiency and effectiveness were based on the operations data at the time of passage. There was also a lack of apparent downstream movement of age-1 steelhead. This resulted in small sample sizes compared to the number of fish released; thus, caution should be taken when interpreting the below survival and passage metrics.

3.4.3.1 Tagging

Fish tagging and releases for winter steelhead occurred from April 18 through April 30, 2023, for low pool and from May 20 through June 3, 2023, for high pool. Steelhead during low pool were too small to tag (< 95 mm FL) in February and March; thus, all steelhead were tagged and released in April. Approximately equal numbers of age-1 winter steelhead were released at the HOR and MOR during each reservoir elevation (Table 3-13).

Table 3-13. Release location, sample sizes, fork lengths, weights, and standard errors (SE) of age-1 winter steelhead released at Foster in spring 2023. HOR = head-of-reservoir; MOR = mid-of-reservoir; DFR = dead fish release.

Pool Elevation	Release Location	*n*	Length (mm; mean)	SE	Weight (g; mean)	SE
Low	HOR	335	124.45	0.44	17.15	0.19
	MOR	336	125.63	0.48	17.20	0.19
	DFR	78	121.26	0.89	16.27	0.34
	Total	749	124.65	0.31	17.08	0.13
High	HOR	419	118.51	0.31	15.27	0.13
	MOR	413	119.63	0.38	15.71	0.16
	DFR	88	120.39	0.92	15.48	0.38
	Total	920	119.19	0.24	15.49	0.10
Grand Total		1,669	121.64	0.20	16.20	0.08

3.4.3.2 Survival

Reservoir Survival

A total of 23 age-1 winter steelhead were detected passing Foster during spring low pool. The age-1 winter steelhead released at the HOR during had an estimated survival probability of 0.0269 (0.0088) from release to Foster. The age-1 winter steelhead released at the MOR had an estimated survival probability of 0.0565 (0.0126) from release to Foster. As noted previously, the survival model assumes active migration. If tagged steelhead did not actively emigrate from the reservoir within the life of the tags, these estimates represent the joint probability of migration and survival.

Only 3 of the 832 live RT-tagged age-1 winter released during high pool were detected passing Foster and none of those fish were detected downstream of Foster, providing insufficient detections for reservoir survival estimation.

Dam Passage and Reach Survival

Dead tagged fish were released on each day live tagged age-1 steelhead were released during spring low pool between 18 and 30 April 2023. Censoring the first 28 dead tagged fish released in April resulted in a temporal release distribution that did not differ statistically from the timing of live released steelhead passage mortality (Log-Rank test: χ^2 = 1.354, P = 0.245; Wilcoxon group homogeneity test: χ^2 = 1.173, P = 0.279) (Figure 3-16). Of the remaining 50 dead tagged fish, four (8%) were detected at the Egress Array.

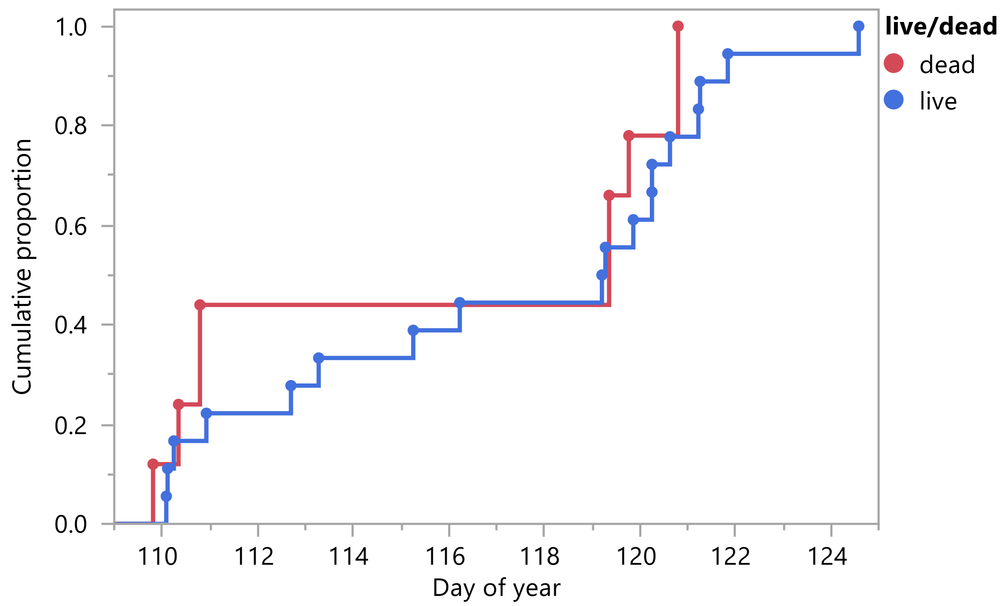

Figure 3-16. Cumulative proportions of live released RT-tagged age-1 winter steelhead mortality (blue) and dead tagged fish releases (red) at Foster during April 2023, after censoring the first 28 dead tagged fish released.

The 23 RT-tagged age-1 winter steelhead that were detected passing Foster during spring low pool had an estimated dam passage survival probability of 0.2439 (0.1059) to the Egress Array (Table 3-14). The 20 fish that passed Foster through the spillway had an estimated dam passage survival probability of 0.2391 (0.1158) (Table 3-14). The 19 fish that passed during nighttime spill operations had an estimated dam passage survival probability of 0.2563 (0.1169) (Table 3-14). Only three age-1 steelhead passed Foster through the turbines and only four passed during daytime turbine operations at low pool, providing insufficient numbers of fish and detections for survival estimation.

Reach survival, from Foster passage to the Santiam Rest Stop Array, could not be estimated due to insufficient detections. These undetected fish had unknown fates. It is possible they died, were predated, remained in the river for the duration of their tag life, moved into a different tributary, or had another fate as the reach survival encompasses approximately 77 rkm downstream of Foster.

Table 3-14. Tag life, detection, and survival probability estimates for RT-tagged age-1 winter steelhead that passed Foster (FOS) during spring low pool, 2023. Standard error estimates ($\widehat{SE}$) are shown in parentheses. EGR = Egress Array, PRM = Waterloo Primary Array, LEB = Lebanon Dam Array, SRS = I-5 Santiam Rest Stop Array, COI = Cole Island Array. nan = insufficient detections for estimation.

Reach	Tag life prob. ($\widehat{SE}$)	Det. Prob. ($\widehat{SE}$)	Survival ($\widehat{SE}$)
	All Routes and Operations (N = 23)		
FOS – EGR[1]	1.0000 (nan)	1.0000 (0.0000)	0.2439 (0.1059)
FOS – PRM	1.0000 (nan)	nan	nan
FOS – LEB	nan	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan
	Spillway (N = 20)		
FOS – EGR[1]	1.0000 (nan)	1.0000 (0.0000)	0.2391 (0.1158)
FOS – PRM	1.0000 (nan)	0.5000 (0.3536)	0.1000 (0.0671)
FOS – LEB	1.0000 (nan)	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan
	Turbine (N = 3)		
FOS – EGR[1]	nan	nan	nan
FOS – PRM	nan	nan	nan
FOS – LEB	nan	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan
	Nighttime Spill (N = 19)		
FOS – EGR[1]	1.0000 (nan)	1.0000 (0.0000)	0.2563 (0.1169)
FOS – PRM	1.0000 (nan)	0.5000 (0.3536)	0.1053 (0.0704)
FOS – LEB	1.0000 (nan)	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan
	Daytime Turbines (N = 4)		
FOS – EGR[1]	nan	nan	nan
FOS – PRM	nan	nan	nan
FOS – LEB	nan	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan

[1]Dam passage survival
[2]Reach survival

3.4.3.3 Reservoir Residency and Migration Travel Times

Steelhead released during spring 2023 in the HOR had a median reservoir residency time of 66.8 h when last detected passing Foster during the day compared to 20.2 h for those detected passing Foster at night (Figure 3-17). When released in the MOR, the median reservoir residency time increased to 237.6 h and 86.8h for daytime and nighttime, respectively (Figure 3-17). Due to the small number of steelhead detected passing Foster during spring, reservoir residence did not differ significantly by diel passage period for either HOR (Mann-Whitney-Wilcoxon test: W = 9; *P* = 0.191) or MOR fish (W = 44; *P* = 0.289; Figure 3-17).

Of the 27 steelhead that passed Foster (including fish that passed during mid or summer pool but were released during low pool), only seven were detected at the Egress Array (Table 3-15). Median travel time of steelhead from Foster to the Egress Array was 0.6 h for fish that passed Foster during the daytime turbine operation and 13.6 h for those that passed during the nighttime spill operation (Table 3-15). Due to the very small sample sizes, the difference was not statistically significant (Mann-Whitney-Wilcoxon test: W = 0; *P* = 0.286; Figure 3-17). Only one steelhead was detected at the Primary Array (Table 3-15; Figure 3-17). The furthest downstream detection of any spring-released steelhead was at Lebanon Dam (*n* = 2, both nighttime passage), and median travel time of those two fish from Foster was 370.0 h (Table 3-15). Table 3-15 outlines the travel time summary for steelhead that passed during spring low pool from Foster to each downstream array, and Figure 3-17 illustrates the travel times by diel period. Of the high pool releases, only three steelhead passed during high pool, and none were detected past the Foster Tailrace Array.

There were also steelhead released in spring low pool in 2022. However, these were age-2 winter steelhead as opposed to the age-1 winter steelhead released in spring low pool 2023; thus, they were different life stages and were not compared.

Table 3-15. Travel time summary for age-1 winter steelhead from Foster Dam to the downstream arrays during spring low pool in 2023. nan = could not be calculated due to the number of fish that passed during that diel period.

Pool Elevation	Reach	Daytime Turbines			Nighttime Spill		
		Median hours (SE)	Mean hours (SE)	*n*	Median hours (SE)	Mean hours (SE)	*n*
Low	FOS – EGR	0.6 (nan)	0.6 (nan)	1	13.6 (14.6)	24.9 (11.7)	6
	FOS – PRM	nan	nan	0	216.6 (nan)	216.6 (nan)	1
	FOS – LEB	nan	nan	0	370.0 (165.0)	370.0 (131.7)	2
	FOS – SRS	nan	nan	0	nan	nan	0
	FOS – COI	nan	nan	0	nan	nan	0
	FOS – WIL	nan	nan	0	nan	nan	0

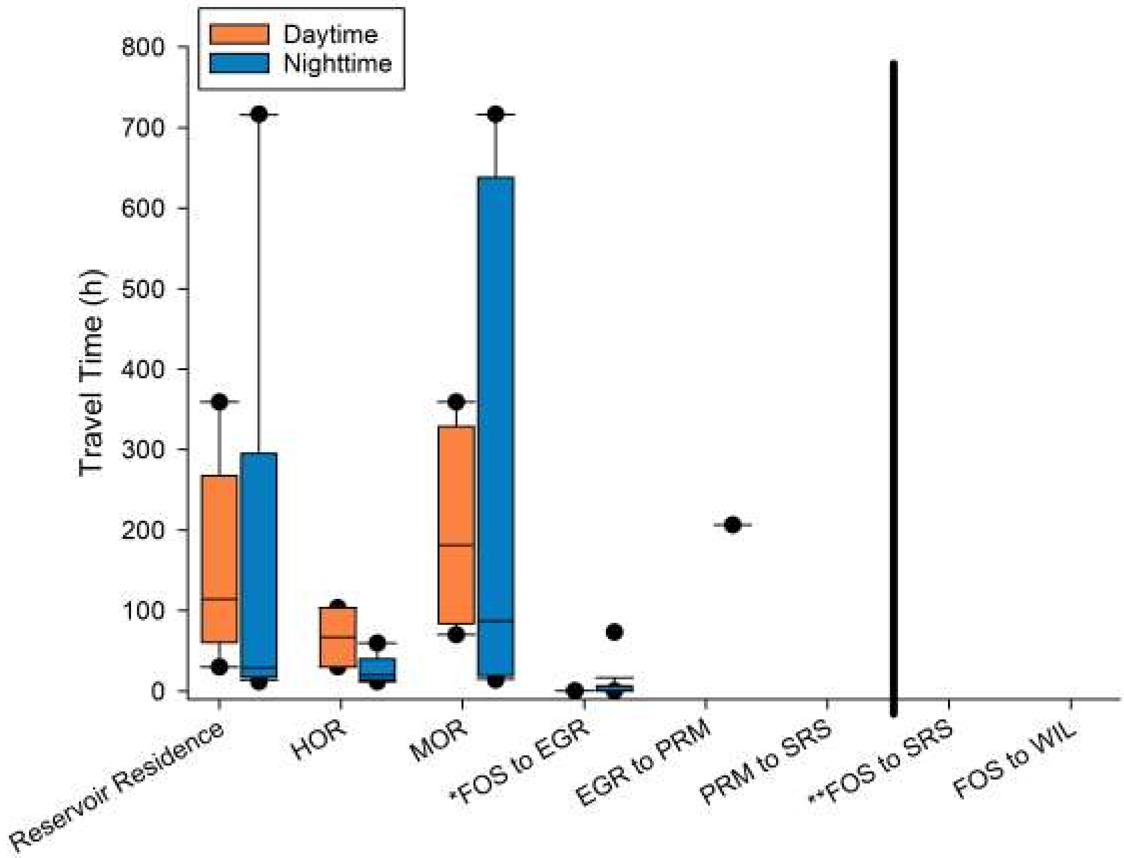

Figure 3-17. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir, MOR = mid-of-reservoir), and travel times between reaches for age-1 winter steelhead released at Foster during spring 2023 (FOS; EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). Daytime classification indicates fish with last detections at Foster Dam during the daytime turbines operation, while nighttime fish had last detections occurring at night during nighttime spill operations (indicating time of passage). Lines within the boxes represent medians, box boundaries indicate the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. The * indicates ViRDCt survival array and the ** indicates the reach survival array. The solid vertical line is a delineator to show the travel time from Foster through all the reaches and directly to the reach survival array and to the furthest downstream array at Willamette Falls. This figure does not include three age-1 winter steelhead that were both released and passed during high pool. One outlier is not depicted to manage the scale of the y-axis: 1153 h from a MOR daytime fish.

3.4.3.4 Passage Distributions

During low pool, 215 steelhead were detected after release and included in the analysis conducted to summarize movements of detected fish (Table 3-16). Most of these fish (62.3%) were detected in the near forebay and available to pass Foster, but never did (Table 3-16). Only

12.6% of steelhead released during low pool were detected passing Foster (Table 3-16). A small proportion were identified as no route predation (7.0%; i.e., never detected at Foster but detected on other RT arrays downstream) or were detected only in the extended forebay but did not approach the dam (16.7%; Table 3-16). Approximately 2.0% of fish had a final detection at the Sunnyside Array and never passed, indicating upstream movement (Table 3-16). Most (82.6%) of the RT-tagged steelhead that passed Foster during low pool did so during nighttime spill operations with 78.9% of those fish passing via the spillway (Table 3-17; Figure 3-18).

A similar pattern of low downstream passage proportions was observed at Foster during high pool conditions. Of the 205 steelhead detected and analyzed for movements; most (43.9%) were detected in the near forebay but did not pass (Table 3-16). Only three of the steelhead released during high pool were detected passing Foster (1.5%; Table 3-16). However, a higher proportion of fish were presumed to be no route predation (21.0%; i.e., never detected at Foster but detected on other RT arrays downstream) or were detected only in the extended forebay but did not approach the dam (30.7%; Table 3-16). All three of the steelhead that passed Foster during high pool did so during the daytime turbine operations with two passing via the spillway and one through the turbines (Table 3-17). For those age-1 steelhead that passed Foster, the proportions were too low to identify clear trends with passage and discharge (Figure 3-19).

Predation of steelhead was presumed to occur during both pool elevations, as 8.8% of fish detected in the extended forebay, near forebay, or passed downstream, were presumed to have been predated at Foster or further downstream (Table 3-16). With the fate of undetected fish being unknown, we are unable to get an exact estimate of predation but are able to provide a minimum estimation.

Table 3-16. Movement summary (proportions [prop.] and sample sizes) of age-1 winter steelhead released at Foster by pool elevation.

Pool Elevation	Detected after Release (*n*)	No Route Predation		Final Detection at Sunnyside – Never Passed		Extended Forebay Detection – Never Passed		Near Forebay Detection – Never Passed		Downstream Passage		Presumed Predation after any Forebay or Downstream Detection[1]	
		Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Sub Prop.	*n*
Low	215	0.070	15	0.014	3	0.167	36	0.623	134	0.126	27	0.125	25
High	205	0.210	43	0.029	6	0.307	63	0.439	90	0.015	3	0.043	7
Overall	420	0.138	58	0.021	9	0.236	99	0.533	224	0.071	30	0.088	32

[1] Predation as summarized is presumed, based on assumptions outlined in the methods.
Note: This table is based on the pool elevation during which fish were released. It includes fish that were released during low pool and passed during mid pool (during reservoir refill) or summer pool (after the operational treatment ended), which were not included in the survival analyses. Fish that did not have an assigned route of passage (i.e., Dam = No Route, Turbines, or Spillway; Table 3-17) were also included.

Table 3-17. Passage proportions by route of passage for RT-tagged age-1 winter steelhead released at Foster Dam by pool elevation. A "Dam" route indicates a specific route (turbines or spillway; unit 1 or 2; or spill bay 1–4) could not be determined.

		Overall		Daytime Turbines		Nighttime Spill	
Pool Elevation	**Route**	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***
Low	**Turbines**	**0.130**	**3**	**0.333**	**1**	**0.667**	**2**
	Unit 1	0.667	2	1.000	1	0.500	1
	Unit 2	0.333	1	0.000	0	0.500	1
	Spillway	**0.783**	**18**	**0.167**	**3**	**0.833**	**15**
	Spill Bay 1	0.000	0	0.000	0	0.000	0
	Spill Bay 2	0.167	3	0.333	1	0.133	2
	Spill Bay 3	0.389	7	0.000	0	0.467	7
	Spill Bay 4	0.444	8	0.667	2	0.400	6
	Dam	**0.087**	**2**	**0.000**	**0**	**1.000**	**2**
	No Route	0.000	0	0.000	0	0.000	0
	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	1.000	2	0.000	0	1.000	2
	Overall		**23**	0.174	**4**	0.826	**19**
High	**Turbines**	**0.333**	**1**	**1.000**	**1**	**0.000**	**0**
	Unit 1	1.000	1	1.000	1	0.000	0
	Unit 2	0.000	0	0.000	0	0.000	0
	Spillway	**0.667**	**2**	**1.000**	**2**	**1.000**	**0**
	Spill Bay 1	0.000	0	0.000	0	0.000	0
	Spill Bay 2	0.000	0	0.000	0	0.000	0
	Spill Bay 3	0.000	0	0.000	0	0.000	0
	Spill Bay 4	1.000	2	1.000	2	1.000	0
	Dam	**0.000**	**0**	**0.000**	**0**	**0.000**	**0**
	No Route	0.000	0	0.000	0	0.000	0
	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	0.000	0	0.000	0	0.000	0
	Overall		**3**	**1.000**	**3**	**0.000**	**0**

Note: Fish that passed during mid pool (May 15, 2023, at 6:00 am through May 21, 2023, at 5:59 am) or summer pool (June 16, 2022, at 6:00 am through the end of the study on Aug. 21, 2023, at 4:25 pm), were excluded from the analyses as there were no operational treatments during these periods.

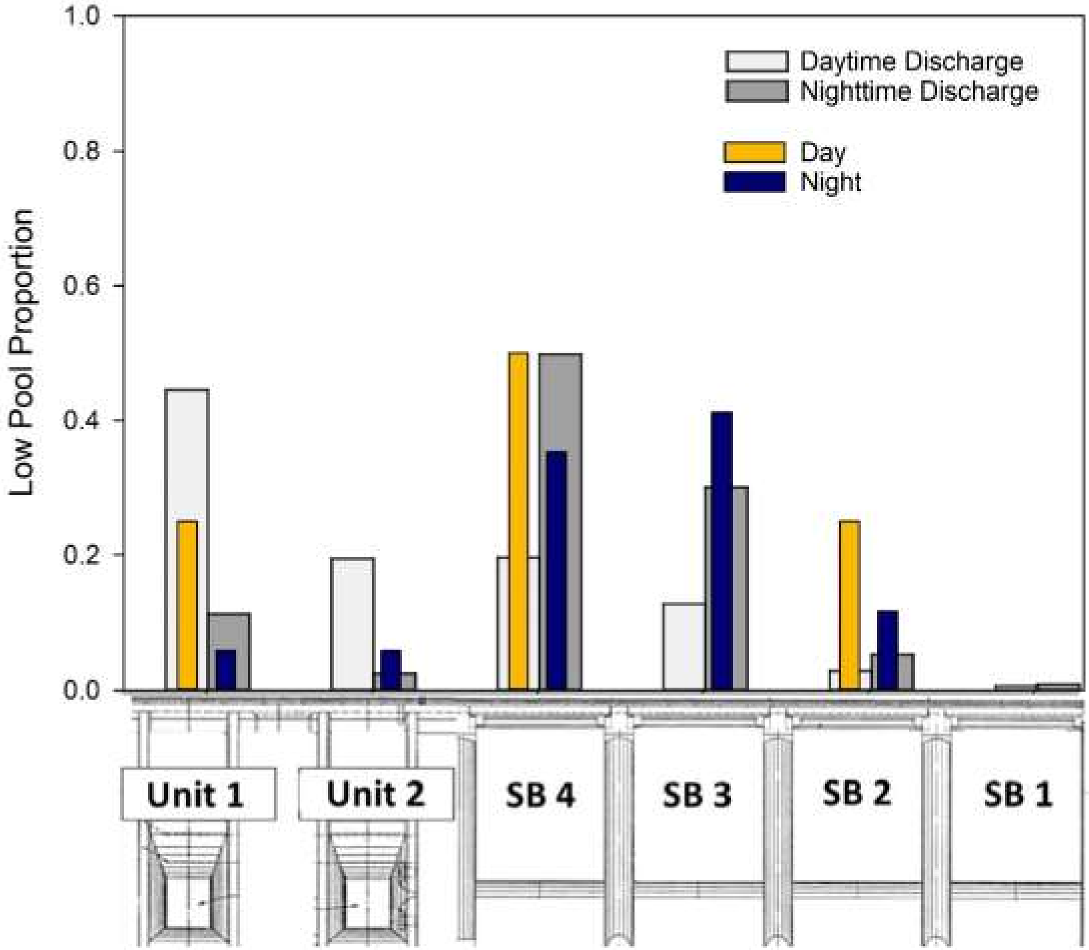

Figure 3-18. Diel passage proportions for age-1 winter steelhead passed during spring low pool at Foster compared to the amount of discharge through the same route (SB = Spill Bay). The view of passage routes is looking downstream from the reservoir.

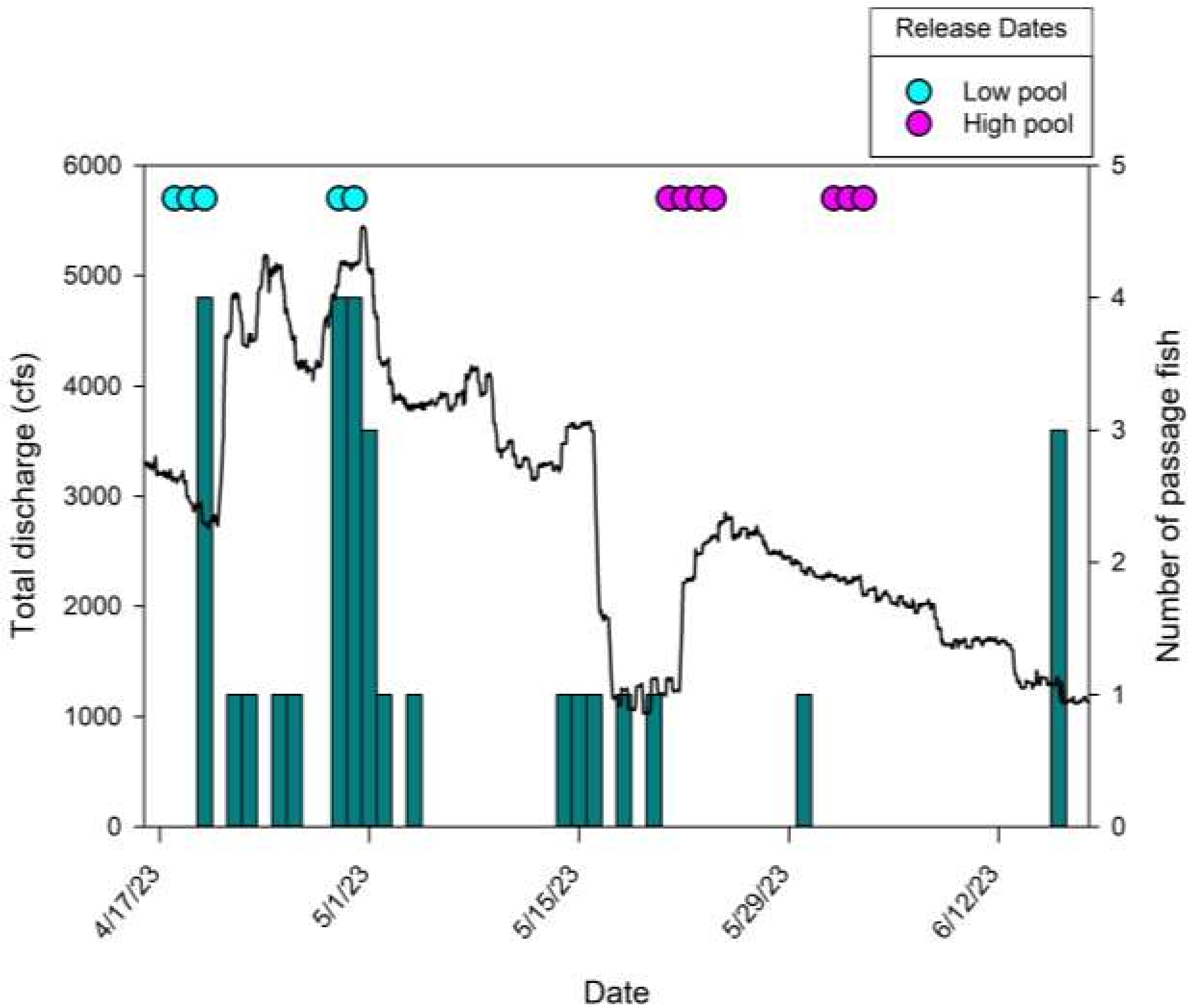

Figure 3-19. Total discharge (solid black line; left y-axis) as compared to number of passed age-1 winter steelhead (bar plot; right y-axis) at Foster. Circle symbols indicate the dates of fish releases. Fish were detected passing Foster throughout spring from April 20 to June 16.

3.4.3.5 Efficiency and Effectiveness

Age-1 winter steelhead had poor overall DPE during low (15.4%) and high (2.4%) pool, as well as during daytime turbines and nighttime spill operations (range: 0.00-12.5%; Table 3-18; Figure 3-20). It should be noted that both pool stages had low sample sizes, with 21 steelhead passing during low pool and only 3 during high pool. The FPE was also poor and lower than DPE as 3 fish passed via the turbines during low pool and 1 during high pool (Table 3-18).

Despite DPE and FPE being low, the overall SPE was relatively high (85.7%) during low pool and was higher during the nighttime spill than the daytime turbines but not significantly (75.0% and 88.2% respectively; z-test; $Z = -0.310$, $P = 0.757$; Table 3-18; Figure 3-20). For the steelhead that passed Foster during low pool, the overall spillway effectiveness was high (1.5) but was lower during the nighttime spill (1.02) than the daytime turbines (2.08), indicating the spillway was a relatively effective route compared to the turbines (Table 3-18; Figure 3-20).

Table 3-18. Passage efficiencies and effectiveness for age-1 winter steelhead at Foster in spring low pool 2023. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while the Spillway Passage Efficiency (SPE) is relative to the total number of fish that passed the dam (as indicated by "|| Dam"). Effectiveness is based on the SPE and the total dam discharge through those routes. Standard errors are in parentheses.

Metric	Overall	Daytime Turbines	Nighttime Spill
DPE	**0.154 (0.031)**	**0.029 (0.014)**	**0.125 (0.028)**
FPE	**0.132 (0.029)**	**0.022 (0.013)**	**0.110 (0.027)**
SPE || Dam	0.857 (0.076)	0.750 (0.217)	0.882 (0.078)
Spillway Effect.	1.496 (0.133)	2.082 (0.601)	1.024 (0.091)

DPE = dam passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).
FPE = fish passage efficiency; proportion of fish passing via a non-turbine route relative to the number detected in the near forebay (< 100 m from dam-face).
SPE = spillway passage efficiency; proportion of fish that passed Foster through Spill Bays 1–4.
Spillway Effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.

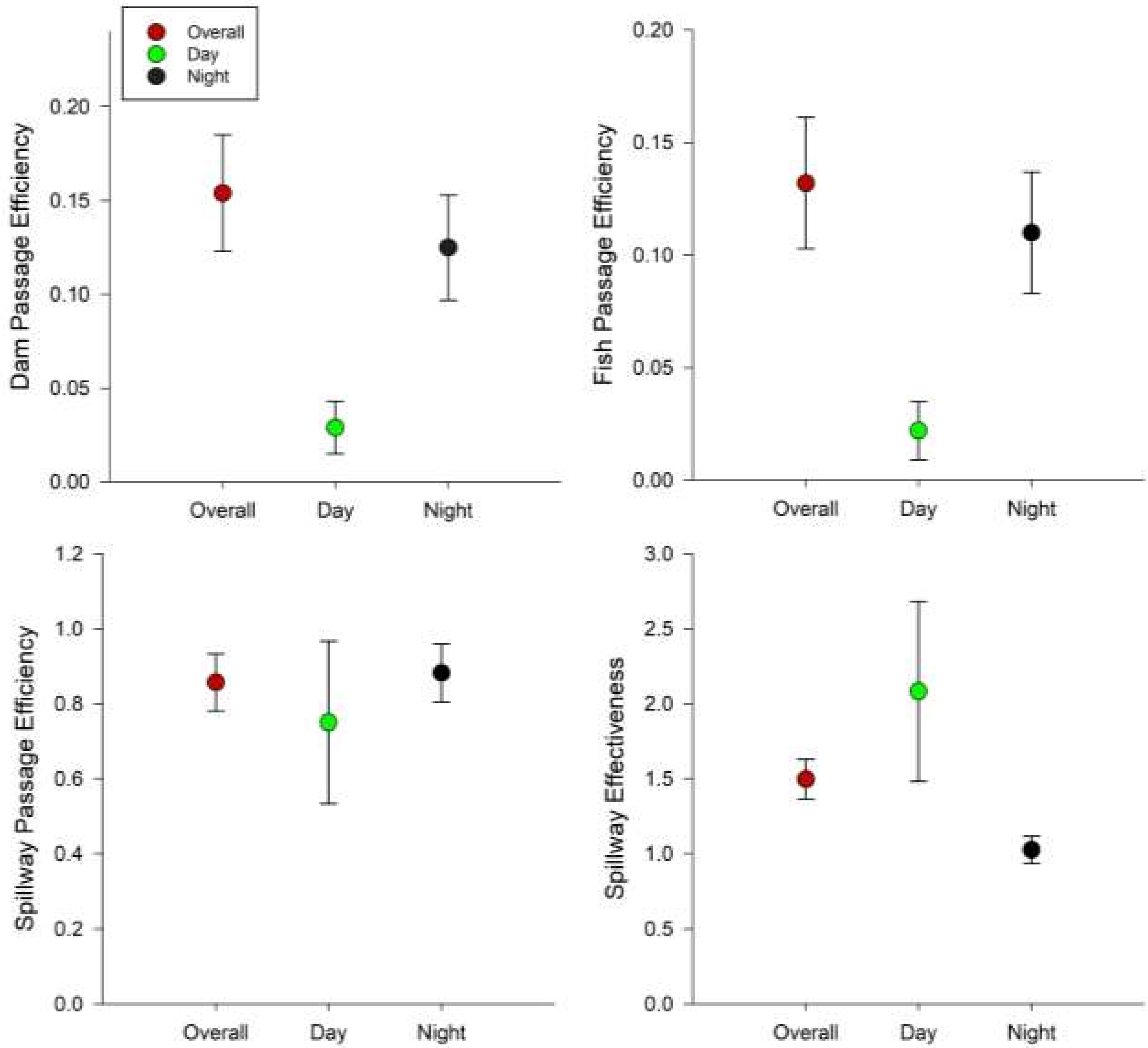

Figure 3-20. Dam passage efficiency, fish passage efficiency, spillway passage efficiency, and effectiveness of age-1 winter steelhead released at Foster in spring low pool of 2023. Error bars represent standard errors (SE) of the mean. A lack of error bars indicates the SE was 0.000.

3.4.4 Fall – Environmental Conditions

3.4.4.1 Temperature and Forebay Elevation

Data collected on environmental conditions included forebay elevation by seasonal periods and forebay temperature. Temperature data was provided courtesy of the USACE operations office, and the elevation data was gathered from the USGS Water Data for the Nation website.

The Foster forebay elevation also follows a “rule curve” managed by the USACE Water Management Reservoir Regulators. The rule curve dictates lowering the forebay pool elevation in fall to prepare for storage and flood control during winter months. Generally, the fall pool drawdown begins on or after October 1. Any deviations in the timing of drawdown periods were coordinated through the Reservoir Regulators and local stakeholders.

During the low pool season of fall 2023 (October 1 – December 16), the forebay elevation fluctuated from 611–633 ft. Whereas the average elevation was 618 ft., a high water event from storm events in early December resulted in the spike in forebay elevation (Figure 3-21). Excluding this high water event, the maximum forebay elevation for fall low pool was 623 ft.

Forebay temperature data was obtained from a temperature string that recorded hourly temperatures at depths ranging from 0.5-80 ft. (Figure 3-21). Throughout the month of October, there was a thermocline at approximately 40 ft. (Figure 3-21). The water above the thermocline had an average temperature of 15.2 °C (range: 9.2–19.9 °C), while the water below had an average temperature of 8.7 °C (range: 8.2–10.3 °C). The water above the thermocline cooled in the beginning of November ($\bar{x}$ = 12.2 °C) (Figure 3-21). Around November 6, a plume of relatively warm water penetrated the cooler water beneath the thermocline (Figure 3-21). After this event, the water column became roughly isothermal by November 10, with an average temperature of 8.8 °C (Figure 3-21). Between November 26 and December 3, the reservoir was drawn down to its minimum elevation of 611 ft., which yielded an average of 6.0 °C throughout the water column, the lowest temperature observed during fall low pool (Figure 3-21).

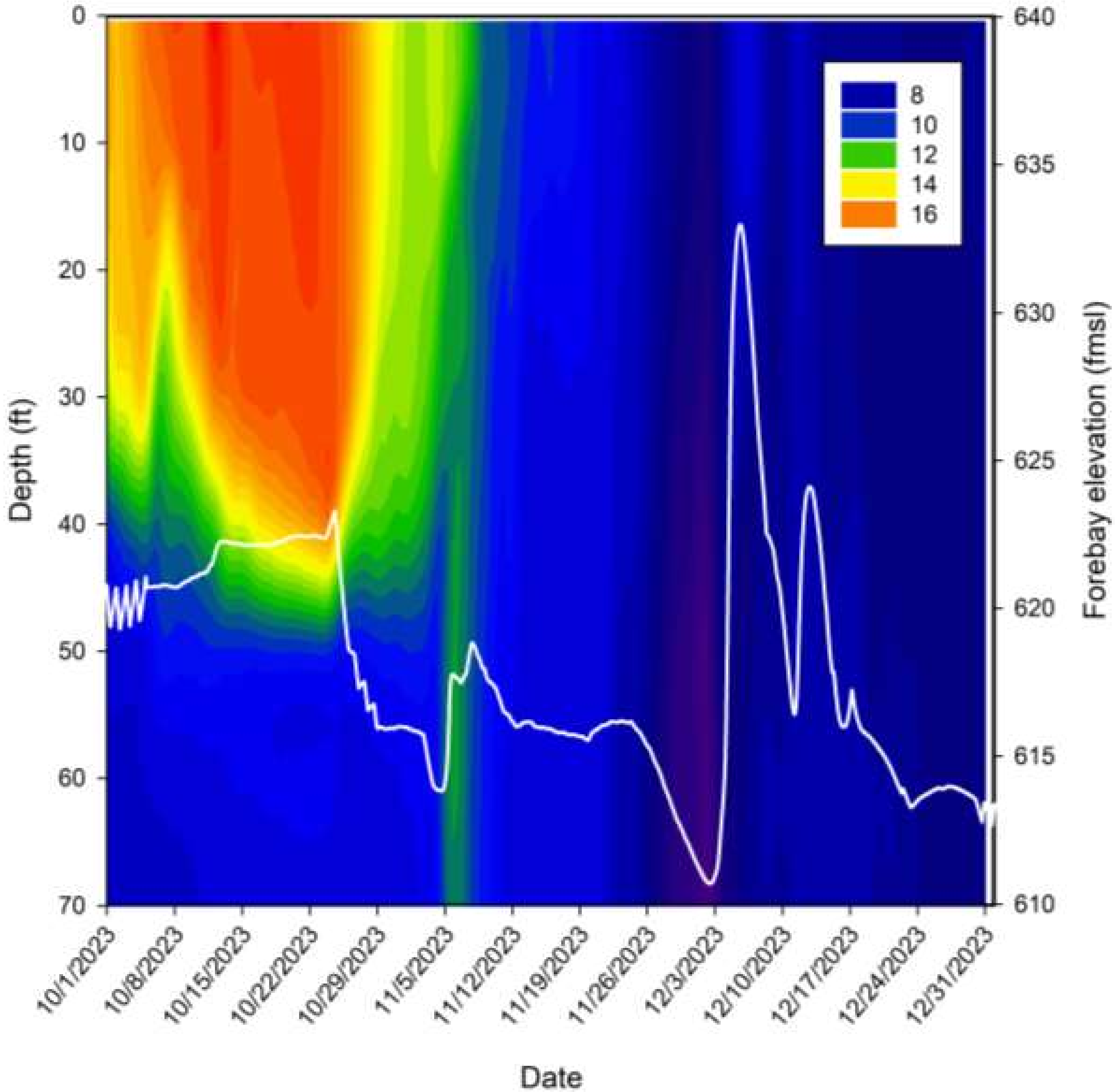

Figure 3-21. Daily average forebay elevation (solid white line; right axis) and temperature (°C) at depth (contour plot; left axis) in the Foster Forebay from October 1 through December 31, 2023.

3.4.4.2 Discharge

The mean daily discharge at Foster during fall low pool was 2,860 cfs. It was approximately equal by diel period (daytime: 2,825 cfs; nighttime: 2,878 cfs). The mean daily discharge range for the season was 0–2,137 cfs.

3.4.5 Fall – Subyearling Chinook Salmon

The following sections describe reservoir, dam passage and reach survival; reservoir residency and migration travel times; passage route distributions; and efficiency and effectiveness results from the fall 2023 study period for subyearling Chinook salmon released at Foster. Although the planned treatments were daytime turbines from 06:00–19:59 and nighttime spill from 20:00–05:59 each day, the operations data did not always match the planned treatment timing. As a result, the survival estimates, reservoir residency, travel time, passage distributions, and efficiency and effectiveness were based off of the operations data at the time of passage.

3.4.5.1 Tagging

Fish tagging and releases occurred from Oct 2 through Nov 30, 2023. Approximately equal numbers of subyearling Chinook salmon were released at the HOR and MOR (Table 3-19).

Table 3-19. Release location, sample sizes, fork lengths, weights, and standard errors (SE) of subyearling Chinook salmon released at Foster in fall 2023. HOR = head-of-reservoir; MOR = mid-of-reservoir; DFR = dead fish release.

Release Location	*n*	Length (mm; mean)	SE	Weight (g; mean)	SE
HOR	60	154.02	1.70	38.87	1.37
MOR	60	153.32	1.87	38.67	1.51
DFR	46	156.74	2.04	41.43	1.81
Total	166	154.52	1.07	39.51	0.89

3.4.5.2 Survival

Reservoir Survival

The 60 RT-tagged subyearling Chinook salmon released at Foster HOR had an estimated survival probability of 0.5167 (0.0645) from release to Foster passage. The 60 subyearling Chinook salmon released at Foster MOR had an estimated survival probability of 0.6833 (0.0601) from release to Foster passage.

Dam Passage and Reach Survival

Dead tagged fish were released from Foster each day live tagged fish were released for dam passage survival estimation using the ViRDCt model. A total of 45 dead tagged subyearling Chinook salmon and 51 dead tagged steelhead were released from Foster during the fall study. Of those, two (4.4%) dead tagged subyearling Chinook salmon and two (3.9%) dead tagged steelhead were detected at the Egress Array. Forty-nine of the dead-tagged fish were released during daytime turbine operations with 4.1% of them being detected at the Egress Array and 47 were released during night spill operations with 4.3% of them being detected at the Egress Array. Because the proportions detected were similar between species and operations, all dead tagged fish were pooled for each estimate of Foster dam passage survival (i.e., overall and by species, passage route, and dam operation). Combined, 4.2% of dead tagged fish released at Foster were detected at the Egress Array.

For the overall dam passage survival estimate, the timing of all dead tagged fish releases differed significantly from that of live released subyearling Chinook salmon mortality at Foster (Log-Rank test: χ^2 = 3.256, P = 0.071; Wilcoxon group homogeneity test: χ^2 = 5.353, P = 0.021;

Figure 3-22). Censoring the first 12 dead tagged fish that were released prior to the first apparent mortality event resulted in temporal distributions that more closely matched (Log-Rank test: χ^2 = 1.412, P = 0.235; Wilcoxon group homogeneity test: χ^2 = 2.013, P = 0.156; Figure 3-23).

For the estimates of dam passage survival during daytime turbine operations and for fish that passed Foster through the turbines, the first apparent mortality event occurred on November 7; therefore, the first 40 dead released fish were censored to ensure the temporal distribution of dead released fish matched that of Foster daytime turbine operation passage mortality (Figure 3-24) and overall turbine mortality (Figure 3-25) (Log-Rank test: $\chi^2 \leq 0.168$, $P \geq 0.682$; Wilcoxon group homogeneity test: $\chi^2 \leq 0.280$, $P \geq 0.597$). For the estimate of dam passage survival of fish that passed during the nighttime spill operation and for fish that passed Foster through the spillway, the first apparent mortality event occurred on October 4. Therefore, the first eight dead released fish were censored to ensure the timing of dead fish releases matched the timing of Foster mortality for live released fish that passed during nighttime spill operations (Figure 3-26) and for those that passed via the spillway during either operation (Figure 3-27) (Log-Rank test: $\chi^2 \leq 0.912$, $P \geq 0.340$; Wilcoxon group homogeneity test: $\chi^2 \leq 1.183$, $P \geq 0.277$).

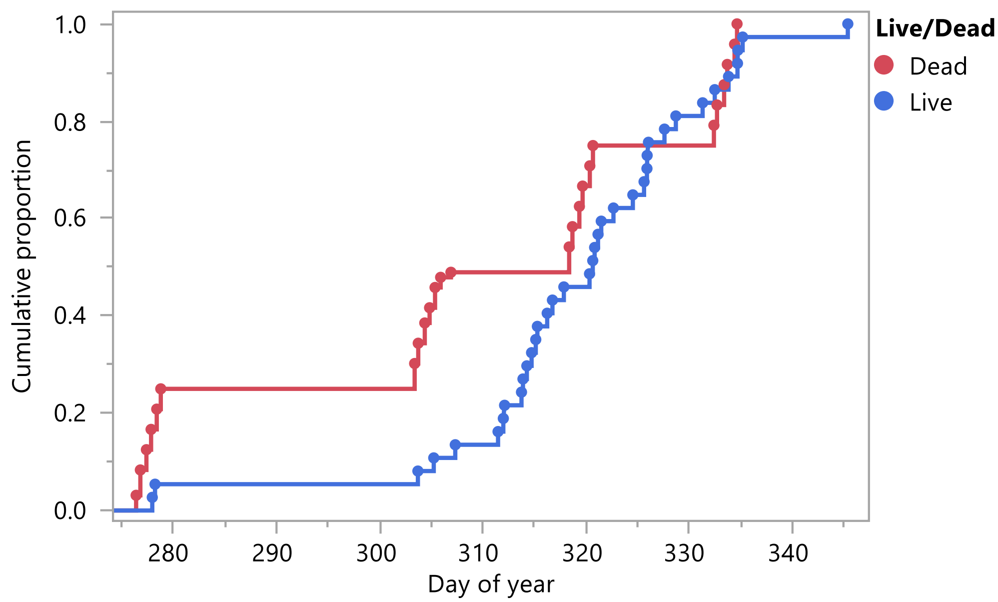

Figure 3-22. Cumulative proportions of live released RT-tagged subyearling Chinook salmon mortality (blue) and all dead tagged fish releases (red) at Foster during fall, 2023.

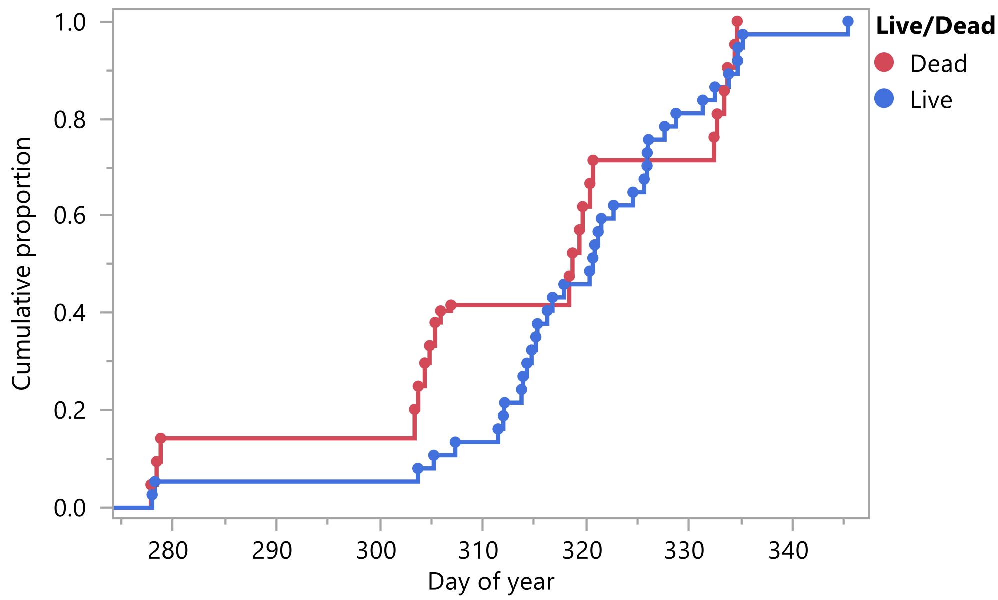

Figure 3-23. Cumulative proportions of live released RT-tagged subyearling Chinook salmon mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first 12 dead tagged fish released.

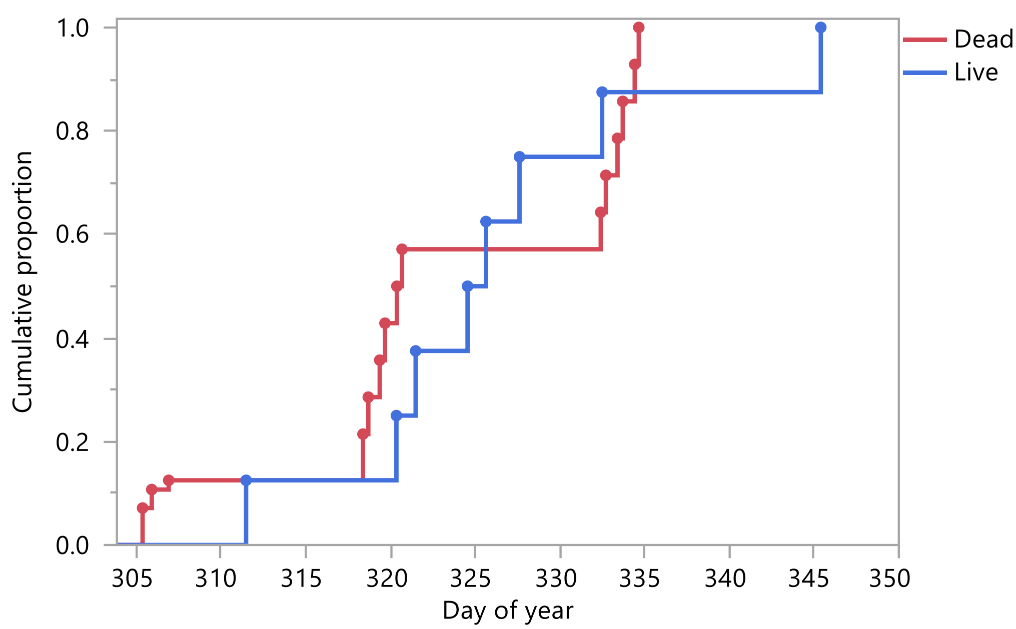

Figure 3-24. Cumulative proportions of live released RT-tagged daytime turbine subyearling Chinook salmon mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first 40 dead tagged fish released.

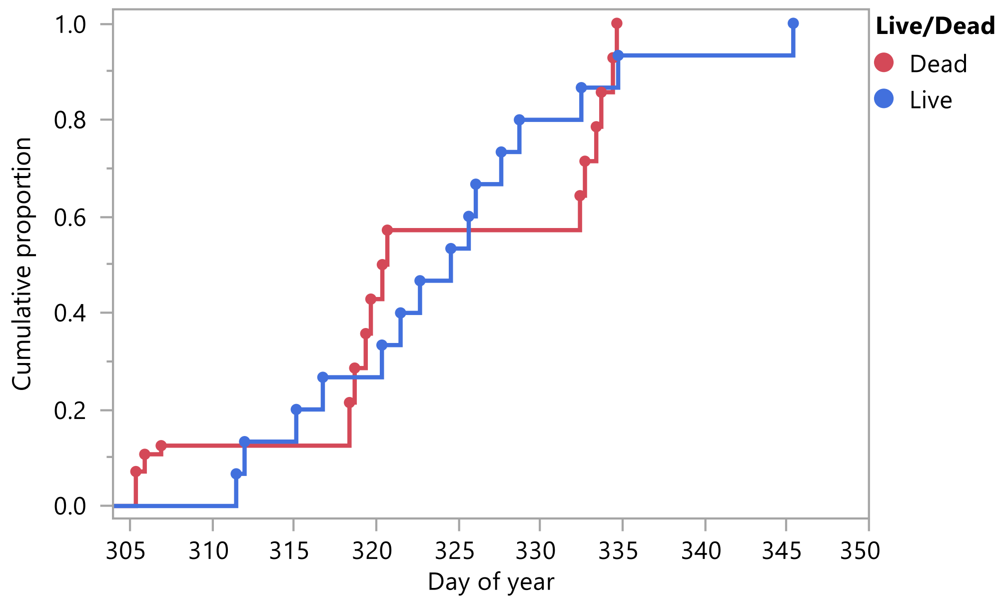

Figure 3-25. Cumulative proportions of live released RT-tagged subyearling Chinook salmon turbine mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first 40 dead tagged fish released.

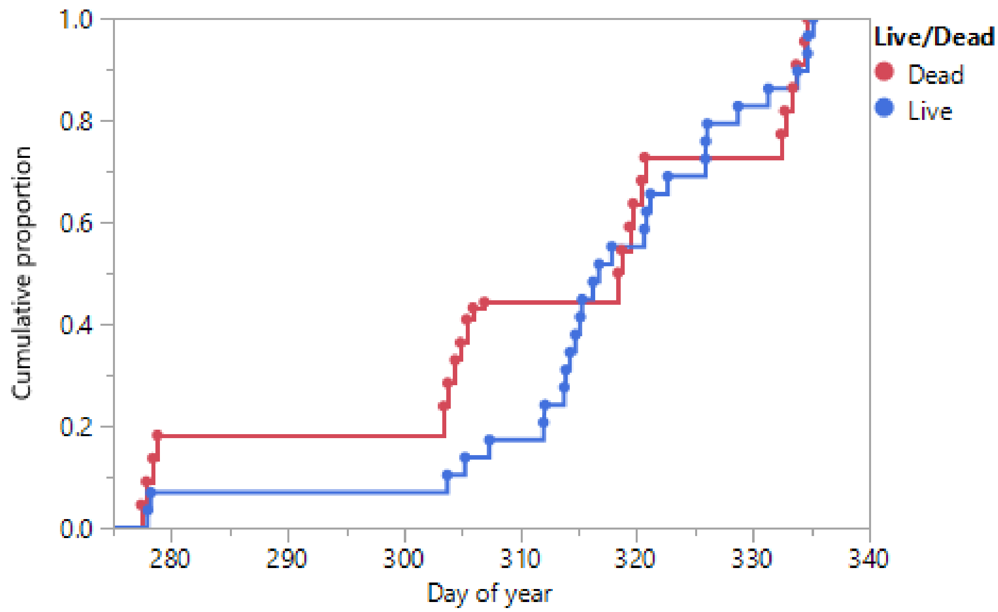

Figure 3-26. Cumulative proportions of live released RT-tagged nighttime spill subyearling Chinook salmon mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first eight dead tagged fish released.

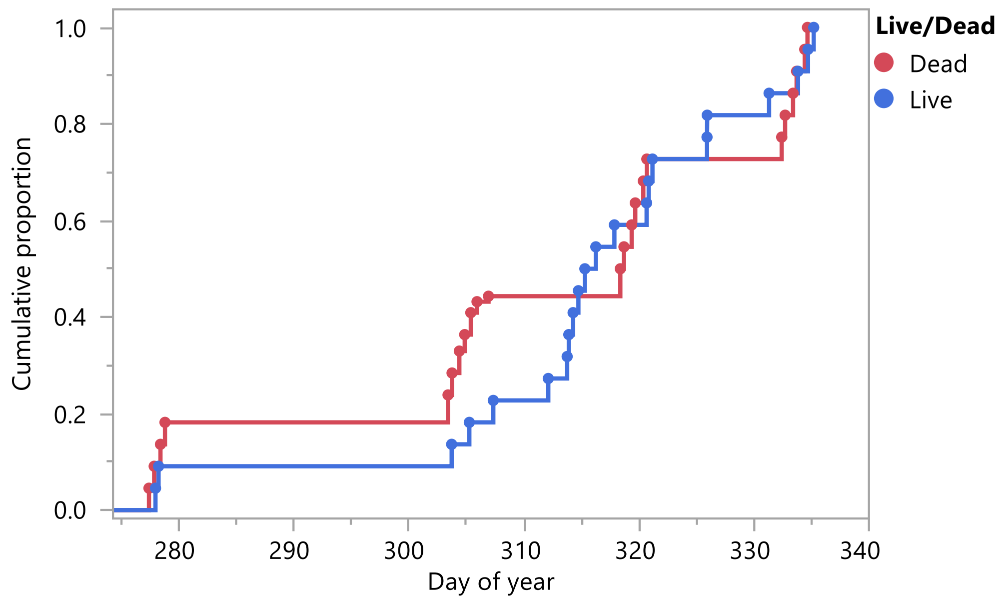

Figure 3-27. Cumulative proportions of live released RT-tagged subyearling Chinook salmon spillway mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first eight dead tagged fish released.

Of the RT-tagged subyearling Chinook salmon released in Green Peter and Foster reservoirs, 179 were detected passing Foster during the fall study. These fish had an overall estimated dam passage survival probability of 0.8980 (0.0235) from Foster passage to the Egress Array (Table 3-20), which was very similar to the pooled estimate from studies conducted in 2018 and 2022 (*S* = 0.8971; *SE* = 0.0116). The 145 subyearling Chinook salmon that passed Foster through the spillway had an estimated dam passage survival probability of 0.9516 (0.0185), which was significantly higher than that of the 33 fish that passed through the turbines ($\hat{S}_D$ = 0.6542; $\widehat{SE}$ = 0.0890) (Table 3-20). Because 37% of subyearling Chinook salmon that passed during daytime turbine operations did so via the spillway (Table 3-23), estimated dam passage survival probabilities were similar for subyearling Chinook salmon that passed Foster during nighttime spill ($\hat{S}_D$ = 0.9038; $\widehat{SE}$ = 0.0251) and daytime turbine ($\hat{S}_D$ = 0.8655; $\widehat{SE}$ = 0.0668) operations (Table 3-20).

Survival from Foster to the Primary Array was estimated to be 0.7945 (0.0306) for subyearling Chinook salmon in the fall of 2023 (Table 3-20). This estimate did not differ from the pooled estimates obtained during studies conducted in 2016 and 2022 (*S* = 0.7511; *SE* = 0.0118) or from those conducted in 2015 and 2018 (*S* = 0.8371; *SE* = 0.0105).

Overall reach survival, estimated from Foster passage to the Santiam Rest Stop Array, was estimated to be 0.6094 (0.0368) for subyearling Chinook salmon during the fall (Table 3-20). This estimate was significantly greater than the overall reach survival estimate obtained during the 2022 study (*S* = 0.428; *SE* = 0.029; χ^2 = 14.342; *P* < 0.001). Reach survival was significantly greater for subyearling Chinook salmon that passed Foster via the spillway ($\hat{S}$ = 0.6692; $\widehat{SE}$ = 0.0395) compared to those that passed through the turbine at Foster ($\hat{S}$ = 0.3671; $\widehat{SE}$ = 0.0846) (Table 3-20). However, because 37% of subyearling Chinook salmon that passed during daytime turbine operations did so via the spillway (Table 3-23), reach survival was similar for fish that passed Foster during nighttime spill ($\hat{S}$ = 0.6153; $\widehat{SE}$ = 0.0404) and daytime turbine ($\hat{S}$ = 0.6000; $\widehat{SE}$ = 0.0894) operations (Table 3-20).

Undetected fish had unknown fates. It is possible they died, were predated, remained in the river for the duration of their tag life, moved into a different tributary, or had another fate as the reach survival encompasses approximately 77 rkm downstream of Foster.

Table 3-20. Tag life, detection, and survival probability estimates for RT-tagged subyearling Chinook salmon (CH0) released in Green Peter and Foster reservoirs that passed Foster (FOS) during fall 2023. Standard error estimates ($\widehat{SE}$) are shown in parentheses. EGR = Egress Array, PRM = Waterloo Primary Array, LEB = Lebanon Dam Array, SRS = I-5 Santiam Rest Stop Array, COI = Cole Island Array. Note: one CH0 that passed FOS could not be assigned to the spillway or turbine route and one fish passed FOS in January 2024, after operations day turbine/night spill operations ended. nan = insufficient detections for estimation.

Reach	Tag life prob. ($\widehat{SE}$)	Det. Prob. ($\widehat{SE}$)	Survival ($\widehat{SE}$)
All Routes and Operations (N = 179)			
FOS – EGR[1]	1.0000 (0.0002)	0.9789 (0.0121)	0.8980 (0.0235)
FOS – PRM	1.0000 (0.0005)	0.9051 (0.0250)	0.7945 (0.0306)
FOS – LEB	1.0000 (0.0000)	0.9815 (0.0130)	0.7727 (0.0318)
FOS – SRS[2]	1.0000 (0.0000)	0.8759 (0.0322)	0.6094 (0.0368)
FOS – COI	1.0000 (0.0000)	0.9312 (0.0251)	0.6094 (0.0368)
Spillway (N = 145)			
FOS – EGR[1]	1.0000 (0.0002)	0.9839 (0.0113)	0.9516 (0.0185)
FOS – PRM	1.0000 (0.0005)	0.9076 (0.0266)	0.8570 (0.0296)
FOS – LEB	1.0000 (0.0000)	0.9896 (0.0104)	0.8281 (0.0317)
FOS – SRS[2]	1.0000 (0.0000)	0.8820 (0.0334)	0.6692 (0.0395)
FOS – COI	1.0000 (0.0000)	0.9339 (0.0261)	0.6692 (0.0395)
Turbine (N = 33)			
FOS – EGR[1]	1.0000 (0.0000)	0.9444 (0.0540)	0.6542 (0.0890)
FOS – PRM	1.0000 (0.0000)	0.8870 (0.0752)	0.5466 (0.0869)
FOS – LEB	1.0000 (0.0000)	0.9424 (0.0559)	0.5466 (0.0869)
FOS – SRS[2]	1.0000 (nan)	0.8255 (0.1119)	0.3671 (0.0846)
FOS – COI	1.0000 (nan)	0.9080 (0.0875)	0.3671 (0.0846)
Nighttime Spill (N = 148)			
FOS – EGR[1]	1.0000 (0.0000)	0.9832 (0.0118)	0.9038 (0.0251)
FOS – PRM	1.0000 (0.0000)	0.9043 (0.0274)	0.8049 (0.0329)
FOS – LEB	1.0000 (0.0000)	0.9778 (0.0155)	0.7862 (0.0343)
FOS – SRS[2]	1.0000 (0.0000)	0.8734 (0.0356)	0.6153 (0.0404)
FOS – COI	1.0000 (0.0000)	0.9176 (0.0298)	0.6153 (0.0404)
Daytime Turbines (N = 30)			
FOS – EGR[1]	1.0000 (0.0000)	0.9545 (0.0444)	0.8655 (0.0668)
FOS – PRM	1.0000 (0.0000)	0.9091 (0.0613)	0.7333 (0.0807)
FOS – LEB	1.0000 (0.0000)	1.0000 (0.0000)	0.7333 (0.0807)
FOS – SRS[2]	1.0000 (0.0000)	0.8889 (0.0741)	0.6000 (0.0894)
FOS – COI	1.0000 (0.0000)	1.0000 (0.0000)	0.6000 (0.0894)

[1]Dam passage survival
[2]Reach survival

3.4.5.3 Reservoir Residency and Migration Travel Times

Tagged Chinook salmon released during fall low pool had residence times that were greater than 4 days; therefore, diel period of passage likely had little influence on residence time. The reservoir residence times of fish released in the HOR did not differ based on diel passage period (Mann-Whitney-Wilcoxon test: W = 75; P = 0.237; Figure 3-28). However, MOR released fish spent a significantly longer amount of time in the reservoir if they passed during the day compared to those that passed at night (Mann-Whitney-Wilcoxon test: W = 142; P = 0.037; Figure 3-28).

A total of 64 Chinook that passed Foster reached the Egress Array. Travel were similar from Foster to Egress Array for fish that passed during day and night (Mann-Whitney-Wilcoxon test: W = 133; P = 0.351; Figure 3-28). The median travel time from Foster to the Egress Array was 2.4 h for fish that passed Foster during the day (n = 6) and 3.3 h for fish that passed at night (n = 58; Table 3-21). Thirty-three fish detected at the Santiam Rest Stop Array had a median travel time of 27.2 h (n = 2) when passing Foster during daytime and 50.8 h (n = 31) when passing Foster at night (Table 3-21; Figure 3-28), which was not a significant difference due to small sample size (Mann-Whitney-Wilcoxon test: W = 10; P = 0.136; Figure 3-28). Fifteen fish were detected at the furthest downstream array, Willamette Falls. All fifteen of these fish passed Foster at night and had a median travel time of 120.7 h (Table 3-21).

Subyearling Chinook salmon were also released during fall low pool of 2022. Fish spent significantly less time in the reservoir in 2022 compared to those released in 2023 (Mann-Whitney-Wilcoxon test: W = 7311; P < 0.001). This is true for both HOR-released fish (W = 1530; P = 0.001) as well as MOR fish (W = 2113; P < 0.001). The 2022 subyearlings were also significantly faster in their travel times from Foster to the Egress Array (Mann-Whitney-Wilcoxon test: W = 7444; P = 0.001) when compared to the 2023 cohort. There was no difference in median travel times between Foster and the Santiam Rest Stop Array (Mann-Whitney-Wilcoxon test: W = 1868; P = 0.136) or from Foster to Willamette Falls (W = 630; P = 0.468) between the two years.

Table 3-21. Travel time summary for subyearling Chinook salmon from Foster Dam to the downstream arrays during low pool in fall 2023.

		Day			Night		
Pool Elevation	**Reach**	**Median hours (SE)**	**Mean hours (SE)**	***n***	**Median hours (SE)**	**Mean hours (SE)**	***n***
Low	FOS – EGR	2.4 (2.9)	5.2 (2.3)	6	3.3 (8.2)	18.5 (6.5)	58
	FOS – PRM	4.3 (2.0)	5.5 (1.6)	3	17.1 (10.9)	42.6 (8.7)	50
	FOS – LEB	12.9 (71.3)	66.0 (56.9)	3	23.4 (11.3)	57.5 (9.1)	51
	FOS – SRS	27.2 (17.6)	27.2 (14.0)	2	50.8 (15.9)	86.2 (12.7)	31
	FOS – COI	28.4 (17.4)	28.4 (13.9)	2	51.8 (15.6)	86.9 (12.4)	32
	FOS – WIL	nan	nan	0	120.7 (79.9)	197.6 (63.7)	15

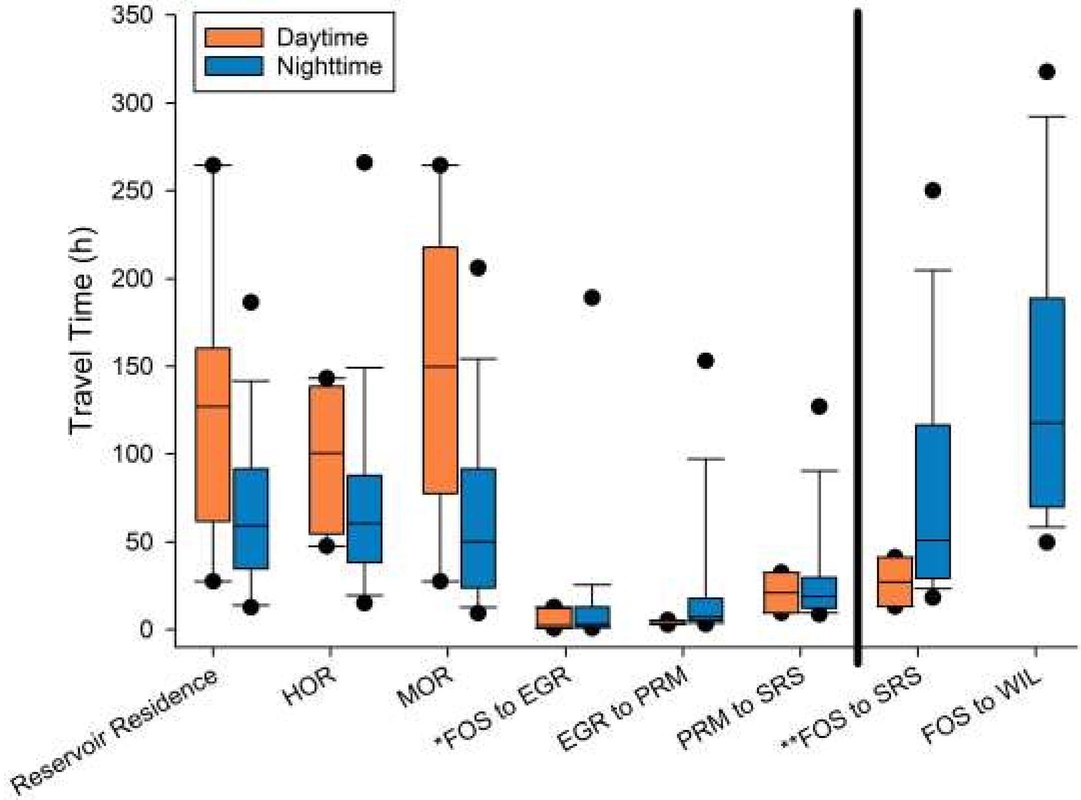

Figure 3-28. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir, MOR = mid-of-reservoir), and travel times between reaches for subyearling Chinook salmon released at Foster during fall 2023 (FOS; EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). Daytime classification indicates fish with last detections at Foster Dam during the day, while Nighttime fish had last detections occurring at night (indicating time of passage). Lines within the boxes represent medians, box boundaries indicate the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. The * indicates ViRDCt survival array and the ** indicates the reach survival array. The solid vertical line is a delineator to show the travel time from Foster through all the reaches and directly to the reach survival array and to the furthest downstream array at Willamette Falls. One outlier is not depicted to manage the scale of the y-axis: 1043 h from FOS to WIL under daytime passage.

3.4.5.4 Passage Distributions

During the fall season, 74.2% of subyearling Chinook salmon passed Foster (Table 3-22). Approximately 19% (n = 23 of 120) of the fish released alive were not detected after release and had unknown fates (e.g., predation, upstream movement, mortality, etc.). Just over 20% of fish were detected in the near forebay (i.e., were available to pass) but did not pass Foster (Table 3-22).

Of the fish that were detected (*n* = 97; Table 3-22), about 1.0% were presumed to be no route predation (i.e., never detected at Foster after release but detected on other RT arrays downstream). One fish had a final detection at the Sunnyside Array and never passed, indicating upstream movement from release (Table 3-22). Approximately 3.0% of subyearlings were detected at the extended forebay but did not approach the Foster near forebay (Table 3-22). About 20.0% of subyearlings were detected at the near forebay but did not pass, and 74.2% migrated downstream of Foster (Table 3-22). Although the proportion was small, about 8.3% of subyearlings detected in the extended forebay, near forebay, or passed Foster were presumed to have been predated after detection (Table 3-22). This minimum estimation of predation does not include the unknown fates of undetected fish, which could have been from predation.

The majority of subyearling Chinook salmon (82.6%) passed Foster during nighttime spill operations (Table 3-23). The primary route of passage for subyearling Chinook salmon was the spillway, with 80.9% of fish passing that route (Table 3-23). Most of the fish passed via Spill Bay 4 (84.7%), followed by Spill Bay 3 (11%), and Spill Bay 2 (4.2%; Table 3-23; Figure 3-29).

Of the fish that passed through the spillway, 91.7% passed during nighttime spillway operations and 8.3% passed during the daytime turbine operations (Table 3-23). About 1.0% of fish had undefined routes of passage (Table 3-23). It should be noted that Table 3-22 includes only fish released in Foster Reservoir, whereas Table 3-23 includes fish that were released in Foster and Green Peter reservoirs. Discharge did not appear to affect subyearling Chinook salmon passage, and there were no clear trends between discharge and passage (Figure 3-30).

Table 3-22. Movement summary (proportions [prop.] and sample sizes) of subyearling Chinook salmon released in Foster Reservoir during fall low pool.

Pool Elevation	Detected after Release (*n*)	No Route Predation		Final Detection at Sunnyside – Never Passed		Extended Forebay Detection – Never Passed		Near Forebay Detection – Never Passed		Downstream Passage		Presumed Predation after any Forebay or Downstream Detection[1]	
		Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Sub Prop.	*n*
Low	97	0.010	1	0.010	1	0.031	3	0.206	20	0.742	72	0.083	8

[1] Predation as summarized is presumed, based on assumptions outlined in the methods.
Note: This table is based on the pool elevation during which fish were released. Fish that did not have an assigned route of passage (i.e., Route = Dam; Table 3-23) were excluded.

Table 3-23. Passage proportions by route of passage for RT-tagged subyearling Chinook salmon released in Foster and Green Peter reservoirs during fall low pool. A "Dam" route indicates a specific route (turbines or spillway; unit 1 or 2; or spill bay 1–4) could not be determined.

Pool Elevation	Route	Overall		Daytime Turbines		Nighttime Spill	
		Proportion	*n*	Proportion	*n*	Proportion	*n*
Low	**Turbines**	**0.180**	**32**	**0.563**	**18**	**0.438**	**14**
	Unit 1	0.563	18	0.611	11	0.389	7
	Unit 2	0.438	14	0.500	7	0.500	7
	Spillway	**0.809**	**144**	**0.083**	**12**	**0.917**	**132**
	Spill Bay 1	0.000	0	0.000	0	0.000	0
	Spill Bay 2	0.042	6	0.000	0	1.000	6
	Spill Bay 3	0.111	16	0.125	2	0.875	14
	Spill Bay 4	0.847	122	0.082	10	0.918	112
	Dam	**0.011**	**2**	**0.500**	**1**	**0.500**	**1**
	No Route	0.500	1	0.000	0	1.000	1
	Turbines	0.500	1	1.000	1	0.000	0
	Spillway	0.000	0	0.000	0	0.000	0
	Overall		**178**	0.174	**31**	0.826	**147**

Note: Fish that passed during no treatment (Dec. 16, 2023, at 8:11 am through the end of the study on Mar. 2, 2024, at 12:00 pm), were excluded from the analyses as there were no operational treatments during these periods.

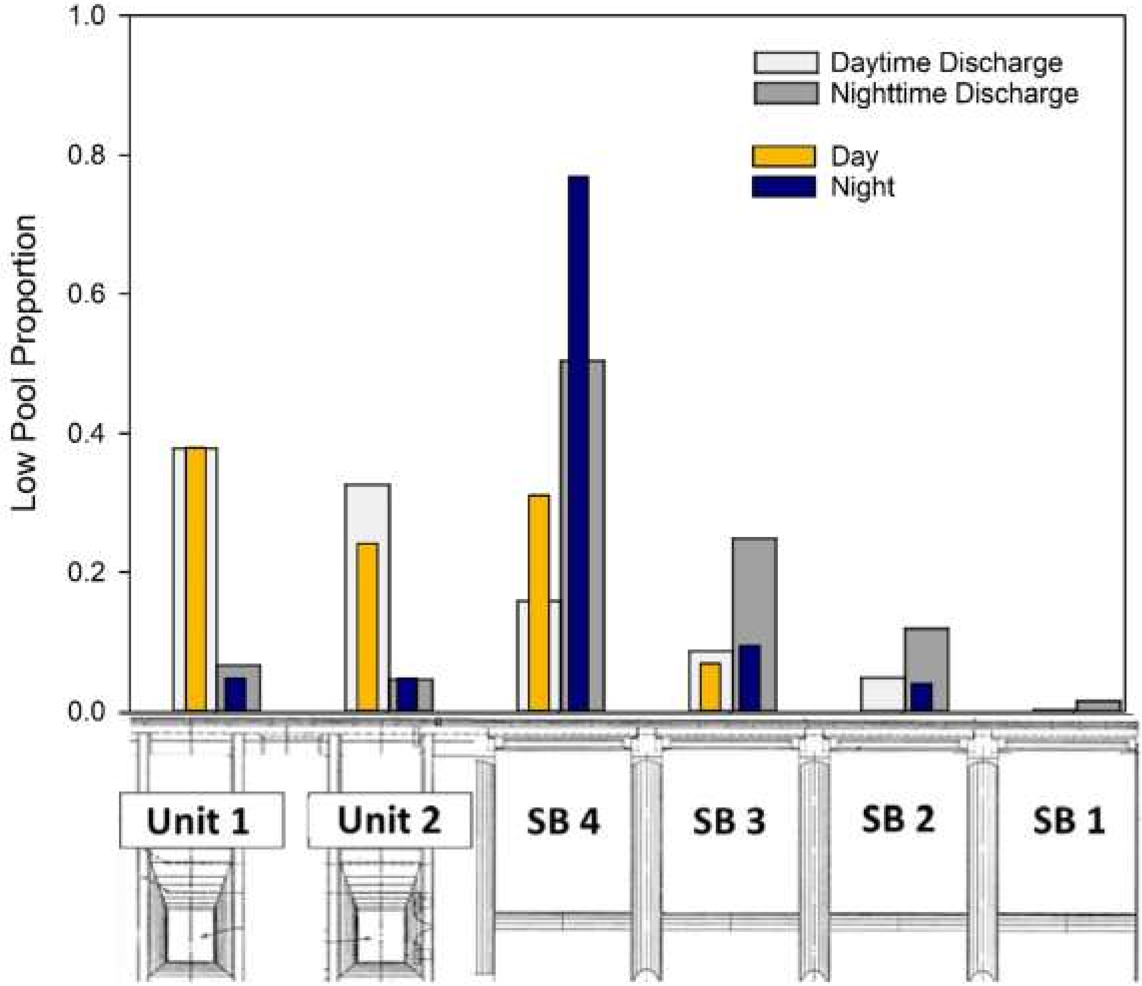

Figure 3-29. Diel passage proportions at Foster for subyearling Chinook salmon passed during fall low pool compared to the amount of discharge through the same route (SB = Spill Bay). The view of passage routes is looking downstream from the reservoir. Passage proportions include subyearling Chinook released at both Foster and Green Peter Dams.

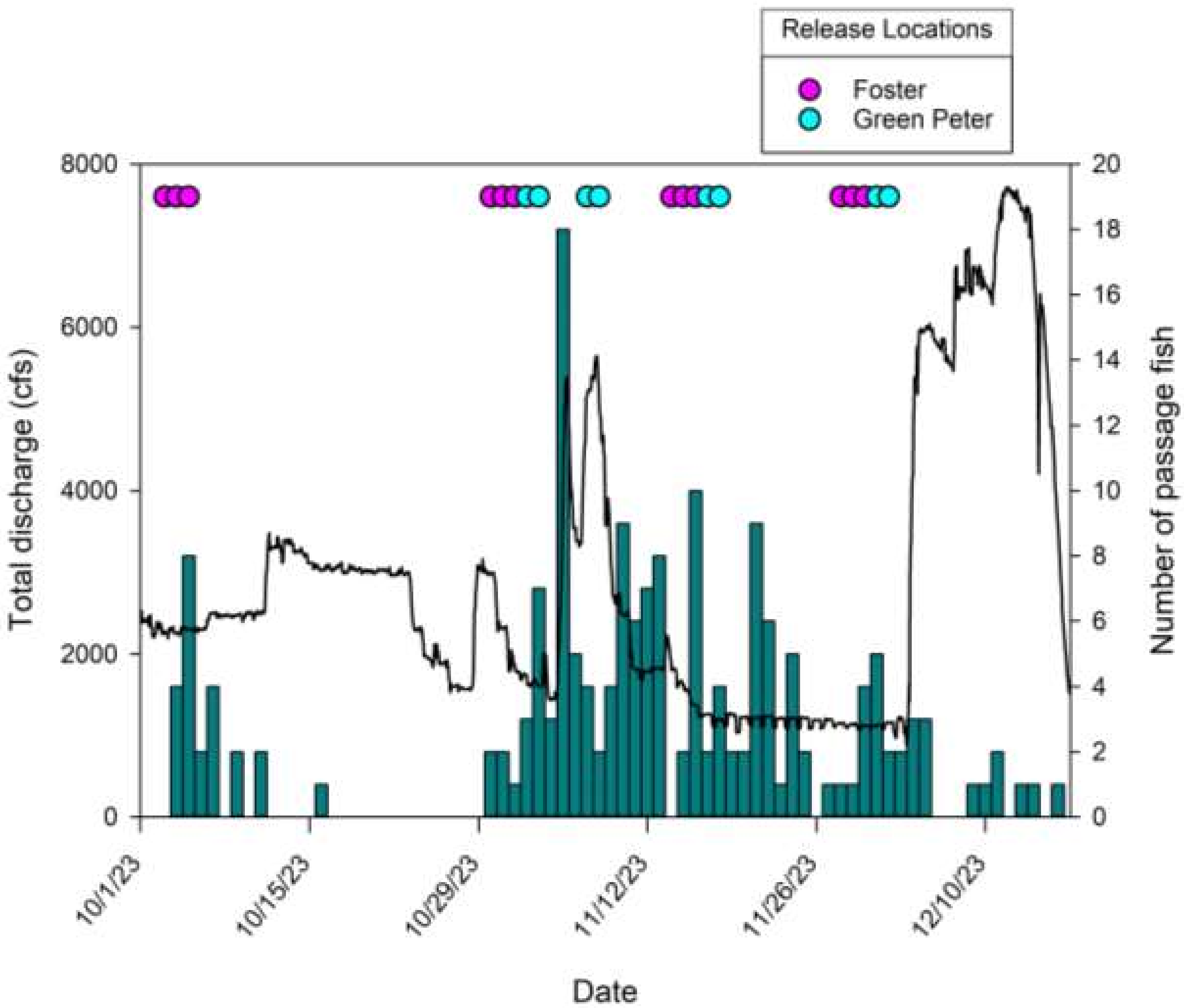

Figure 3-30. Total discharge (solid black line; left y-axis) as compared to number of passed subyearling Chinook salmon (bar plot; right y-axis) at Foster. Circle symbols indicate the dates and locations of fish releases. Fish were detected passing Foster during fall low pool from October 4 to December 16. Subyearling Chinook salmon passage counts are inclusive of both Foster and Green Peter released fish. One fish passed after fall low pool during the no treatment period and is not included in this figure.

3.4.5.5 Efficiency and Effectiveness

Subyearling Chinook salmon released into Green Peter and Foster reservoirs were included in these analyses and had an overall DPE of 76.6%. The DPE during nighttime spill was 63.6% compared to 13.0% during daytime turbine passage (Table 3-24; Figure 3-31). A similar finding was observed for the FPE, as the majority of subyearling Chinook salmon passing Foster did so via a non-turbine route (Table 3-23). Overall SPE was 81.9% with daytime SPE (40.0%) being much lower than nighttime SPE (90.5%; Table 3-24; Figure 3-31). Finally, the overall spillway effectiveness and during daytime turbine and nighttime spill passage was ≥ 1.02, indicating the spillway was an effective route.

Overall DPE for subyearling Chinook salmon in the fall of 2023 was similar to DPE from 2022 (z-test; $Z = 0.641$, $P = 0.521$; Figure 3-31; Liss et al. 2022). During 2023, a total of 32 fish passed via turbines compared to 13 fish in 2022. Additionally, both daytime turbines and nighttime spill DPE in 2023 were not statistically different than daytime turbines and nighttime spill DPE in 2022 ($Z \geq 0.466$, $P \geq 0.164$; Figure 3-31). Overall FPE was borderline significantly lower in 2023 than in 2022 (z-test; $Z = 1.889$, $P = 0.059$; Figure 3-31; Liss et al. 2022). Daytime turbines and nighttime spill FPE in 2023 were not statistically different than 2022 ($Z \geq 0.381$, $P \geq 0.585$; Figure 3-31; Liss et al. 2022).

Finally, overall SPE was significantly lower in 2023 when compared to 2022 (z-test; $Z = 5.249$, $P < 0.001$). Both daytime turbines and nighttime spill SPE in 2023 were significantly lower than 2022 ($Z \geq 3.866$, $P < 0.001$; Figure 3-31; Liss et al. 2022). Differences in SPE between 2023 and 2022 is mostly attributed to more (and a higher proportion of) fish passing through the turbines in 2023. In 2023, spillway effectiveness was slightly lower than 2022 but still proved to be effective as it was ≥ 1.02 overall, and during daytime and nighttime passage (Figure 3-31).

Table 3-24. Passage efficiencies and effectiveness for subyearling Chinook salmon at Foster in the fall of 2023. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while the Spillway Passage Efficiency (SPE) is relative to the total number of fish that passed the dam (as indicated by "|| Dam"). Effectiveness is based on the SPE and the total dam discharge through those routes. Standard errors are in parentheses.

Metric	Overall	Daytime Turbines	Nighttime Spill
DPE	**0.766 (0.028)**	**0.130 (0.022)**	**0.636 (0.032)**
FPE	**0.628 (0.032)**	**0.052 (0.015)**	**0.576 (0.033)**
SPE || Dam	0.819 (0.029)	0.400 (0.089)	0.905 (0.024)
Spillway Effect.	1.213 (0.043)	1.351 (0.302)	1.019 (0.027)

DPE = dam passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).
FPE = fish passage efficiency; proportion of fish passing via a non-turbine route relative to the number detected in the near forebay (< 100 m from dam-face).
SPE = spillway passage efficiency; proportion of fish that passed Foster through Spill Bays 1–4.
Spillway Effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.

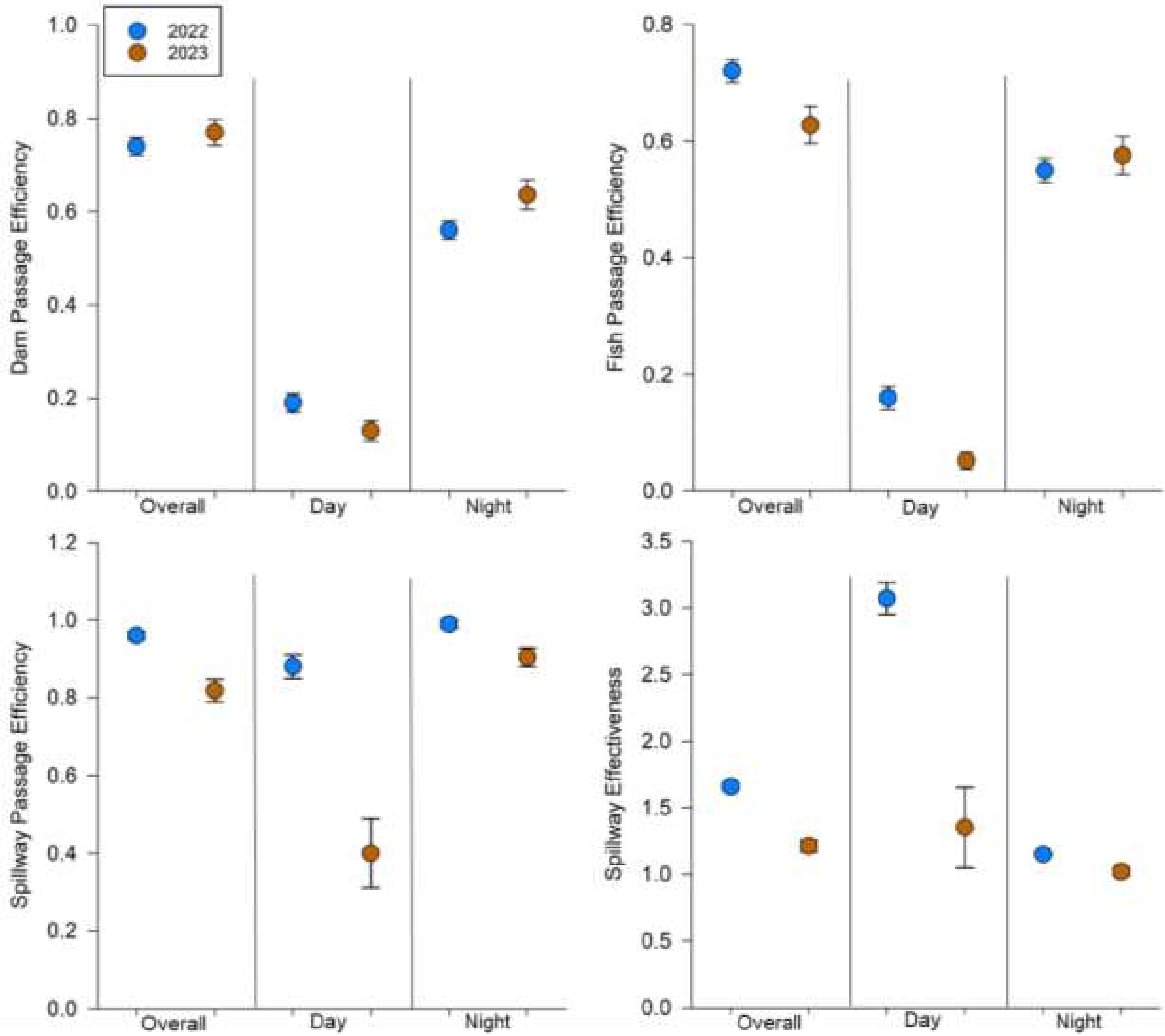

Figure 3-31. Dam passage efficiency, fish passage efficiency, spillway passage efficiency, and effectiveness of subyearling Chinook salmon released during low pool at Foster in fall 2022 and 2023. Error bars represent standard errors (SE) of the mean. A lack of error bars indicates the SE was 0.000.

3.4.6 Fall – Age-1+ Winter Steelhead

The following sections describe reservoir, dam passage and reach survival; reservoir residency and migration travel times; passage route distributions; and efficiency and effectiveness results from the fall 2023 study period for age-1+ winter steelhead released at Foster. Although the planned treatments were daytime turbines from 06:00–19:59 and nighttime spill from 20:00–05:59 each day, the operations data did not always match the planned treatment timing. As a result, the survival estimates, reservoir residency, travel time, passage distributions, and efficiency and effectiveness were based on the operations data at the time of passage.

3.4.6.1 Tagging

Fish tagging and releases occurred from Oct 2 through Nov 30, 2023. Approximately equal numbers of age-1+ steelhead were released at the HOR and MOR (Table 3-25).

Table 3-25. Release location, sample sizes, fork lengths, weights, and standard errors (SE) of age-1+ steelhead released at Foster in fall 2023. HOR = head-of-reservoir; MOR = mid-of-reservoir; DFR = dead fish release.

Release Location	*n*	Length (mm; mean)	SE	Weight (g; mean)	SE
HOR	763	144.11	0.63	30.66	0.42
MOR	764	144.37	0.59	30.67	0.39
DFR	51	145.39	2.35	31.13	1.53
Total	1578	144.28	0.42	30.68	0.28

3.4.6.2 Survival

Reservoir Survival

The 763 RT-tagged age-1+ steelhead released at Foster HOR during the fall had an estimated survival probability of 0.1202 (0.0118) from release to Foster passage. The 764 age-1+ steelhead released at Foster MOR had an estimated survival probability of 0.1728 (0.0137) from release to Foster passage. However, the survival model assumes active migration; therefore, if tagged fish were not active migrants, survival estimates represent the joint probability of migration and survival.

Dam Passage and Reach Survival

As mentioned previously, no differences were observed in the proportion of dead tagged fish released at Foster that were detected at the Egress Array by species or operation in the fall. Therefore, dead tagged fish of both species and operations could be pooled for all dam passage survival estimates. The timing of dead tagged fish releases at Foster differed from the timing of age-1+ steelhead mortality (Log-Rank test: $\chi^2 = 17.589$, $P < 0.001$; Wilcoxon group homogeneity test: $\chi^2 = 13.878$, $P < 0.001$; Figure 3-32). The first apparent age-1+ steelhead mortality occurred on October 3. Removing the first 16 dead tagged fish that were released resulted in a temporal distribution that more closely matched the timing of Foster passage mortality for the live released fish (Figure 3-33). However, because dead tagged fish releases did not continue through to the end of live released age-1+ steelhead passage, the distributions differed significantly (Log-Rank test: $\chi^2 = 7.151$, $P = 0.008$; Wilcoxon group homogeneity test: $\chi^2 = 1.927$, $P = 0.165$). Therefore, the primary assumption of the ViRDCt model, which states that dead released fish are representative of the live released fish that die during dam passage, may have been violated. As such, the age-1+ steelhead dam passage survival estimate may be biased and should be interpreted with caution.

The first 16 dead released fish were censored for estimating dam passage survival of age-1+ steelhead that passed Foster via the spillway and during night spill operations. This group of dead tagged fish most closely matched the timing of age-1+ steelhead spillway and night spill mortality (Figure 3-34 and Figure 3-36). However, the release timing of this group still differed significantly from the timing of mortality (Log-Rank test: $\chi^2 \geq 6.591$, $P \leq 0.010$; Wilcoxon group homogeneity test: $\chi^2 \geq 1.761$, $P \leq 0.185$), thus violating the ViRDCt model assumption of representativeness.

Therefore, age-1+ steelhead spillway and nighttime spill passage survival estimates may be biased and should be interpreted with caution.

The first apparent age-1+ steelhead turbine passage mortality occurred on October 13 and the last occurred on December 15. Releases of dead tagged fish from Foster occurred from October 3 to November 30. Censoring the first eight dead released fish resulted in temporal distributions that were statistically similar (Log-Rank test: χ^2 = 0.427, P = 0.513; Wilcoxon group homogeneity test: χ^2 = 0.268, P = 0.870; Figure 3-35). The first 12 dead released fish had to be censored to obtain statistically similar temporal distributions for the estimation of dam passage survival for age-1+ steelhead that passed Foster during daytime turbine operations (Log-Rank test: χ^2 = 3.260, P = 0.071; Wilcoxon group homogeneity test: χ^2 = 0.632, P = 0.427; Figure 3-37).

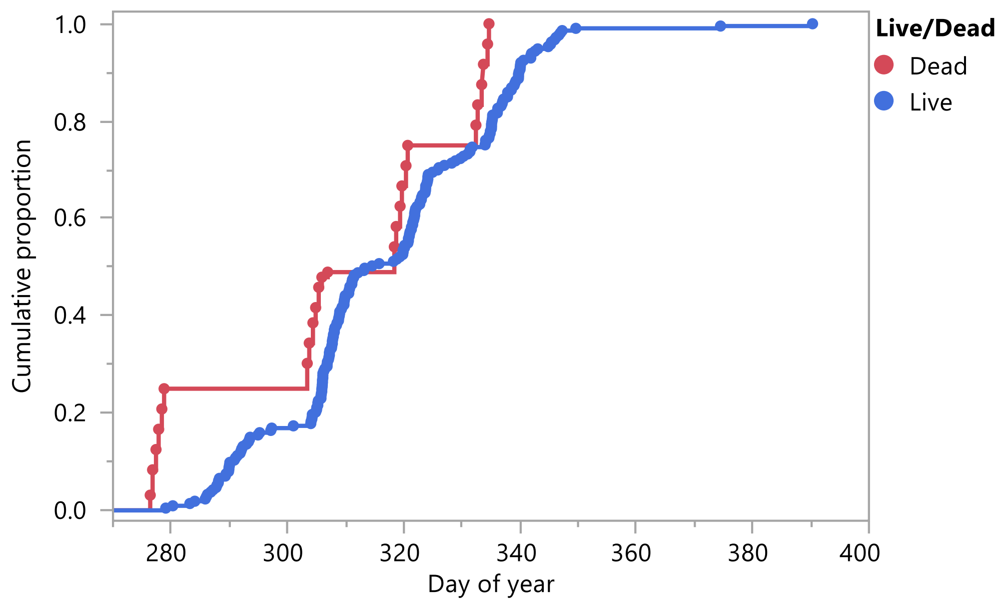

Figure 3-32. Cumulative proportions of live released RT-tagged age-1+ steelhead mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023.

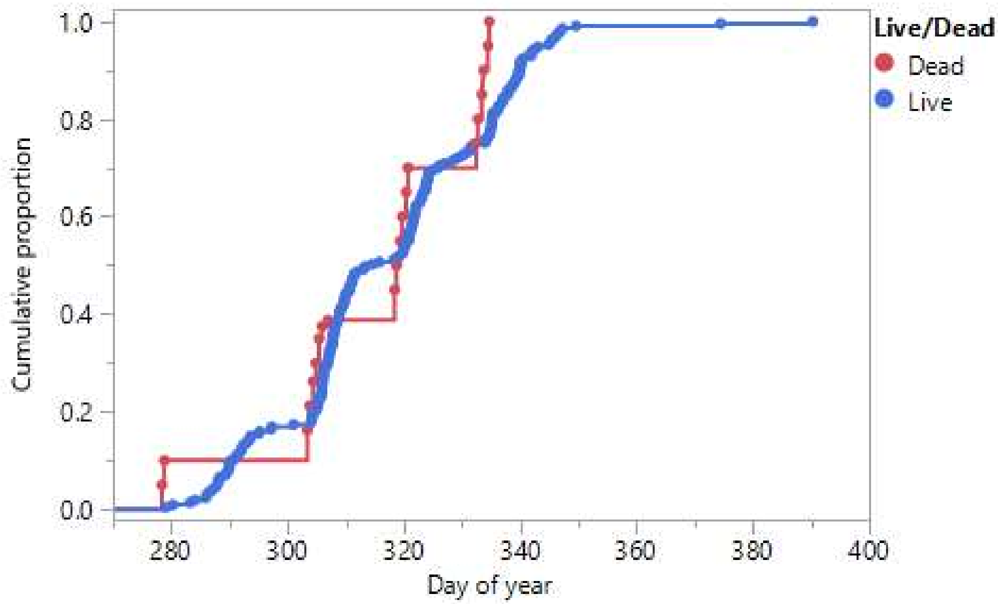

Figure 3-33. Cumulative proportions of live released RT-tagged age-1+ steelhead mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first 16 dead released fish.

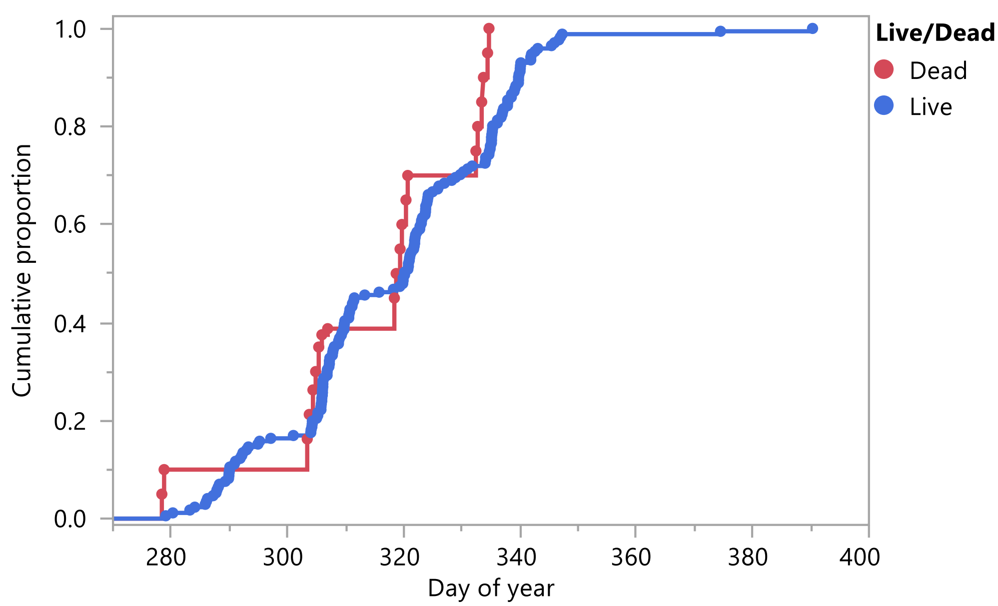

Figure 3-34. Cumulative proportions of live released RT-tagged age-1+ steelhead spillway passage mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first 16 dead released fish.

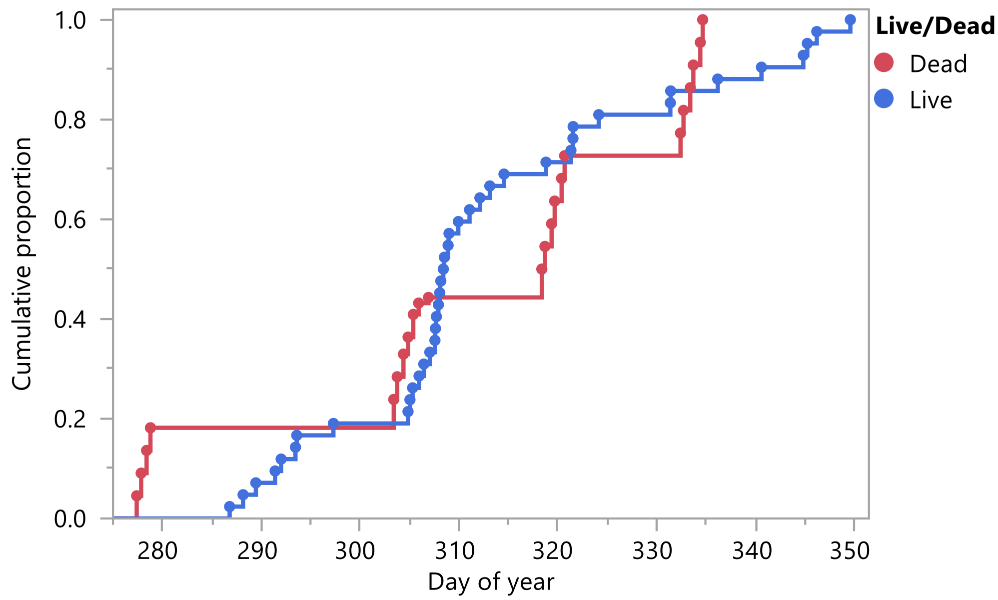

Figure 3-35. Cumulative proportions of live released RT-tagged age-1+ steelhead turbine passage mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first eight dead released fish.

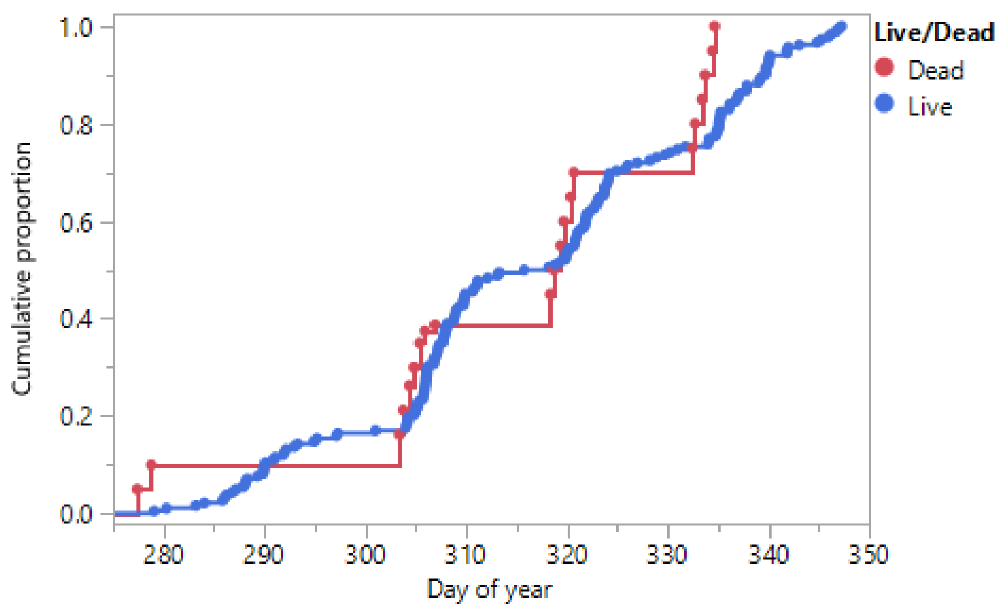

Figure 3-36. Cumulative proportions of live released RT-tagged age-1+ steelhead nighttime spill passage mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first 16 dead released fish.

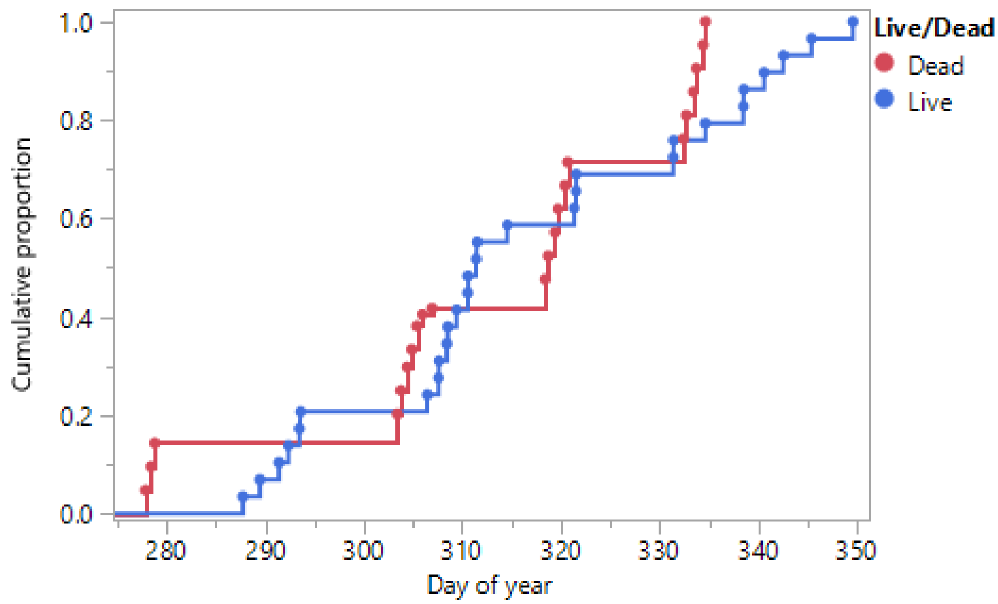

Figure 3-37. Cumulative proportions of live released RT-tagged age-1+ steelhead daytime turbine passage mortality (blue) and dead tagged fish releases (red) at Foster during fall, 2023 after censoring the first 12 dead released fish.

The 223 RT-tagged age-1+ steelhead detected passing Foster had an estimated dam passage survival probability of 0.3011 (0.0361; Table 3-26). However, this estimate assumes there was no change in the rate of detecting dead fish at the Egress Array after dead tagged fish releases ceased but passage of live released age-1+ steelhead continued. Dam passage survival was similar for age-1+ steelhead that passed Foster through the spillway ($\hat{S}_D$ = 0.3054; $\widehat{SE}$ = 0.0397) and turbines ($\hat{S}_D$ = 0.2778; $\widehat{SE}$ = 0.0730) (Table 3-26). Age-1+ steelhead that passed Foster during nighttime spill operations had an estimated dam passage survival probability of 0.3074 (0.0385; Table 3-26). Dam passage survival could not be estimated for age-1+ steelhead that passed Foster during daytime turbine operations because no fish that passed during this operation were detected downstream of the Egress Array. Therefore, detection probability of the Egress Array could not be estimated.

Reach survival, estimated from Foster passage to the Santiam Rest Stop Array could not be estimated for age-1+ steelhead because no age-1+ steelhead were detected at or downstream of the Santiam Rest Stop Array (Table 3-26). These undetected fish had unknown fates. It is possible they died, were predated, remained in the river for the duration of their tag life, moved into a different tributary, or had another fate as the reach survival encompasses approximately 77 rkm downstream of Foster.

Table 3-26. Tag life, detection, and survival probability estimates for RT-tagged age-1+ steelhead that passed Foster (FOS) during fall, 2023. Standard error estimates ($\widehat{SE}$) are shown in parentheses. EGR = Egress Array, PRM = Waterloo Primary Array, LEB = Lebanon Dam Array, SRS = I-5 Santiam Rest Stop Array, COI = Cole Island Array. nan = insufficient detections for estimation.

Reach	Tag life prob. ($\widehat{SE}$)	Det. Prob. ($\widehat{SE}$)	Survival ($\widehat{SE}$)
All Routes and Operations (N = 223)			
FOS – EGR[1]	0.9808 (0.0012)	1.0000 (0.0000)	0.3011 (0.0361)
FOS – PRM	0.9558 (nan)	0.6667 (0.2722)	0.0633 (0.0283)
FOS – LEB	0.8640 (nan)	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan
Spillway (N = 178)			
FOS – EGR[1]	0.9763 (0.0014)	1.0000 (0.0000)	0.3054 (0.0397)
FOS – PRM	0.9503 (nan)	1.0000 (0.0000)	0.0473 (0.0163)
FOS – LEB	0.5920 (nan)	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan
Turbine (N = 43)			
FOS – EGR[1]	0.9998 (0.0004)	1.0000 (0.0000)	0.2778 (0.0730)
FOS – PRM	1.0000 (nan)	1.0000 (0.0000)	0.0233 (0.0230)
FOS – LEB	1.0000 (nan)	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan
Nighttime Spill (N = 192)			
FOS – EGR[1]	0.9782 (0.0013)	1.0000 (0.0000)	0.3074 (0.0385)
FOS – PRM	0.9558 (nan)	0.6667 (0.2722)	0.0736 (0.0328)
FOS – LEB	0.8640 (nan)	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan
Daytime Turbines (N = 29)			
FOS – EGR[1]	0.9997 (nan)	nan	nan
FOS – PRM	nan	nan	nan
FOS – LEB	nan	nan	nan
FOS – SRS[2]	nan	nan	nan
FOS – COI	nan	nan	nan

[1]Dam passage survival
[2]Reach survival

3.4.6.3 Reservoir Residency and Migration Travel Times

When comparing reservoir residence times by release location, fish released at HOR were found to be statistically similar whether their dam passage occurred at day or night (Mann-Whitney-Wilcoxon test: W = 648; P = 0.092; Figure 3-38). The same was also true when comparing MOR fish (Mann-Whitney-Wilcoxon test: W = 1186; P = 0.138; Figure 3-38). However, the number of fish passing during the day was quite small, likely contributing to the lack of power to detect a difference. Also, with such long residence times, diel passage period likely had little to no effect on residence time.

A total of 72 steelhead that passed Foster were detected downstream at the Egress Array (Table 3-27). Median travel time from Foster to Egress Array was 193.3 h for fish that passed during the daytime turbine operations (*n* = 8) and 157.6 for fish that passed during the nighttime spill operations (*n* = 64), which was not a significant difference (Mann-Whitney-Wilcoxon test: W = 239; *P* = 0.768; Figure 3-38). Although 30 steelhead passed Foster during the daytime turbine operations, none of those fish were detected further downstream than the Egress Array. Of the 191 fish that passed the dam during nighttime spill, only 9 were detected at the Primary Array (Figure 3-38). The furthest downstream age-1+ winter steelhead were detected was at Lebanon Dam (*n* = 2; both nighttime passage). Median travel time of these two fish from Foster to the Lebanon Array was 712.3 h (Table 3-27). No steelhead were released during fall low pool of 2022, so no comparison to previous years is offered.

Table 3-27. Travel time summary for age-1+ winter steelhead from Foster Dam to the downstream arrays during low pool in fall 2023.

		Daytime Turbines			Nighttime Spill		
Pool Elevation	**Reach**	**Median hours (SE)**	**Mean hours (SE)**	***n***	**Median hours (SE)**	**Mean hours (SE)**	***n***
Low	FOS – EGR	193.3 (132.3)	244.1 (105.6)	8	157.6 (53.0)	262.3 (42.3)	64
	FOS – PRM	nan	nan	0	440.2 (123.2)	543.3 (98.3)	9
	FOS – LEB	nan	nan	0	712.3 (472.1)	712.3 (376.7)	2
	FOS – SRS	nan	nan	0	nan	nan	0
	FOS – COI	nan	nan	0	nan	nan	0
	FOS – WIL	nan	nan	0	nan	nan	0

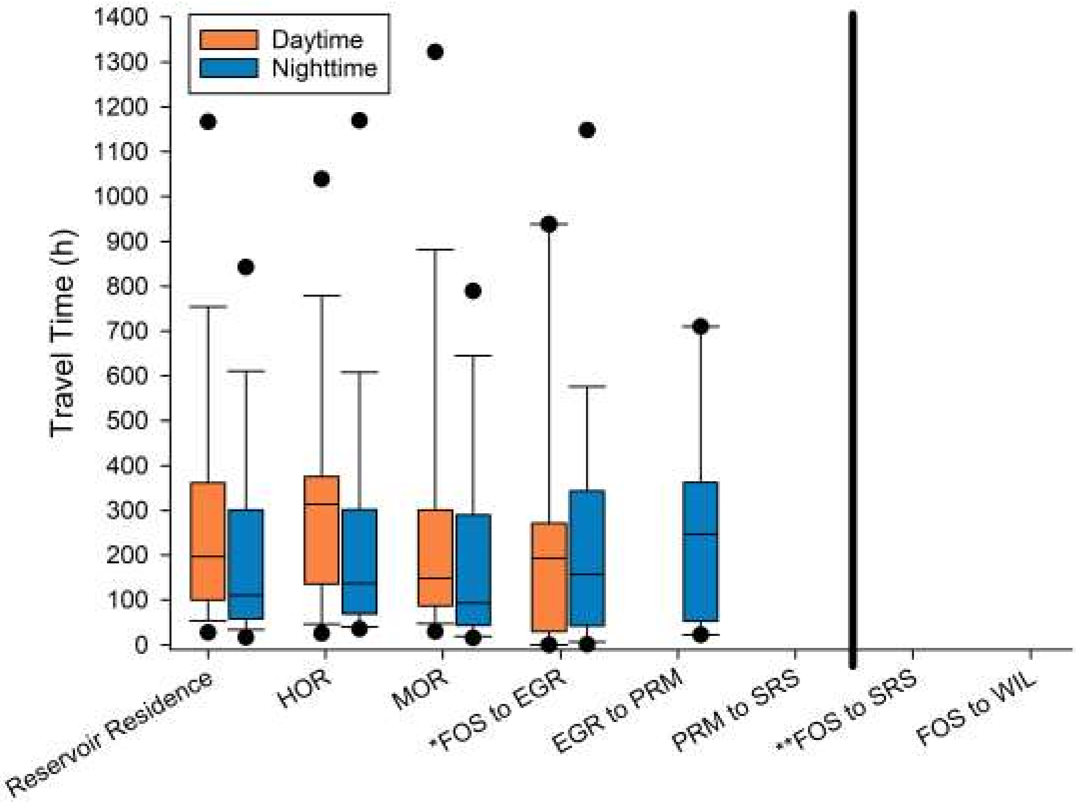

Figure 3-38. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir, MOR = mid-of-reservoir), and travel times between reaches for age-1+ winter steelhead released at Foster in fall 2023 (FOS; EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). Daytime classification indicates fish with last detections at Foster Dam during the day, while Nighttime fish had last detections occurring at night (indicating time of passage). Lines within the boxes represent medians, box boundaries indicate the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. The * indicates ViRDCt survival array and the ** indicates the reach survival array. The solid vertical line is a delineator to show the travel time from Foster through all the reaches and directly to the reach survival array and to the furthest downstream array at Willamette Falls.

3.4.6.4 Passage Distributions

Of the 711 steelhead that were detected, the majority (45.9%) were detected in the near forebay but did not pass (Table 3-28). About 12.9% of fish were detected in the extended forebay, but never approached the near forebay (i.e., dam face; Table 3-28). Almost a third of fish used for movement analyses passed Foster (31.4%; n = 223; Table 3-28). Twenty-five fish (3.5%) had a final detection at the Sunnyside Array, which was indicative of upstream movement after release (Table 3-28).

Predation was presumed to occur. Approximately 6% of fish were identified as a no route predation (i.e., never detected at Foster after release but detected on other RT array downstream; Table 3-28). Of all steelhead detected in the extended forebay, near forebay, or passed downstream, 10.2% were predated after detection (Table 3-28). This serves as a minimum predation estimate, as the fates of undetected fish are unknown and cannot be included.

Approximately 31% of age-1+ steelhead passed Foster in fall (Table 3-28), a large proportion compared to the age-1 steelhead that moved downstream in the spring. Most fish passed via the spillway (79.6%; Table 3-29) with Spill Bay 4 being the spill bay most commonly used by steelhead, followed by Spill Bay 3 and Spill Bay 2 (Table 3-29; Figure 3-39). Most fish passed during nighttime spillway operations (93.2%; Table 3-29). About 20% of fish passed via the turbines, with 60.5% of the turbine passage occurring during nighttime spillway operations (Table 3-29). Only 0.9% (n = 2) of fish were unable to be assigned a route of passage (Table 3-29). Discharge did not appear to affect age-1+ steelhead passage, and there were no clear trends with discharge and passage (Figure 3-40).

Table 3-28. Movement summary (proportions [prop.] and sample sizes) of age-1+ winter steelhead released in Foster Reservoir during fall low pool.

Pool Elevation	Detected after Release (n)	No Route Predation		Final Detection at Sunnyside – Never Passed		Extended Forebay Detection – Never Passed		Near Forebay Detection – Never Passed		Downstream Passage		Presumed Predation after any Forebay or Downstream Detection[1] Sub	
		Prop.	n	Prop.	n	Prop.	n	Prop.	n	Prop.	n	Prop.	n
Low	711	0.063	45	0.035	25	0.129	92	0.459	326	0.314	223	0.102	68

[1] Predation as summarized is presumed, based on assumptions outlined in the methods.
Note: This table is based on the pool elevation during which fish were released. Fish that did not have an assigned route of passage (i.e., Route = Dam; Table 3-29) were excluded.

Table 3-29. Passage proportions by route of passage for RT-tagged age-1+ winter steelhead released in Foster Reservoir during fall low pool. A “Dam” route indicates a specific route (turbines or spillway; unit 1 or 2; or spill bay 1–4) could not be determined.

Pool Elevation	Route	Overall		Day		Night	
		Proportion	*n*	Proportion	*n*	Proportion	*n*
Low	**Turbines**	**0.195**	**43**	**0.395**	**17**	**0.605**	**26**
	Unit 1	0.512	22	0.455	10	0.545	12
	Unit 2	0.488	21	0.333	7	0.667	14
	Spillway	**0.796**	**176**	**0.068**	**12**	**0.932**	**164**
	Spill Bay 1	0.006	1	0.000	0	1.000	1
	Spill Bay 2	0.085	15	0.133	2	0.867	13
	Spill Bay 3	0.170	30	0.033	1	0.967	29
	Spill Bay 4	0.739	130	0.069	9	0.931	121
	Dam	**0.009**	**2**	**0.000**	**0**	**1.000**	**2**
	No Route	1.000	2	0.000	0	1.000	2
	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	0.000	0	0.000	0	0.000	0
	Overall		**221**	0.131	**29**	0.869	**192**

Note: Fish that passed during no treatment (Dec. 16, 2023, at 8:11 am through the end of the study on Mar. 2, 2024, at 12:00 pm), were excluded from the analyses as there were no operational treatments during these periods.

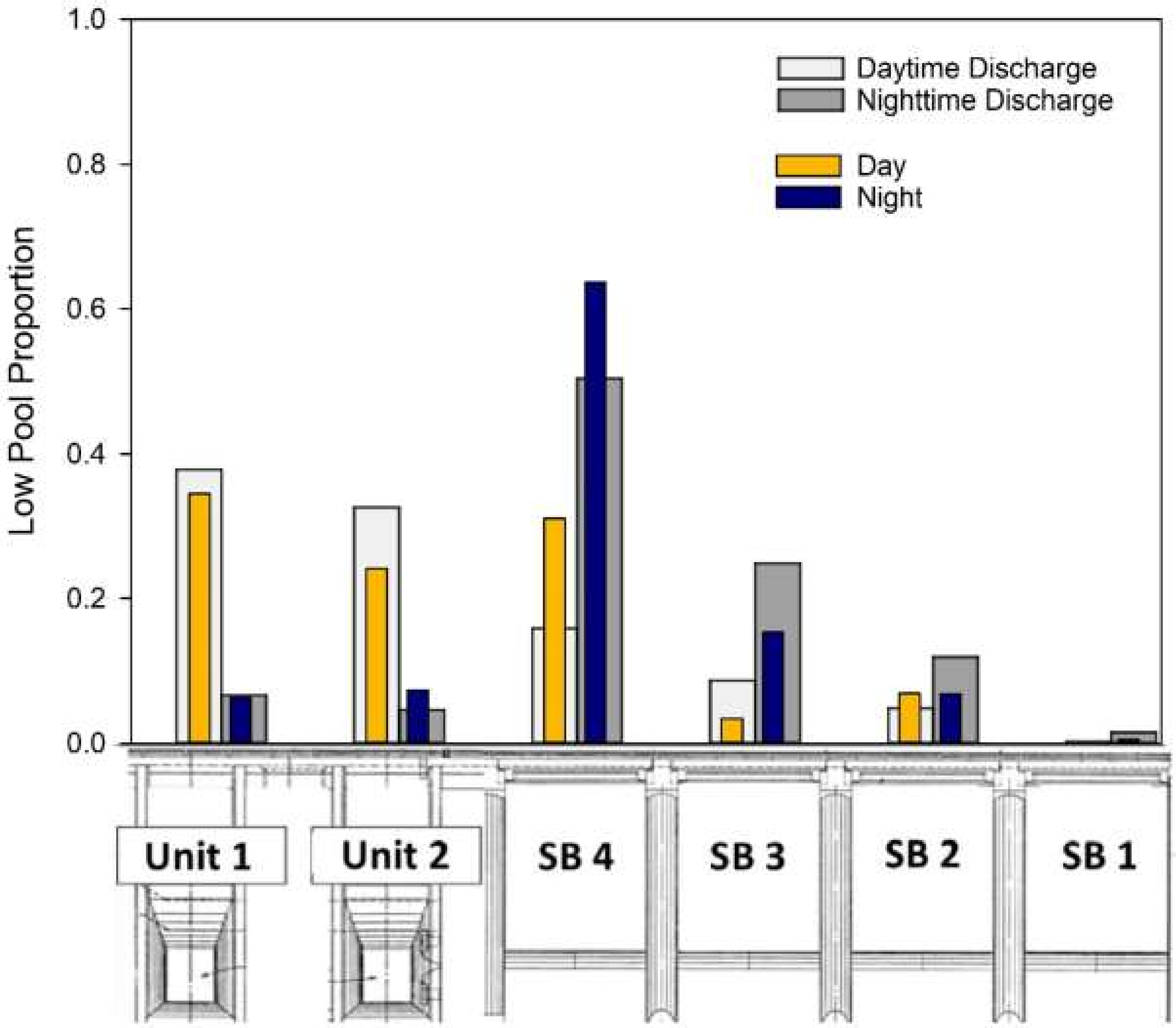

Figure 3-39. Diel passage proportions for age-1+ winter steelhead passed during fall low pool at Foster compared to the amount of discharge through the same route (SB = Spill Bay). The view of passage routes is looking downstream from the reservoir.

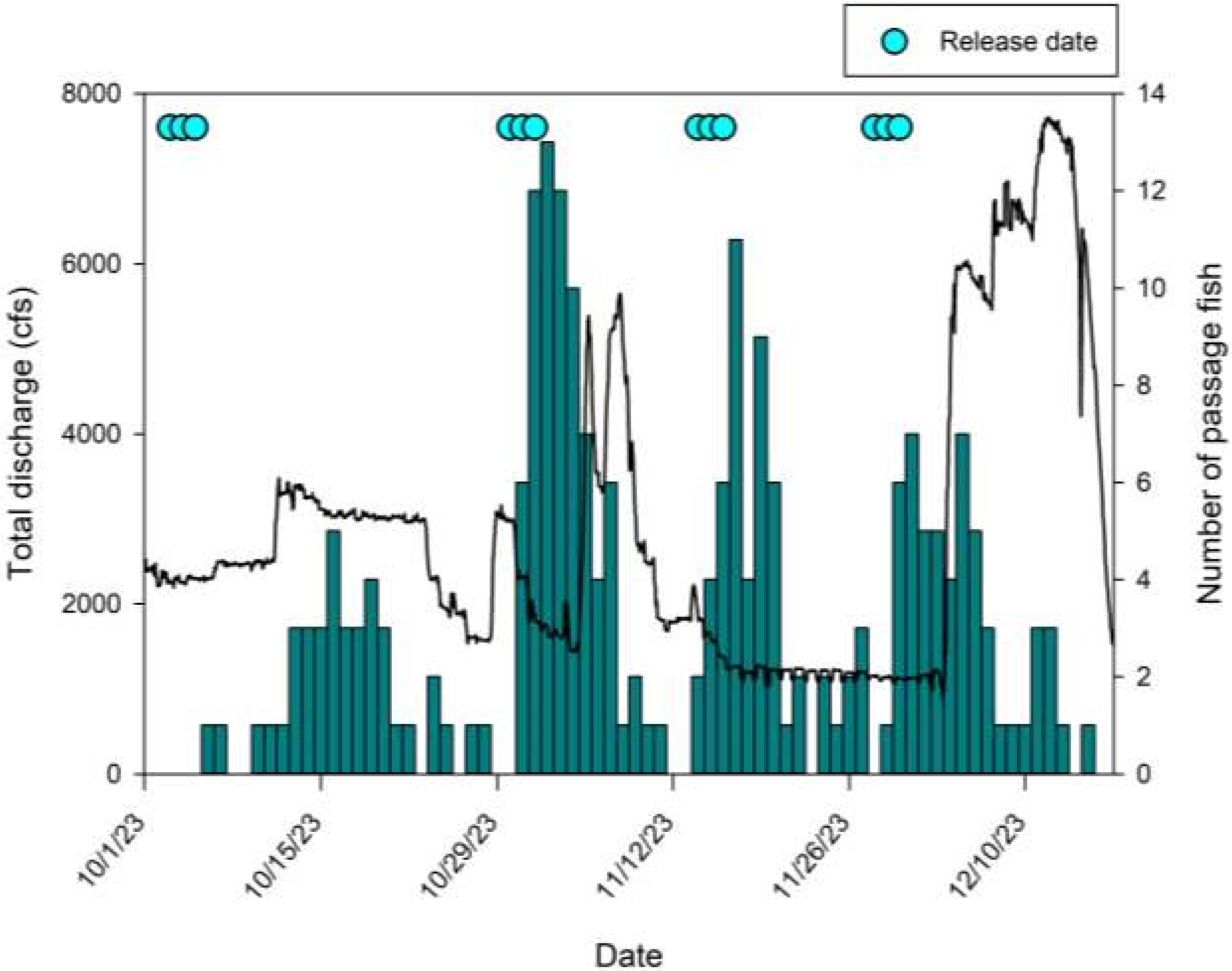

Figure 3-40. Total discharge (solid black line; left y-axis) as compared to number of passed age-1+ winter steelhead (bar plot; right y-axis) at Foster. Circle symbols indicate the dates of fish releases. Fish were detected passing Foster during fall low pool from October 6 to December 15. Two fish passed after fall low pool during the no treatment period and were not included in the figure.

3.4.6.5 Efficiency and Effectiveness

A total of 546 age-1+ winter steelhead were included in the efficiency and effectiveness analyses during fall low pool, with a total of 219 fish having known passage routes (Table 3-28). Overall fall low pool DPE was 40.1%, daytime turbine DPE was 5.3%, and nighttime spill DPE was 34.8% (Table 3-30, Figure 3-41). Nearly 20% of all low pool fish passed via the turbines and overall FPE was 32.2%, daytime turbine FPE was 2.4%, and nighttime spill FPE was 29.9% (Table 3-30, Figure 3-41). Both DPE and FPE were relatively low; however, it may not be directly indicative of poor conditions at Foster, as previous studies have had similar results of steelhead remaining in the reservoir instead of moving downstream (Hughes et al. 2016, 2017, 2021; Liss et al. 2020, 2023).

Overall fall low pool SPE was 80.4%, daytime turbine SPE was 44.8%, and nighttime spill SPE was 85.8% (Table 3-30, Figure 3-41). Low pool spillway effectiveness was > 1.0 overall and during the daytime turbine operation, but 0.97 during the nighttime spill operation (Table 3-30; Figure 3-41). Reduced effectiveness during nighttime spill is attributed to the spillway efficiency being lower than the proportion of discharge through spillways (i.e., night SPE = 0.858 and nighttime spillway proportion of discharge = 0.887). During the fall of 2015 and 2016 age-1+ winter steelhead were released into Foster Reservoir and had very low passage rates (Hughes et al 2016, 2017). A combined 239 age-1+ winter steelhead were released over these 2 study years and only 15 fish passed the dam indicating age-1+ steelhead have low outmigration rates (Hughes et al. 2017).

During the no treatment period (after December 16, 2023) only 10 age-1+ winter steelhead were available to pass, with 2 fish passing through the spillway. One fish passed during the night and the other during the day.

Table 3-30. Passage efficiencies and effectiveness for age-1+ winter steelhead at Foster in fall low pool 2023. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while the Spillway Passage Efficiency (SPE) is relative to the total number of fish that passed the dam (as indicated by "|| Dam"). Effectiveness is based on the SPE and the total dam discharge through those routes. Standard errors are in parentheses.

Metric	Overall	Daytime Turbines	Nighttime Spill
DPE	**0.401 (0.021)**	**0.053 (0.010)**	**0.348 (0.020)**
FPE	**0.322 (0.020)**	**0.024 (0.019)**	**0.299 (0.020)**
SPE || Dam	0.804 (0.027)	0.448 (0.092)	0.858 (0.025)
Spillway Effect.	1.190 (0.040)	1.514 (0.312)	0.967 (0.029)

DPE = dam passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).
FPE = fish passage efficiency; proportion of fish passing via a non-turbine route relative to the number detected in the near forebay (< 100 m from dam-face).
SPE = spillway passage efficiency; proportion of fish that passed Foster through Spill Bays 1–4.
Spillway Effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.

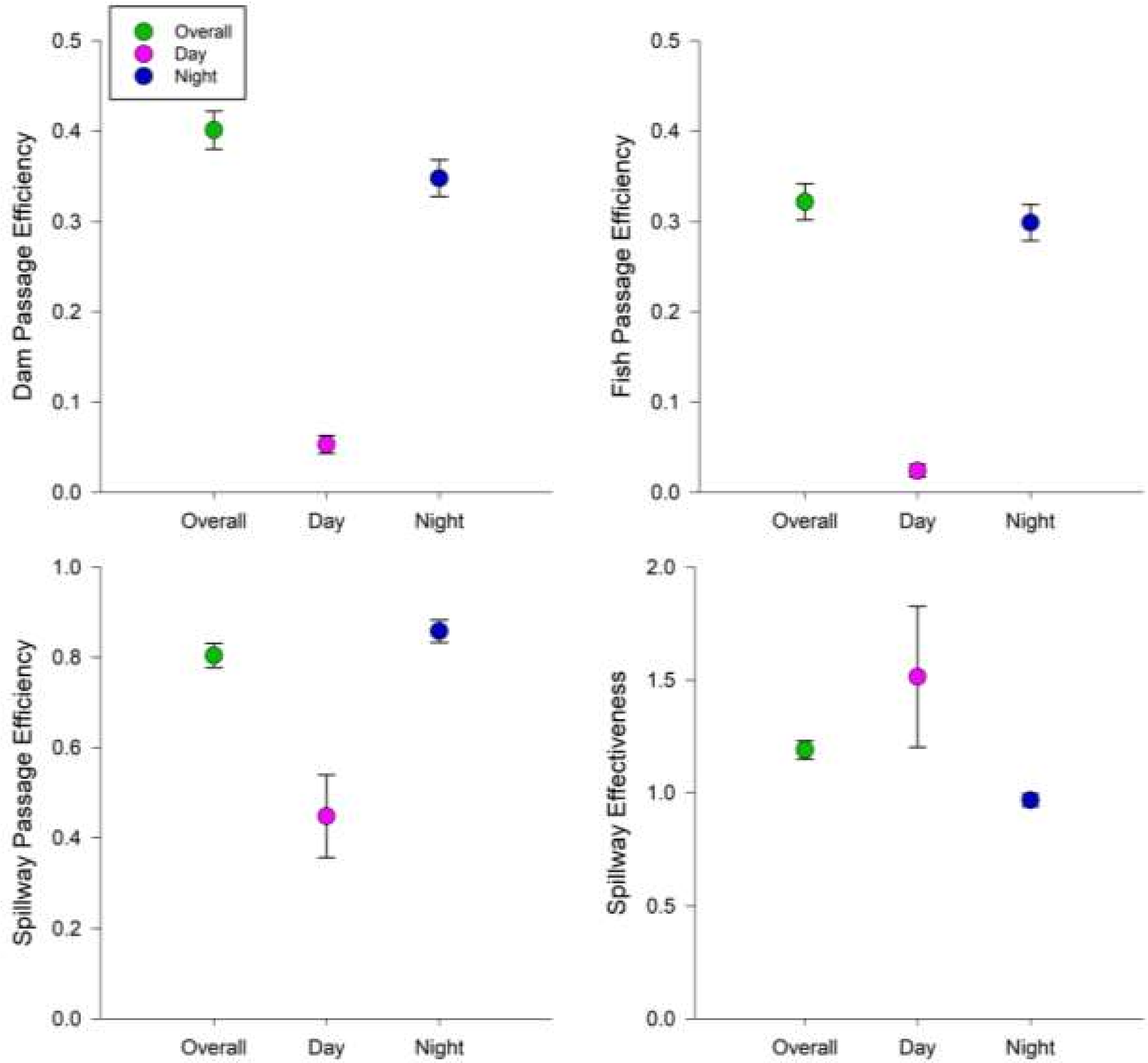

Figure 3-41. Dam passage efficiency, fish passage efficiency, spillway passage efficiency, and effectiveness of age-1+ winter steelhead released during low pool at Foster in Fall 2023. Error bars represent standard errors (SE) of the mean. A lack of error bars indicates the SE was 0.000.

4.0 Discussion

All spring study results for the yearling Chinook salmon released at Foster should be interpreted with caution. Fewer yearling Chinook salmon were tagged and released than what was planned due to disease, leading to smaller sample sizes and results that may not reflect population-level trends.

Survival

Dam passage survival was consistently higher than reach survival for subyearling Chinook salmon during the Green Peter fall deep drawdown (~73% compared to 23%), and for all species and seasons at Foster (~80 and 90% compared to ~31 and 61% for yearling and subyearling Chinook salmon dam passage and reach survival, respectively; and ~24 and 30% dam passage with no reach survival estimates for age-1 and age-1+ winter steelhead, respectively). Survival estimates from Foster to the Egress Array in 2023 were similar to results from 2018 (ranging from ~87% during low pool to ~81% during high pool; Liss et al. 2020). The higher dam passage survival estimates are likely due to its shorter river distance between dam and the survival array, as dam passage survival is estimated approximately 5 rkm downstream of Green Peter and the reach survival estimate was approximately 81 rkm downstream. Because of this additional distance, reach survival included other factors that occur well downstream of the dams, such as river topography, environmental conditions, or biological interactions (predation). As a result, estimating survival over a shorter reach (dam passage) allows for more meaningful comparisons between passage routes, diel passage periods, and operations that are less influenced by other factors that may cause mortality downstream of the dams that are unrelated to dam passage conditions.

The deep drawdown RO operation treatment at Green Peter in the fall represented fish emigration from the Green Peter Reservoir after the reservoir elevation was drawn down below the turbine penstocks. Results indicated the north and south ROs had similar estimates of dam passage and reach survival. These results suggest that both routes of RO passage are approximately equivalent in their survivability for downstream salmon passage. For both routes, the greatest decrease in survival occurred from Green Peter to Foster. This may have been from an influx of predators in that reach of river, as they may have also passed the dam during the drawdown and are not migratory; thus, they remained in that reach. It may have also been related to the amount of time they spent in that reach relative to other reaches (i.e., more time = more potential for mortality).

Small proportions of steelhead passing Foster is consistent with previous studies (Hughes et al. 2016, 2017). Hughes et al. (2016, 2017) reported passage proportions of 4.3% and 7.6% for age-1+ steelhead released in the fall in 2015, and 2016, respectively. Age-1 steelhead had not previously been released in the spring prior to the 2023 study but previous reporting on the life history characteristics of steelhead in the South Santiam River would suggest that the passage proportions observed in this study are representative of age-1 steelhead, as this life stage does not typically migrate. Instead, steelhead rear in the reservoir and migrate out in the spring at age-2 (Romer et al. 2016; Monzyk et al. 2017). Therefore, it is unlikely age-1 steelhead would move in spring when they are also unlikely to move in fall as age-1+. Because steelhead typically pass at age-2, passage metrics reported for age-1 and age-1+ steelhead are not likely to be representative of most steelhead that pass Foster.

For those age-1 and age-1+ steelhead that did pass Foster, dam passage survival estimates were poor even though they were higher than reach survival estimates. The survival results for the spring age-1 steelhead should also be interpreted with caution as only 23 fish passed the dam during low pool and 3 passed during high pool, although survival remained poor with a larger number of age-1+ steelhead passing the fall (n = 223). Survival could not be estimated for age-1 steelhead in previous studies (Hughes et al. 2016, 2017), so no comparisons could be made. For both age classes most fish passed via the spillway, which is typically a safer route of passage compared to the turbines (Hughes et al. 2016, 2017; Liss et al. 2020). Therefore, it is possible the low survival was a result of the small size of steelhead (mean length = 122 mm FL in spring, 144 mm FL in fall) compared to when they typically migrate as age-2 steelhead (mean FLs of 182 mm, 172 mm, and 178 mm in 2015, 2016, and 2022, respectively; Hughes et al. 2016, 2017; Liss et al. 2023) and they may have been more susceptible to predation after dam passage, as larger fish (e.g., trout) and birds are often observed to be in that area. It is also possible the low survival could have been caused by residualization of tagged fish between Foster and the Egress Array.

At Foster, survival for daytime turbine and nighttime spillway operations could not often be compared because few to no fish passed during the daytime turbine operations. When sufficient sample sizes allowed for a route of passage survival comparison (spillway compared to the turbines), survival varied. For subyearling Chinook salmon, survival was higher via the spillway than turbines; however, for age-1+ winter steelhead, survival was similarly poor between the spillway and turbines. Again, this poor survival (or potential residualization of tagged fish) may have been a result of the small size of the steelhead and the potential for increased predation. In previous study years, spillway passage survival estimates for Chinook salmon and steelhead was similar to turbine passage survival estimates; however, the majority of fish passed via the spillway (Liss et al. 2022). Collectively, these results suggest that more fish are passing the spillway and at night; thus, the nighttime spillway operation is beneficial for downstream fish passage and survival.

Reservoir Residency and Travel Times

Fish released at Green Peter had differing reservoir residency times based on whether the fish passed during day or night, but overall spent a median of 18 h in the reservoir before passage. The majority of fish passed during the night (~85%), which is similar to what has been reported for subyearling Chinook salmon at Foster in the past (Hughes et al. 2016, 2017, Liss et al. 2020, 2023). When comparing travel times to downstream reaches, daytime and nighttime fish had similar proportions of fish detected at each site. From Green Peter Reservoir to Sunnyside, 68.8% of daytime passed fish were detected compared to 71.3% of nighttime fish. For Egress Array to Primary Array, daytime fish (22.9%) and nighttime fish (23.9%) were again similar. This pattern held true through the most downstream site, as 8.3% of daytime fish and 11.2% of nighttime fish had calculated travel times from Santiam Rest Stop to Willamette Falls. The 2023 study year was the first year evaluating the Green Peter Reservoir deep drawdown operation, so travel time comparisons to previous study years were not possible.

During spring 2023 at Foster, nighttime-passed yearling Chinook salmon and age-1 steelhead had shorter overall reservoir residencies than daytime-passed salmon and steelhead. Nighttime-passed yearling Chinook salmon, daytime- and nighttime-passed age-1 steelhead all had greater reservoir residency times for MOR released fish compared to HOR releases. The longer MOR residency time could not be compared to previous study years for age-1 steelhead because this was the first year they were released in the spring as age-1 fish. However, the longer MOR residency time in 2023 finding contrasts with the 2022 spring Chinook salmon, where MOR releases resulted in shorter reservoir residencies. It was presumed to be because of the decreased distance needed to travel between release location and Foster. The longer MOR residency times observed in the 2023 study could be attributed to a number of factors. First, the yearling Chinook salmon may have been ill even though they were not displaying symptoms at the time of the February tagging. Delayed onset disease symptoms once in the reservoir could have inhibited instinctual fish movements. Additionally, after the onset of the disease for untagged study fish fewer fish were tagged and released. This resulted in a smaller sample size than originally planned, which may have also affected the median residency time results. Age-1 steelhead were small in size, which may have been affected by aspects of the MOR environment (e.g., deep, no shoreline, no attraction flow, needing to search for cover/habitat) that contributed to longer residence times.

The nighttime-passed subyearling Chinook salmon and age-1+ steelhead released at Foster in fall had shorter overall reservoir residency compared to daytime-passed fish. Nighttime-passed Chinook salmon and daytime- and nighttime-passed steelhead had shorter MOR residency times than fish released at the HOR. Daytime-passed Chinook salmon had a longer MOR residency time than fish released at the HOR. Age-1+ steelhead released at HOR with daytime dam passage had the longest reservoir residency (median = 314 h); however, sample sizes were small for daytime-passed steelhead (n = 30 total), which may have affected the results. All the residency times (daytime/nighttime/HOR/MOR) for both species were longer in the fall than in the spring. This longer residence time in fall-released fish compared to spring has also been observed in passage studies of Chinook salmon at other dams in the Willamette Basin (Beeman et al. 2014).

For the spring season, travel times to the reaches downstream of Foster varied for daytime-passed yearling Chinook salmon compared to nighttime-passed fish. Travel times for nighttime-passed fish were slower to the Egress and Primary Arrays, but faster to Lebanon Dam and the confluence of the Santiam and Willamette rivers. Only nighttime-passed made it to the furthest array downstream at Willamette Falls. These results may have been because fewer daytime-passed fish were detected at the downstream arrays compared to the nighttime-passed fish. No age-1 steelhead made it further downstream than the Primary Array during low pool, although travel times to the Egress Array were faster for nighttime-passed fish than daytime-passed fish. No high pool released fish made it to the Egress Array. No concrete conclusions can be discerned from these results about the migration behavior of yearling Chinook salmon nor age-1 steelhead as they relate to the operational treatments during the spring study.

For the fall season, travel times to the reaches downstream of Foster also varied. Travel times for nighttime-passed fish subyearling Chinook salmon were faster to the Egress Array but slower to all other arrays compared to daytime-passed fish. Only nighttime-passed made it to the furthest array downstream at Willamette Falls. This again may have been caused by the much smaller sample sizes of fish that were daytime-passed compared to nighttime-passed fish. Although a much larger number of age-1+ steelhead were detected and passed Foster in fall than in spring, few fish made it past the Egress Array. Nighttime-passed steelhead were faster to the Egress Array than daytime-passed fish, and only nighttime-passed fish made it past the Egress Array. The furthest downstream travel was to Lebanon Dam. Compared to subyearling Chinook salmon released in fall during the 2022 study, travel times were slower to all reaches for fish from the 2023 study. It's unclear what may have caused this, as the median discharge at the time of passage was similar in 2022 (1,825 cfs) and in 2023 (1,790 cfs). However, in 2023, 25% of subyearling Chinook salmon passed when total discharge was ≤ 1,200 cfs. In 2022, 100% of subyearling Chinook salmon passed when discharge was ≥ 1,240 cfs (Liss et al. 2023) and water temperatures were also similar. For age-1+ steelhead, similar to spring no concrete conclusions could be made about the migration behavior of age-1+ steelhead as it relates to the operational treatments.

Passage Distributions

Across all species and seasons, the majority of fish released at Green Peter and Foster dams passed during the night, a pattern that was also observed in the 2022 study. At Green Peter, roughly half (53.2%) of fish that were detected after release successfully passed the dam. The most common route of passage was the south RO at night, with 60.4% of RO passage occurring via that route and timing. However, this may have been because the north RO was closed for the majority of the treatment period. According to dam operations, the north RO (RN) was not open from November 11–December 6.

The initial planned date of refilling the Green Peter reservoir was December 16. During the fall study, the reservoir was to be kept at about 780 ft., or 35 ft. above the RO intakes at 745 ft. However, by December 1, the reservoir began filling quickly due to storm events and a winter flood. At 08:00 on December 1, forebay elevation was 775 ft. By the same time on December 3, the elevation was 800 ft. (55 ft. above the RO intakes). The forebay elevation finally reached 900 ft. on December 15. A final fish release for the season was performed during December 1–December 2 (n = 187 fish). Because of the environmental conditions in the watershed, the final cohort of subyearling Chinook salmon had less time to pass when the RO intakes were at the deep drawdown elevation (780 ft.). As a result, only 13 of the 187 fish passed Green Peter, with several of the fish passing through ROs when the intakes were over 150 ft. underwater.

All spring-released yearling Chinook salmon that passed Foster (n = 34) did so by Spill Bay 4, with most (67.6%) of these passages occurring at night. A similar trend was observed in spring 2022, where yearling Chinook salmon passing via Spill Bay 4 accounted for 90.1% of all dam passage. For fall-released subyearling Chinook salmon, 68.5% passed using Spill Bay 4 and 91.8% of those passages occurred at night. These results mimic those obtained in 2022; a total of 61.3% of subyearling Chinook passage was through Spill Bay 4. This may have also been because Spill Bay 4 typically has the most discharge when the spillway is operated.

Of the spring-released age-1 steelhead, only 12.6% (n = 27) passed Foster. The steelhead released in fall were older, age-1+, and passed the dam at a higher proportion (31.4%, n = 223). These results are similar to those found in previous studies regarding winter steelhead passage at Foster (Romer et al. 2016; Monzyk et al. 2017). Researchers found that age-1 fish comprised only 13% of passing winter steelhead, whereas 84% were age-2 (Monzyk et al. 2017). Monzyk et al. (2017) also found that >97% of winter steelhead passage occurred during the spring (March–June). Although the sample size was small, 2.1% of age-1 steelhead in spring and 3.5% of age-1+ steelhead in fall had final detections at the Sunnyside Array, which is upstream of Foster and may indicate rearing or predation in the reservoir.

No yearling Chinook salmon and only three age-1 steelhead passed Foster through the turbines during spring low pool. In the fall, 18% of subyearling Chinook salmon passed Foster through the turbines, with a majority (56.3%) of those passages occurring during the day. Of the age-1+ steelhead that passed Foster, 19.5% passed through the turbines, with only 37.2% of steelhead turbine passages occurring during the day. These results indicated that turbine use did not occur only during the day as originally planned; thus, leading to some night turbine passage. However, it was a lesser used route than the spillway for both species and seasons. In the fall, it is possible that subyearling Chinook were subjected to warmer surface water temperatures and could have dived deeper to seek cooler water, which would have allowed easy access to the penstock openings (Li et al. 2015).

Efficiency and Effectiveness

The Green Peter Reservoir began to fill quickly throughout the beginning of December from storm events. This is likely why passage through the ROs for the final release group of subyearling Chinook salmon was inhibited. Subyearling Chinook salmon typically reside in the top of the water column (shallower than 16 m; Li et al. 2018) and the entrance to the ROs increased from approximately 30 ft. to 150 ft., resulting in the need for fish to dive (sound) deep to find a route of passage. Although unlikely for most fish to sound to deep depths, some fish were documented as passing the ROs during that time. Although this affected passage proportions, it did not have an effect on DPE because the fish that did not sound were also not detected on the RO antennas and therefore did not attempt passage. This indicates that the DPE did not change as the fish were not technically available to pass after water elevations rose.

The calculated RNE (0.298) and RN Effectiveness (0.824) were artificially low because the RN was closed for much of the release season. Therefore, not many fish were able to pass through it compared to the overall number of fish that passed Green Peter (n = 94 of 316). If the RNE was calculated based on the total number of fish that passed by ROs only during the period RN was open, then the RNE would be greater. This would subsequently yield a greater value for RN Effectiveness as well. It is also difficult to conclude whether fish were preferentially passing through the RS by choice or by necessity because it was the only available route of passage.

At Foster in the spring, DPE was 0.548 for yearling Chinook salmon and 0.154 for age-1 steelhead. These low values are due to the number of fish available to pass but did not. The lack of passage may have been linked to the colder water temperatures or photoperiod, environmental cues that typically affect run timing (Keefer et al. 2008). For age-1 steelhead that were available to pass but did not, it may have also been because of life history characteristics and their tendency to reside in the reservoir until age-2 (Romer et al. 2016; Monzyk et al. 2017). In fall, DPE was 0.766 for subyearling Chinook salmon and 0.401 for age-1+ steelhead. This indicates that of the fish available to pass, a greater proportion passed the dam. The fall releases aligned with the run timing of subyearling Chinook salmon environmental cues (temperature, photoperiod), which may have contributed to the greater DPE. Although the DPE is still low for age-1+ steelhead, it was greatly improved compared to the spring age-1 steelhead, indicative that migration may be more likely for older fish and supporting the previous research that steelhead migrate as age-2 (Romer et al. 2016; Monzyk et al. 2017).

Overall SPE was high at Foster regardless of species or season (0.804–1.00), demonstrating the tendency of fish to use the spillway as the primary route of passage. When separated into daytime and nighttime, SPE was still high for spring released yearling Chinook salmon and age-1 steelhead during low pool (0.818–1.00 for nighttime and 0.900 for daytime for age-1 steelhead only). For fish released in the fall, SPE was high for fish that passed Foster at night (0.905 for subyearling Chinook salmon, 0.858 for age-1+ steelhead) and much lower for fish that passed during the day (0.400 and 0.448, respectively). These values highlight the increased daytime use of turbine passage by subyearling Chinook salmon and age-1+ steelhead released in the fall.

Spillway effectiveness, or the proportion of fish that passed over the spillway divided by the proportional spillway discharge, was high across all species and seasons at Foster, indicating the spillway was effective at passing fish. An effectiveness of 1.0 or greater is considered high, and spillway effectiveness was 1.746 for yearling Chinook salmon and 1.496 for age-1 steelhead in the spring, and 1.213 for subyearling Chinook salmon and 1.190 for age-1+ steelhead in the fall. This indicates that although yearling Chinook salmon and age-1 steelhead may have been available to, but did not pass Foster in spring (low DPE), the spillway was a very effective route of passage for those that did pass, and spillway operations should continue.

The slightly lower effectiveness values from the fall may have been caused by the increased discharge observed in that season (2,860 cfs in the fall compared to 2,129 cfs in spring low pool). For both seasons, spillway effectiveness was higher for daytime passage than nighttime passage, with the greatest differences observed in spring fish (2.776 daytime compared to 1.161 nighttime for yearling Chinook salmon, 2.498 compared to 0.950 for age-1 steelhead). Although nighttime spillway effectiveness was still high for all species and seasons (≥0.950), the greater effectiveness for daytime indicates fish were still effectively passing via the spillway even when proportionally less water was being discharged.

Environmental Conditions

At Green Peter, observed differences in passage proportions between the two ROs were noted. The main contributor to this difference was likely due to the RN being closed for the majority of the treatment period (25 days). However, discharge proportion by route (RN = 36%, RS = 64%) was relatively close to passage proportion by route (RN = 30%, RS = 70%). Discharge did not appear to affect survival, as survival was similar for each RO. The timing of fish passage appeared to be most affected by forebay elevation and time of year. During the December releases, fewer fish passed after release, which may have been caused by the increase in forebay elevation (thereby increasing the depth Chinook salmon needed to sound to find the RO to pass the dam), or a decrease in water temperature (5–10 °C compared to the 10+ °C of the earlier releases).

During the spring season at Foster, discharge was similar for low and high pool elevations. Although the steelhead released in spring were subjected to similar discharge during both low pool and high pool, 25 steelhead passed during low pool compared to 3 at high pool, suggesting there were other factors influencing spring steelhead passage. The overall lack of passage may have been from life history characteristics of age-1 steelhead typically not migrating (Romer et al. 2016, Hughes et al. 2016, 2017; Monzyk et al. 2017). During high pool it may have also been a result of the warmer water temperatures (10–20 °C during high pool compared to the 8–10 °C of low pool).

The mean daily discharge at Foster during fall low pool was 2,860 cfs (daytime daily: 2,825 cfs; nighttime daily: 2,878 cfs). While daily discharge was greater during fall low pool, it did not appear to stimulate faster migration out of the reservoir for subyearling Chinook salmon nor age-1+ steelhead. However, there was a greater number of steelhead that passed Foster during fall. This may have been an artifact of age (age-1+), larger fish size, or water temperatures holding relatively consistent at an appropriate range to promote fish passage (between 8–12 °C).

Predation

Age-1+ steelhead released at Foster in the fall had the highest number of presumed predation events (n = 113). Spring-released age-1 steelhead had the second highest number of presumed predation events (n = 90). However, these estimates represent a small percentage of steelhead released alive (7.4% and 6.0%, respectively). Predation was presumed for 9 subyearling Chinook released at Foster in the fall. Yearling Chinook salmon released in spring had the largest percentage of suspected predation events (12.1%). In spring, 18 yearling Chinook salmon were presumed to have predation events, which is a high number due to the few fish that were tagged and released due to disease.

Avian predation was originally reported for the Foster study area in 2018 (Liss et al. 2020). It was noted in 2022 (Liss et al. 2023) and again in the current study. Cormorants (*Phalacrocorax auratus*) and common mergansers (*Mergus merganser*) are frequently observed in the Foster Reservoir, often resting on the log boom. Because of these observations, travel times for released fish were analyzed with extra scrutiny for behaviors that could fittingly be explained by avian predation, such as impossibly quick travel downstream or returning to sites upstream of the dams after dam passage.

Predation has also been observed by larger salmonids in the Foster tailrace. In spring 2022, a rainbow trout was caught by a local angler with 11 RT tags from PNNL-released fish in its gut. All tags were associated with dead releases (DFR), which highlights the potential for fish predation in the tailwaters if fish are unable to migrate swiftly downstream. This was also anecdotally observed in spring 2024. A large salmonid in the Foster tailwaters immediately caught and ate a dead fish upon its release. If fish are not able to recover quickly after dam passage, it could leave them susceptible to predation.

Less is known about the potential predation at Green Peter as this is the second year of study and the first year for the fall deep drawdown operation. For fish released at Green Peter this fall, 78 total predation events were suspected. The draw down of the reservoir may have caused habitat or cover to be less available for Chinook salmon, potentially affecting their ability to hide from other fish or avian predators. Additionally, predator fish species were likely flushed out of the Green Peter Reservoir during the draw down. These predator fish may have resided in the stretch of river between Green Peter and Foster, which may be why the majority (*n* = 54) of the presumed predation events occurred between the Green Peter forebay and the first array downstream at Sunnyside.

5.0 Management Applications

The 2023 Evaluation of Foster Dam Spillway and Green Peter Dam Spillway and Regulating Outlet Operations for Juvenile Fish Passage: Year 2 encountered a few challenges. Primarily, yearling Chinook salmon in spring were diseased, and unable to be used for evaluations of spillway operations at Green Peter for the entire season, and at Foster after the first tagging event in February. Another challenge was the lack of migration by age-1 and age-1+ winter steelhead. This was not unexpected, as previous literature has also documented this finding (Romer et al. 2016; Monzyk et al. 2017; Hughes et al. 2016, 2017) and it was not recommended to evaluate age-1 steelhead at Foster (Hughes et al. 2016, 2017; Liss et al. 2020). It is recommended to perform the study again in spring at Green Peter and Foster using healthy yearling Chinook salmon to provide a full-scale evaluation and cross-years comparison of the spillway operations. It is not recommended to tag and release age-1 steelhead in future studies.

The objectives of the Green Peter task in fall were to evaluate the deep drawdown RO operations as a potential route of passage for subyearling Chinook salmon. The fall study was intended to evaluate passage efficiency and survival for only the ROs – e.g., for subyearling Chinook salmon emigrating from the Green Peter Reservoir after the reservoir elevation was drawn down below the turbine penstocks. Results suggest that the ROs overall were efficient and effective at passing subyearling Chinook salmon. Dam passage survival was high, indicating that the deep drawdown could be a viable option for salmon passage. However, reach survival was poor. Even if the reservoir is drawn down on a yearly basis, it may not necessarily result in high rates of returning adults when downstream-migrating juveniles are encountering poor survival to the confluence of the mainstem Willamette River. There are many unknowns as to what is causing the poor survival as there is a lot a fish may encounter in the 81 rkm journey (e.g., inability to find cover/seek shelter, susceptibility to avian or fish predation, fishing pressures, etc.). However, the greatest decrease in survival occurred from Green Peter to Foster. Delayed effects of dam passage would have likely occurred in the reach from Green Peter to Sunnyside; thus, a more likely scenario is the potential increase in predation if predator fish were also passed during the deep drawdown. The stretch of river can be shallow and narrow from Green Peter to Foster, ideal conditions for predator fish (dependent on the gradient and species).

The objectives of the Foster task were to evaluate if the nighttime spillway operations provided safer and more efficient passage compared to daytime turbine operations for yearling Chinook salmon and age-1 winter steelhead in spring and subyearling Chinook salmon and age-1+ winter steelhead in fall. For Chinook salmon, results suggest that the majority of fish passed at night for both yearling and subyearling age classes. Nighttime spillway operations provided a safe route of passage for fish released in spring (although no fish passed the turbines, so survival could not be compared) and during fall, although daytime survival was similar. For steelhead, results suggest that low proportions of age-1+ (fall) and even lower proportions of age-1 (spring) steelhead passed the dam. For those that did pass, the majority of fish passed at night, and nighttime spillway operations provided a safer passage than daytime turbine operations as survival was higher for nighttime passed fish (even though it was still poor overall).

Spillway passage efficiency was higher for nighttime spillway operations than daytime for yearling and subyearling Chinook salmon, and age-1 and age-1+ steelhead, suggesting the spillway was an efficient route of passage. Overall, the spillway was also effective for both age classes of Chinook salmon and steelhead. No yearling Chinook salmon passed during the day in spring, so spillway effectiveness was higher during nighttime spillway operations compared to daytime turbine operations. Interestingly, spillway effectiveness was higher for the daytime turbine operations than nighttime spillway for subyearling Chinook salmon and age-1 and age-1+ steelhead, but this is likely because some fish passed via the spillway during the daytime even though spillway discharge was relatively low.

Collectively, the results from the 2023 study support previous findings that Chinook salmon and steelhead pass the dam in greater proportions at night than during the day (Hughes et al. 2016, 2017; Liss et al. 2020, 2023). Results also support previous findings that the nighttime spillway operation is a safer and more efficient route of passage than turbine passage for downstream-migrating juvenile salmonids at Foster (Liss et al. 2023). In 2023, no evaluations of the spring spillway operations could be performed at Green Peter and the evaluations of the spring spillway operations for yearling Chinook salmon at Foster were limited due to fish disease. This was also the first year to evaluate fish passage and survival from Foster to the Santiam River confluence after RO operations at Green Peter in fall after the deep drawdown, so comparisons to previous study years were not possible. Results from this year suggest that the ROs, after the reservoir was drawn down below the penstock elevation, were a safe and efficient route of passage for downstream migrating subyearling Chinook salmon.

Performing another full-scale study at Green Peter and Foster during spring and fall to account for interannual environmental and fish behavior and migration conditions is recommended. A full-scale study at Green Peter in the spring is highly recommended to better understand if there are differences between operational treatments, and to continue to evaluate fish survival and migrations downstream of Green Peter because we were not able to perform a full-scale study in 2023. The variables of interest from this year's study (diel survival, migration travel times, passage distributions, and efficiency and effectiveness) can all fluctuate annually depending on dam operations (discharge) and environmental conditions (river temperature, snowmelt/rainfall, etc.). Multiple study years can also consider fish behavior (stock genetics, different species, size, etc.) as well as differences in operational factors (nighttime spill and 24/7 spill; RO operations, and turbine and spillway operations); therefore, it is important to have data from multiple study years. It is also recommended to evaluate the efficiency and survival of subyearling Chinook salmon that pass Green Peter during the draw down (while the pool is above the penstocks) to compare the ROs and turbines as routes of passage and more fully assess the effectiveness of the fall deep drawdown operation. In future fall studies at Green Peter, the study objectives and statistical assumptions should be evaluated to determine if the MOR release site can be at a location that is available throughout the fall draw down, or if the MOR release location is not necessary and only release fish at the HOR release location. At Green Peter, reservoir passage efficiency (RPE) estimates between the point of release and forebay detection at the dam should also be considered for evaluation. The RPE can be useful for understanding the relative contribution of reservoir mortality (before fish make it to the dam) and delay and/or passage prevention caused by the dam.

Finally, future studies should utilize the same design setup for cross-years comparisons of dam passage survival and reach survival. Should objectives change, building upon the design is recommended. For example, if an objective were to include evaluating the behavior of fish in the reservoirs (to account for fish not moving from release to the forebays of Green Peter and Foster), additional arrays should be considered. With continued advances in acoustic telemetry (AT) technology for detecting individuals in shallow, turbid, and challenging environments, and the ability to tag smaller fish, it may be beneficial to consider using AT in future study years with receivers located at similar sites.

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