PNNL-34370

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Draft Final

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the U.S. Army Corps of Engineers
under Study Code JPL-18-03-HHB

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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 March 2022 through February 2023 to evaluate spillway operations at both dams as a safer and effective route for downstream 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 second, to provide a baseline evaluation of spring spillway operations at Green Peter for juvenile Chinook salmon passage. Where appropriate for Foster, results from the 2022 study were compared to previous study years (2015, 2016, and 2018).

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. Yearling Chinook salmon (*n* = 420) were double tagged with an RT tag and a passive integrated transponder (PIT) tag for the Green Peter study and released into the Green Peter reservoir. Yearling Chinook salmon and age-2 winter steelhead were double tagged with an RT and a PIT tag for the Foster spring study. Chinook salmon and steelhead were released into the Foster reservoir during spring low pool (*n* = 318 and 647, respectively) and high pool (*n* = 547 and 894, respectively). Finally, subyearling Chinook salmon (*n* = 643) were double tagged with an RT and a PIT tag for the Foster fall study and released into the Foster reservoir.

Dam and reach passage survival varied among dams, species, stocks, pool elevations, and seasons. Survival rates for Foster were generally similar to previous study years with the exception of dam passage survival and survival from Foster to the Waterloo Primary Array located

19 river kilometers downstream (i.e., the 2015, 2016, and 2018 reach + tailwaters survival array), which were lower in 2022 compared to the 2015 and 2018 study years. However, there were similar overarching trends, as dam passage and reach survival were similar among operational treatments at Green Peter (nighttime only and 24/7 spill), and they were similar for diel passage periods at Foster in spring for yearling Chinook salmon during high pool and for steelhead during low and high pool; and in fall for subyearling Chinook salmon during low pool. The one exception was in spring for yearling Chinook salmon during low pool, as daytime passage had higher dam passage and reach survival than nighttime passage. However, the sample size of the fish that passed during the day was small (*n* = 16) and may not be an accurate representation of the population. Reach survival was also noticeably lower during low pool than it was for high pool at Foster in spring (to include Green Peter as those releases correlated with Foster low pool).

Reservoir residency times and migration travel times varied in 2022. Compared to previous study years at Foster, the 2022 dam operations used appear to the reduce reservoir residency times. Additionally, the Foster to Waterloo Primary Array travel times were generally shorter in 2022 compared to previous years, particularly for steelhead during high pool. This was likely an artifact of the higher flows during the 2022 high pool season. At Green Peter, fish released during the nighttime spill treatment traveled slower to all reaches downstream of the Sunnyside Array compared to fish released during the 24/7 spill treatment. At Foster in spring 2022, yearling Chinook salmon travel times were similar regardless of if they passed during the day or night, except for high pool when night-passed fish had shorter travel times to the Egress Array than day-passed fish. For steelhead, travel times were similar for day and night passage during low pool. During high pool, night-passed steelhead had shorter travel times to all downstream arrays compared to day-passed steelhead. In fall, subyearling Chinook salmon that passed Foster during the day traveled faster to all arrays downstream of the Egress Array compared to fish that passed at night. At Green Peter fish released during the nighttime spill treatment traveled slower to all reaches downstream of the Sunnyside Array compared to fish released during the 24/7 spill treatment.

Passage distributions also showed similar trends regardless of dam, species, stock, pool elevation, or season. Most fish migrated at night (greater proportions of nighttime passage), and the primary route of passage was through the spillway instead of the turbines (note: the turbines at Green Peter were not operated during the entire spill operations and one turbine at Foster was operated at minimum flow (approximately 200-250 cubic feet per second) during nighttime spill to reduce total dissolved gas levels in the tailwaters).

The dam passage efficiency (DPE) and fish passage efficiency (FPE) varied, but spill passage efficiency (SPE) and effectiveness showed similar trends regardless of dam, species, stock, pool elevation, or season. The overall SPEs were consistently greater than 92%. This contributed to the high overall spillway effectiveness values, which were 1.0 or greater. Green Peter was efficient at passing available yearling Chinook salmon for both the nighttime spill and 24/7 spill treatments (DPE and FPE). At Foster during spring, DPE and FPE were moderate but were similar to previous study years, and in most cases, did not increase from previous study years. For steelhead, DPE and FPE were low, but results did not decrease from previous study years. During fall, the Foster low pool DPE and FPE were again moderate for subyearling Chinook salmon. However, the overall FPE was greater in 2022 than previous study years, indicating the nighttime spillway operations may have improved the ability for Foster to pass available subyearling Chinook salmon.

Acknowledgments

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 2022-01).

Acronyms and Abbreviations

°C	degree(s) Celsius
AIC	Akaike's Information Criterion
ANOVA	analysis of variance
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
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
RO	regulating outlet
R	release
rkm	river kilometer(s)
RPA	reasonable and prudent alternative
rpm	revolutions per minute
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
STH2	juvenile wild surrogate steelhead age-2
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 baseline evaluation of spring spillway operations at Green Peter for juvenile Chinook salmon passage. Results will inform operations of the spillway for fish passage. This study was conducted by researchers from Pacific Northwest National Laboratory (PNNL). 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, regulating outlets (ROs), and spillway. The primary route for water to pass is through the turbines or ROs. The spillway is currently only used to pass excess water as necessary during high water events. 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 during mid-October through early March (depending on winter and early spring precipitation). Reservoir refill begins in February and the spillway is not typically available for operation until early to mid-March.

A juvenile fish bypass system was constructed and operated at Green Peter until 1987 when it was decommissioned. The bypass system was decommissioned because juvenile fish collection and passage survival were too low to support a self-sustaining population upstream of Green Peter. Additionally, adult Chinook salmon and steelhead were returning to the dam in numbers too low to support self-sustaining populations in the watershed above the dam. Currently, the watershed above Green Peter is devoid of anadromous fish.

Fish passage and survival at the spillway has not been evaluated previously; however, research conducted to evaluate similar spillways at high-head dams (e.g., Detroit and Lookout Point dams) showed high survival rates for juvenile fish passing the spillways (Beeman and Adams 2015; Kock et al. 2015; Fischer et al. 2019). 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, behavior, distribution, and movements; route of passage; and downstream survival to inform operations as a route for downstream fish passage.

The objectives for the Green Peter task were to release active tagged (radio telemetry [RT]) fish during two operational periods: (1) continuous (24/7) spillway operation (no turbine operation) and (2) nighttime spillway operation (the turbines were not operated during either operational period), to assess the two operational periods according to the following metrics:

I. Diel downstream passage, including dam passage and reach survival.
    a. Dam passage survival was measured to the first array downstream of Green Peter (Sunnyside Array), located approximately 5 rkm downstream.
    b. Reach survival was measured to the confluence of the Santiam River with the mainstem Willamette River (I-5 Santiam Rest Stop Array), located approximately 80 rkm downstream.
II. Reservoir (forebay) residency time and diel migration travel times.
III. Diel distribution and route distribution of juvenile Chinook salmon into and within the forebay of the dam and during dam passage (passage distributions).
IV. Dam passage efficiency and effectiveness of the nighttime spillway operation compared to the 24/7 spillway operation.

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 2 turbines and a spillway with 4 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 mortality TDG studies informed the current nighttime spillway operations during fall and spring months for downstream fish passage. The 2022 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 are operated for power generation during daylight hours and the spillway is not operated unless required to pass excess water. The timing and periods of the nighttime spill operation scheduled 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 (19:00) to dawn (07:00) during October 1–December 15

The objectives of the Foster task were to determine if the nighttime spillway operations provided safer and more efficient passage route compared to the turbines for subyearling and yearling Chinook salmon and age-2 winter steelhead (or appropriate surrogates) using the following metrics:

I. Seasonal and diel downstream passage, including dam passage, route specific, and reach survival.
    a. Dam passage survival was measured to the first array downstream of Foster (Egress Array), located approximately 3 rkm downstream.
    b. 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.

II. Seasonal and reservoir (forebay) residency time and diel migration travel times.

III. Seasonal and diel distribution and route distribution of juvenile fish into and within the forebay of the dam and during dam passage (passage distributions).

IV. Dam passage efficiency and effectiveness of 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. Tags were placed in the water and dragged at each RT receiver location to assess the size of the detection zone. Testing also occurred to minimize “bleed over” of detections among the detection zones and if any signal detection bleed over was present, to determine signal strength cutoffs to delineate actual fish location within the specified detection zones. 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 and Foster radio telemetry array deployment type, location, and study purpose.

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

(a) Gingerich et al. 2012; (b) Forebay elevation for low pool (613 fmsl); (c) Forebay elevation for high pool (635 fmsl).
[1] Dam passage survival; [2] Reach survival.

2.1.1 Green Peter Dam

This was the first time RT-tagged study fish were released in the reservoir and tracked in the forebay and through Green Peter. Detection zones monitored approach and passage of RT-tagged juvenile Chinook salmon through the spillway (Figure 2-1). Downstream of Green Peter, 9 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 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).

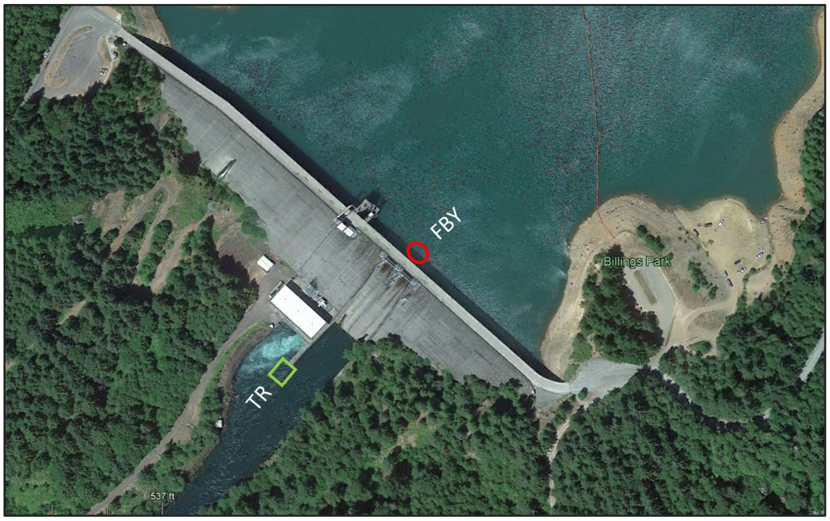

Figure 2-1. Radio telemetry detection locations to assess survival and behavior of juvenile Chinook salmon at Green Peter. The red circle depicts the forebay antenna (FBY), and the green square depicts the tailrace antenna (TR).

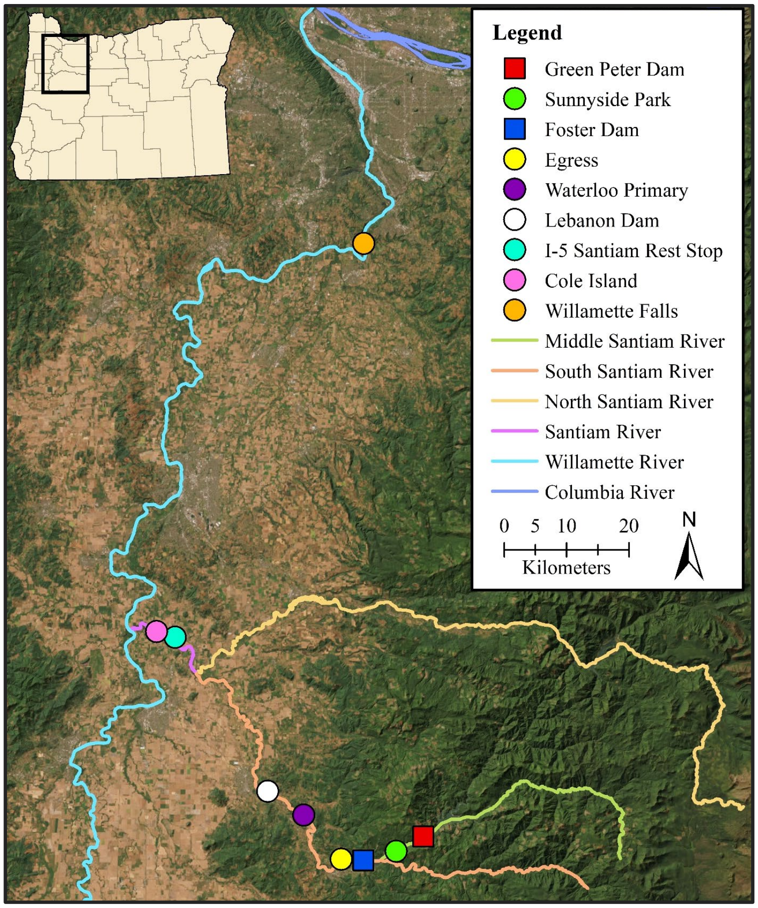

Figure 2-2. Map of the Green Peter/Foster study area. Detection arrays were located at Green Peter Dam (forebay and tailwaters), Sunnyside Park, Foster Dam (forebay, dam, and tailwaters), Egress, Waterloo Primary, Lebanon Dam, I-5 Santiam Rest Stop, Cole Island, and Willamette Falls Dam. The Santiam rivers flow east to west into the Willamette River, which flows from south to north into the Columbia River and the Pacific Ocean.

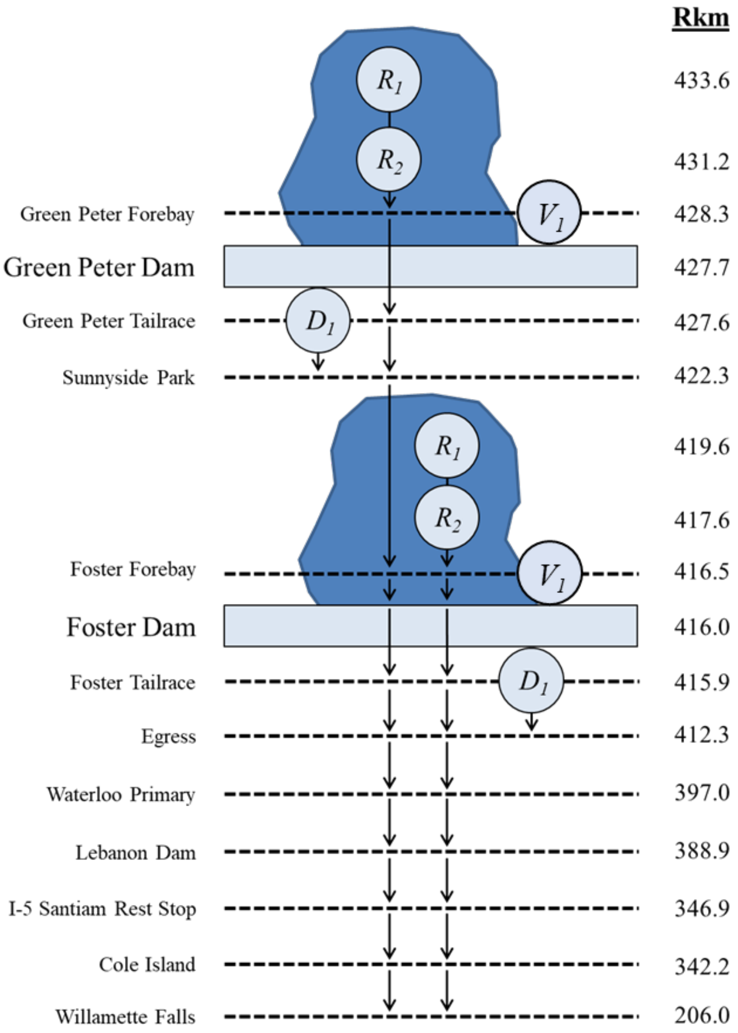

Figure 2-3. Schematic of the study design for Green Peter and Foster releases and approximate locations of detection arrays. R_1 and R_2 represent the head-of-reservoir and mid-of-reservoir release locations, respectively, for both Green Peter and Foster reservoirs. V_1 represents the virtual release 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 6 passage routes (2 turbines and 4 spill bays; Table 2-1; Figure 2-4). Previous studies also evaluated 2 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). As such, they were not evaluated in 2022.

Downstream of Foster, 6 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 (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).

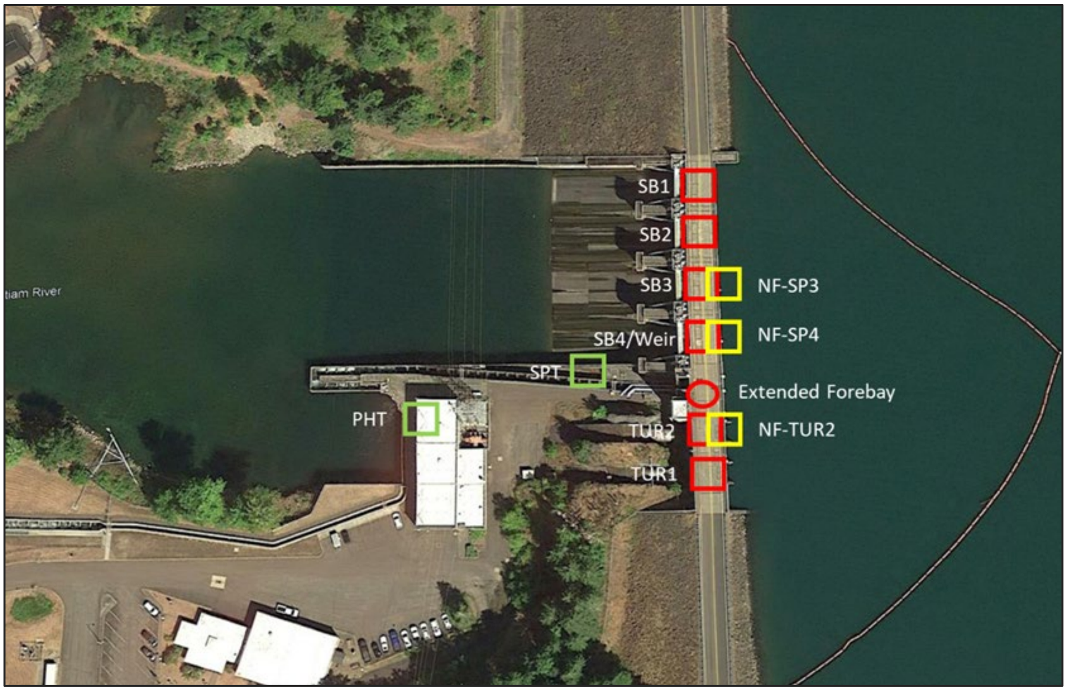

Figure 2-4. Radio telemetry detection locations to assess route-specific survival and behavior of juvenile Chinook salmon and steelhead at Foster. NF = near forebay, PHT = powerhouse tailrace, SB = spill bay, SP = spillway, SPT = spillway tailrace, TUR = turbine.

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). 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, several different frequencies were used to allow for the potential simultaneous detection of multiple tags (e.g., 166.620, 166.740, 166.766, 167.340, 167.380, 167.420, 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 equally distributed to minimize the chance of code collision—when too many fish are in one detection zone at the same time and consequently 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). The Green Peter spring release juvenile Chinook salmon (age-1) size ranged from 102 to 229 mm FL, while the Foster spring salmon size ranged from 114 to 244 mm FL (Table 2-2). Spring-released Foster juvenile winter steelhead (age-2) ranged from 114 to 239 mm FL (Table 2-2). Finally, fall released juvenile Chinook salmon (age-0) at Foster ranged from 97 to 176 mm FL (Table 2-2). Although age-1 steelhead do not typically migrate from the South Santiam River (Romer et al. 2016), this study would have included age-1 steelhead in the overall passage and survival evaluation; however, surrogate age-1 steelhead were not available in 2022. Study fish for the Green Peter and Foster releases were surgically implanted with both an RT tag and a PIT tag. PIT tag detection arrays exist in the Willamette River Basin, at Willamette Falls in the mainstem Willamette River and more recently at Lebanon Dam in the South Santiam River. Although the study fish were PIT tagged, PIT tag data are not reported because the downstream PIT detection sites were not functioning. However, when functioning in future study years, these PIT detection arrays may be used as a secondary identification tool to the RT arrays. Tagged fish were larger than 95 mm FL. This is the recommended minimum length for surgical implantation of tags in Chinook salmon to minimize tag burden, as tag presence may adversely affect survival in fish smaller than 95 mm FL (Geist et al. 2018).

Table 2-2. General information about the fish releases and sizes for yearling Chinook salmon (CH1), age-2 winter steelhead (STH2), and subyearling Chinook salmon (CH0) 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	Spring	Full	CH1	Nighttime Spill Apr 1 at 07:00–Apr 16 at 06:59	212	163 (113–229)	45.1 (13.6–109.9)	105	107
				24/7 Spill Apr 16 at 07:00–May 1 at 06:59	208	164 (102–219)	46.3 (13.5–109.2)	103	105
Foster	Spring	Low Mar 1–May 15	CH1	Nighttime Spill (20:00–05:59) and Daytime Turbines (06:00–19:59)	318	158 (114–215)	38.7 (12.9–98.9)	158	160
			STH2		647	168 (114–221)	44.2 (13.8–109.7)	323	324
		High May 27–June 15	CH1	Nighttime Spill (20:00–05:59) and Daytime Turbines (06:00–19:59)	547	182 (123–244)	59.0 (16.2–138.7)	273	274
			STH2		894	186 (115–239)	60.6 (14.1–124.6)	446	448
Foster	Fall	Low Oct 1–Dec 16	CH0	Nighttime Spill (19:00–06:59) and Daytime Turbines (07:00–18:59)	643	136 (97–176)	29.2 (13.0–58.9)	327	316

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. 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 from Whitcomb Creek into 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. The DFR group were euthanized 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 spillway tailrace.

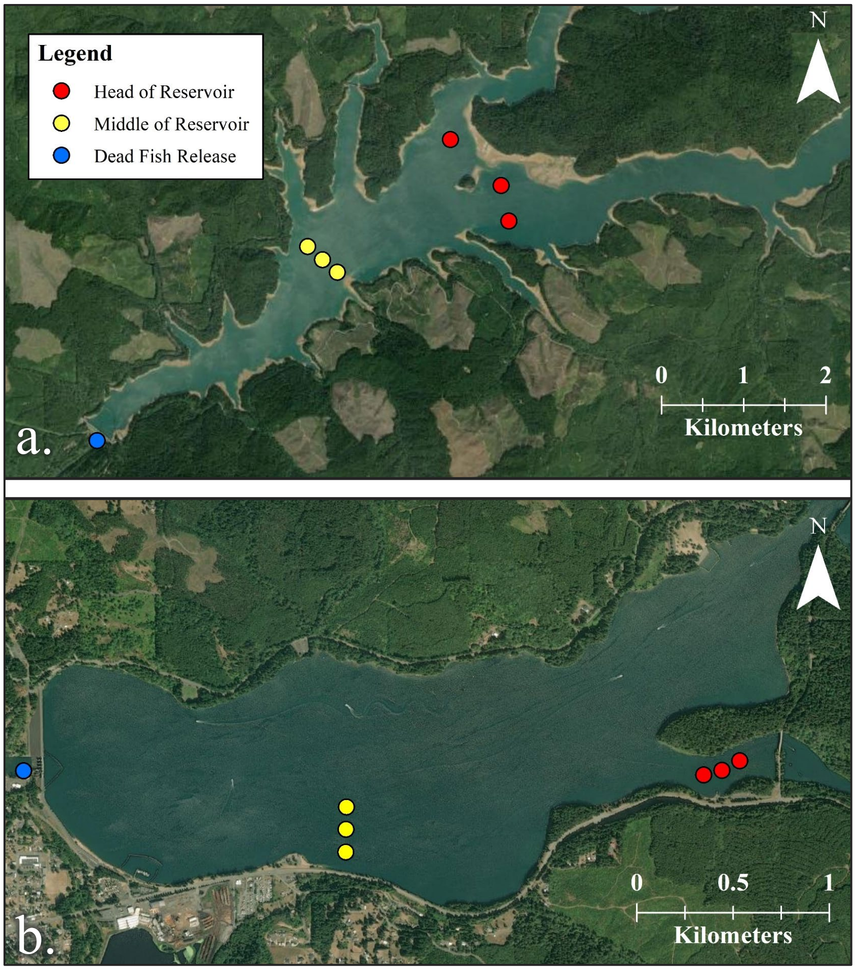

Figure 2-5. Map of reservoir release sites within (a.) Green Peter and (b.) Foster. Red circles indicate release sites located at the head-of-reservoir, furthest upstream of the dams, and the yellow circles indicate sites located at the mid-of-reservoir. Dead fish were released in the taiwaters of each 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, at Green Peter nighttime spill treatment began Apr 2, 2022, at 7:00 am and ended on Apr 16, 2022, at 6:59 am. The 24/7 spill treatment began on Apr 16, 2022, at 7:00 am and ended on May 1, 2022, at 6:59 am.

At Foster, the spring low and high pool daytime turbine operations occurred from 6:00 am to 7:59 pm, and the nighttime spillway operations occurred from 8:00 pm to 5:59 am. Low pool began on Mar 2, 2022, at 6:00 and ended on May 15, 2022, at 5:59 am. High pool began on May 27, 2022, at 6:00 am after the reservoir was filled to summer elevation and ended on June 15, 2022, at 12:00 pm. The spring study period (based on the tag [battery] life of the tags) went through Sept 14, 2022, at 2:30 pm.

The fall daytime turbine operations occurred from 7:00 pm to 6:59 am and nighttime spillway operations occurred from 7:00 am to 6:59 pm. Throughout fall there was one pool elevation: low pool. The operational treatments began on Oct 3, 2022, at 7:00 am and went through Dec 16, 2022, at 6:59 am. The study period (based on tag life) lasted until Feb 21, 2023, at 10:00 am.

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 (i.e., spring and fall) for an assessment of operational life (i.e., 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. When none of these models provided a good fit, the nonparametric Kaplan-Meier estimator was used (Kaplan and Meier 1958). 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. 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 to each downstream detection array. At Green Peter, survival was estimated for all tagged fish detected passing the dam and by spill treatment (nighttime only and 24/7 spill). At Foster, reach survivals were estimated for each species, stock, and pool level, and by diel 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). When detections were insufficient for tag life adjustments, program SURPH (Survival Under Proportional Hazards; Columbia Basin Research, University of Washington) was used to estimate reach survival.

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. Therefore, comparisons of past and 2022 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 ($\alpha = 0.05$) 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 2022 survival estimates differed from those of past studies. A full model, in which survival differed between 2022 and past years (either pooled or individually), was fit, and compared to a reduced model in which survival was equal between 2022 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:

$$
\begin{aligned}
L = & \binom{V_1}{\vec{n}} (S_D p_0 \lambda + (1 - S_D)\omega p_D \Psi)^{n_{11}} \\
& \cdot (S_D(1 - p_0)\lambda + (1 - S_D)\omega(1 - p_D)\Psi)^{n_{01}} \\
& \cdot \left(S_D p_0(1 - \lambda) + (1 - S_D)\omega p_D(1 - \Psi)\right)^{n_{10}} \\
& \cdot \left[S_D(1 - p_0)(1 - \lambda) + (1 - S_D)\left((1 - \omega) + \omega(1 - p_D)(1 - \Psi)\right)\right]^{n_{00}} \\
& \cdot \binom{D_1}{\vec{d}} (\omega p_D \Psi)^{d_{11}} (\omega(1 - p_D)\Psi)^{d_{01}} \\
& \cdot \left(\omega p_{\mathrm{D}}(1 - \Psi)\right)^{d_{10}} \left((1 - \omega) + \omega(1 - p_D)(1 - \Psi)\right)^{d_{00}}.
\end{aligned}
$$

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:

$$
\begin{aligned}
L = & \binom{V_1}{\vec{n}} (S_D p_0 \lambda)^{n_{11}} [S_D(1-p_0)\lambda]^{n_{01}} \\
& \cdot [S_D p_0 (1-\lambda) + (1-S_D)\phi]^{n_{10}} \\
& \cdot [S_D(1-p_0)(1-\lambda) + (1-S_D)(1-\phi)]^{n_{00}} \\
& \cdot \binom{D_1}{\vec{d}} \phi^{d} (1-\phi)^{D-d}
\end{aligned}
$$

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 tailwater array. 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, 73 dead-tagged yearling Chinook salmon were released from the dam during the spring. At Foster, 50 dead-tagged yearling Chinook salmon were released during both spring low pool and spring high pool, 49 dead-tagged steelhead were released during spring low pool, 51 dead-tagged steelhead were released during spring high pool, and 95 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) is 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 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 Primary Waterloo Array (for estimates of Foster passage). Temporal distributions were evaluated using the Wilcoxon group homogeneity test ($\alpha = 0.05$) (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 spillway 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).

Reservoir residence and travel times of RT-tagged fish that passed Foster in 2022 were compared to those from past study years. Because fish travel time data are often right-skewed, the Mann-Whitney U test ($\alpha = 0.05$) was used for comparisons. Residence times from 2015, 2016, and 2018 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, and 2018 (either pooled or individually) were compared to residence times from the 2022 study to evaluate the effect of nighttime spillway operations on reservoir residence times. At Green Peter, reservoir residence and travel times of RT-tagged fish released during nighttime-only spill operations were compared to those released during 24/7 spill operations.

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, 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 2022. 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 spillway (Spillway at Green Peter and Spill Bays 1–4 at Foster) and N_{tur} is the number of fish that passed via turbines (Green Peter and Foster). The ROs were not included in the route-specific passage proportions.

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. 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 give (Dam-Turbine, Dam-Spillway, 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 day and night to determine when study fish were actively passing both Green Peter and Foster. At Green Peter, daytime began at 0700 and lasted until 2059 and nighttime began at 2100 and lasted until 0659. At Foster, daytime began at 0600 and lasted until 1959 and nighttime began at 2000 and lasted until 0559. The differences between Green Peter and Foster were due to operational changes at each dam and the time it takes to travel between the two projects to make changes. Operations had to first be changed at Foster before traveling to Green Peter to make changes.

Predation occurred throughout the study area in 2022. Predation can be difficult to verify; however, several events were considered evidence that predation occurred. Events included fish traveling downstream between detection arrays at a rate beyond which is physically possible, a fish passing a dam and returning upstream into the forebay, or a fish moving between downstream and upstream detection sites multiple times at a rapid rate. 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 at Green Peter or Foster after release but had events that were presumptive of predation. These fish had no useable data other than indication of predation. A fish denoted as “predated after detection” was detected 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 spillway 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 (for Green Peter and Foster, respectively). 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 relative to the number of total fish detected in the near forebay of the dam (Near Forebay) and therefore available to pass, was estimated by the fraction:

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

Where $\widehat{N}_i$ is the estimated abundance of tagged fish that passed Green Peter or Foster through route i (Spill = spillway, TUR = turbine). Again, the ROs were not included in this calculation.

Fish passage efficiency (FPE), the proportion of fish passing via a non-turbine route (i.e., spillway) again relative to the number of total fish in the near forebay and available to pass, was estimated by the fraction:

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

Estimates of DPE and FPE at Foster in 2022 were compared to those from past study years. First, species-, stock-, and pool level-specific estimates of DPE and FPE from 2015, 2016, and 2018 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, and 2018 were pooled for comparison to 2022 estimates. If differences were detected between past study years, 2022 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. Comparisons of DPE and FPE between nighttime-only and 24/7 spill operations at Green Peter were made using two-sided Fisher's exact tests ($\alpha = 0.05$).

Spillway passage efficiency (SPE), the proportion of fish passaging through non-turbine route (i.e., spillway) relative to the number of total fish passing the dam via any route, 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 1-2 at Green Peter and 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, 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.

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

3.0 Results

3.1 Spring Tag Life Study

One group of tags (*N* = 60 tags) was utilized for a spring tag life study for both Green Peter and Foster dams. Tags retained for the spring study assessment of operational tag life had a mean life of 75.8 d (range = 49.8–93.4 d). None of the continuous tag life models (i.e., Weibull 2-parameter, Weibull 3-parameter, Vitality) provided a good fit to the observed tag life data. Therefore, the non-parametric Kaplan-Meier estimator was used to adjust reach survival estimates for the probability of tag failure (Figure 3-1).

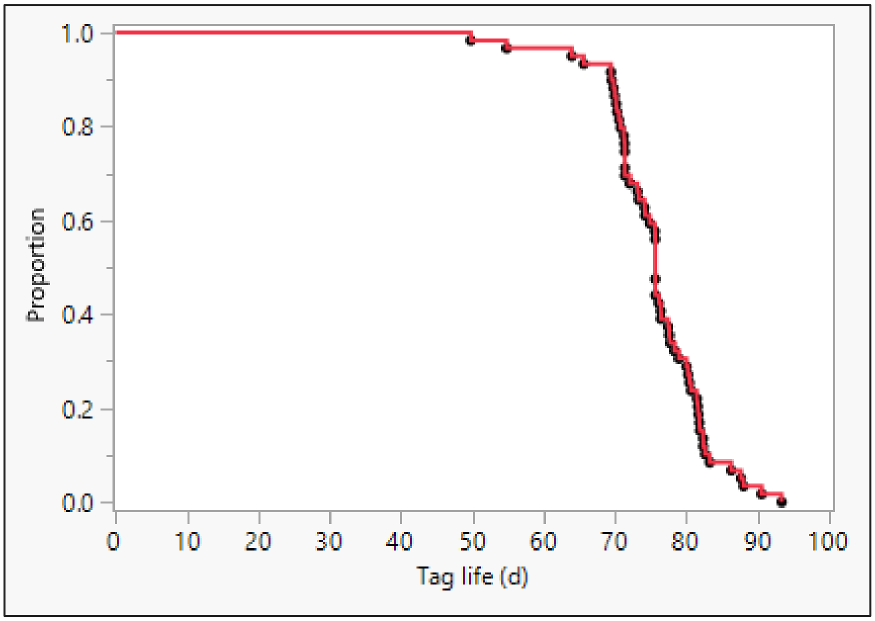

Figure 3-1. Non-parametric Kaplan-Meier estimator fit to the observed tag life of radio tags used during the spring survival studies at Green Peter and Foster dams, 2022.

3.2 Green Peter Dam

3.2.1 Spring – Yearling Chinook Salmon

The following sections describe survival, reservoir residency and travel time, passage distributions, and efficiency and effectiveness results from the spring 2022 study period for yearling Chinook salmon released at Green Peter.

3.2.1.1 Survival

Reservoir Survival

A total of 420 RT-tagged yearling Chinook salmon were released at two locations in Green Peter Reservoir (N = 208 at the head of reservoir and N = 212 at mid-reservoir). Fish released at the HOR had an estimated survival probability of 0.625 (standard error [SE] = 0.034) from release to Green Peter and those released at MOR had an estimated survival of 0.708 (0.031) from release to Green Peter.

Dam Passage and Reach Survival

Dead-tagged fish were released each day live-tagged fish were released; however, the passage of live-released fish continued at Green Peter for almost two weeks after the last dead-tagged fish release. Therefore, the temporal distribution of dead-tagged fish releases did not match that of live-released yearling Chinook salmon mortality (Wilcoxon $\chi^2 = 17.016$; $P < 0.001$; Figure 3-2). Excluding the earliest released dead-tagged fish did not result in a distribution that matched that of live-released yearling Chinook salmon mortality. In addition, dead-tagged fish were only released during the day at Green Peter, when discharge from the dam was low due to operations that differed by diel period (Figure 3-3). Therefore, the ViRDCt assumption that the dead-tagged fish are representative of live-released fish that died during dam passage could have been violated if the probability of detecting dead fish changed after dead-tagged fish releases ceased or if higher nighttime discharges caused dead fish to drift downstream to detection arrays at a higher rate. If the dead fish detection rate was underestimated, the dam passage survival estimate would be biased high.

Because the assumption of the representativeness of dead-tagged fish releases may have been violated for yearling Chinook salmon that passed Green Peter during the spring, associated dam passage survival estimates should be interpreted with caution. No dead-tagged fish released from Green Peter were detected downstream. Therefore, dam passage survival (from Green Peter to the Sunnyside Array) was estimated using the single-release model instead of ViRDCt. Adjustments for the probability of tag failure weren't necessary because all downstream detections occurred before the first tag life tag died.

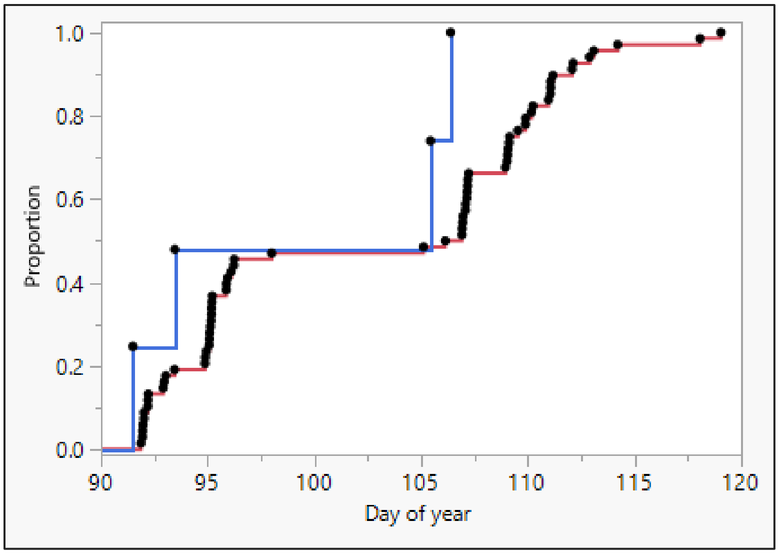

Figure 3-2. Cumulative proportions of live-released RT-tagged yearling Chinook salmon mortality (red) and dead-tagged fish releases (blue) at Green Peter during spring, 2022.

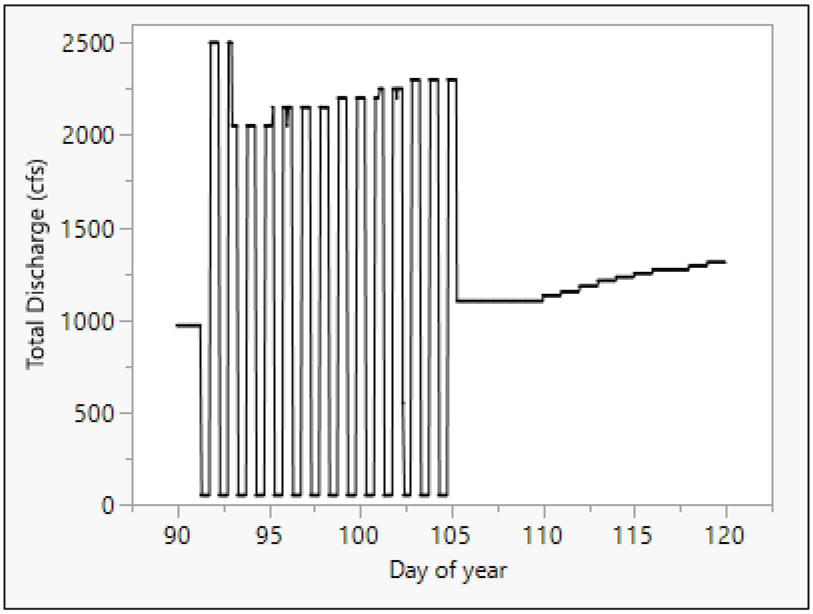

Figure 3-3. Green Peter total discharge by day of year, 2022. Periods of low discharge occurred during the day and periods of high discharge occurred at night.

Excluding two tagged fish that were captured in the screw trap downstream of Green Peter, a total of 222 RT-tagged yearling Chinook salmon passed Green Peter with an estimated survival probability of 0.691 (0.032) to the Sunnyside Array (Table 3-1). All but two tagged yearling Chinook salmon passed Green Peter at night. Neither of the two tagged fish that passed Green Peter during the day were detected downstream of Green Peter. No tagged fish passed Green Peter through the turbines; therefore, survival was not comparable by passage route. During the nighttime spill treatment of early April, 118 tagged fish were detected passing Green Peter. These fish had an estimated survival probability of 0.705 (0.044) to the Sunnyside Array, which was statistically similar to the survival of the 104 tagged fish passed during the 24/7 spill treatment of late April (S = 0.675; SE = 0.048; Table 3-1).

An estimated 43.4% of the tagged fish that passed Green Peter survived to Foster and 32.1% were estimated to have survived to the I-5 Santiam Rest Stop Array (Table 3-1). Survival from Green Peter to all downstream arrays was statistically similar for fish that passed during the nighttime only and 24/7 spill treatments (Table 3-1).

Table 3-1. Tag life, detection, and survival probability estimates for RT-tagged yearling Chinook salmon (CH1) that passed Green Peter (GPR) during spring, 2022. Estimates are shown for all RT-tagged CH1 and by spill operation at the time of Green Peter passage. Standard errors 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: excluding fish caught in the screw trap downstream of GP, 222 tagged CH1 passed Green Peter via the spillway, 220 passed at night, and 2 passed during the day.

Reach	**Tag life prob. (SE)**	**Det. Prob. (SE)**	**Survival (SE)**
	All (N = 222)		
GPR – SUN[1]	*1.000 (0.000)*	*0.958 (0.020)*	*0.691 (0.032)*
GPR – FOS	1.000 (0.000)	0.965 (0.020)	0.434 (0.033)
GPR – PRM	1.000 (0.000)	0.916 (0.031)	0.389 (0.033)
GPR – LEB	1.000 (0.000)	0.986 (0.014)	0.375 (0.033)
GPR – SRS[2]	*1.000 (0.000)*	*0.954 (0.026)*	*0.321 (0.031)*
GPR – COI	1.000 (0.000)	0.896 (0.044)	0.302 (0.032)
	Nighttime only spill (N = 118)		
GPR – SUN[1]	*1.000 (0.000)*	*0.962 (0.027)*	*0.705 (0.044)*
GPR – FOS	1.000 (0.000)	0.957 (0.029)	0.443 (0.046)
GPR – PRM	1.000 (0.000)	0.911 (0.042)	0.400 (0.045)
GPR – LEB	1.000 (0.000)	0.974 (0.025)	0.383 (0.045)
GPR – SRS[2]	*1.000 (0.000)*	*0.974 (0.026)*	*0.331 (0.043)*
GPR – COI	1.000 (0.000)	0.974 (0.026)	0.331 (0.043)
	24/7 spill (N = 104)		
GPR – SUN[1]	*1.000 (0.000)*	*0.955 (0.031)*	*0.675 (0.048)*
GPR – FOS	1.000 (0.000)	0.974 (0.025)	0.424 (0.049)
GPR – PRM	1.000 (0.000)	0.921 (0.044)	0.376 (0.048)
GPR – LEB	1.000 (0.000)	1.000 (0.000)	0.365 (0.047)
GPR – SRS[2]	*1.000 (0.000)*	*0.923 (0.052)*	*0.313 (0.046)*
GPR – COI	1.000 (0.000)	0.826 (0.079)	0.256 (0.044)

[1] Dam passage survival; [2] Reach survival.

3.2.1.2 Reservoir Residency and Migration Travel Times

Two 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 3-4). Thereafter, travel times for these fish were removed from further analyses as these individuals would be delayed and could bias the results.

Fish released during the nighttime spill treatment spent significantly less time in the reservoir than fish released during the 24/7 spill treatment ($Z = 3.756$, $P < 0.001$) (Figure 3-4). Fish spent a median of approximately 41 hours in the reservoir before passing Green Peter during the nighttime spill treatment compared to the 87.5 hours that fish spent in the reservoir during the 24/7 spill treatment (Figure 3-4).

With the exception of the Green Peter to Sunnyside, travel time from Green Peter to downstream arrays differed significantly by spill operation. Yearling Chinook salmon that passed Green Peter during the nighttime-only spill operation generally took longer to reach the Sunnyside Array than those that passed during the 24/7 spill operation; however, the difference was not significant ($Z = 1.896$, $P = 0.058$). Travel times from Green Peter to all other downstream arrays were significantly greater for fish that passed during nighttime spill treatment ($Z \geq 2.761$, $P \leq 0.006$). The difference in travel times between operations may have been from differences in discharge from Green Peter between the two operations. During the nighttime spill treatment, the mean discharge was 2,219 cfs through a larger spill bay gate opening (approximately 2.2 ft). During the 24/7 spill treatment, the spill bay gate opening was smaller (approximately 1.3 ft) and discharge from Green Peter was consistent between day and night, averaging 1,191 cfs (Figure 3-3).

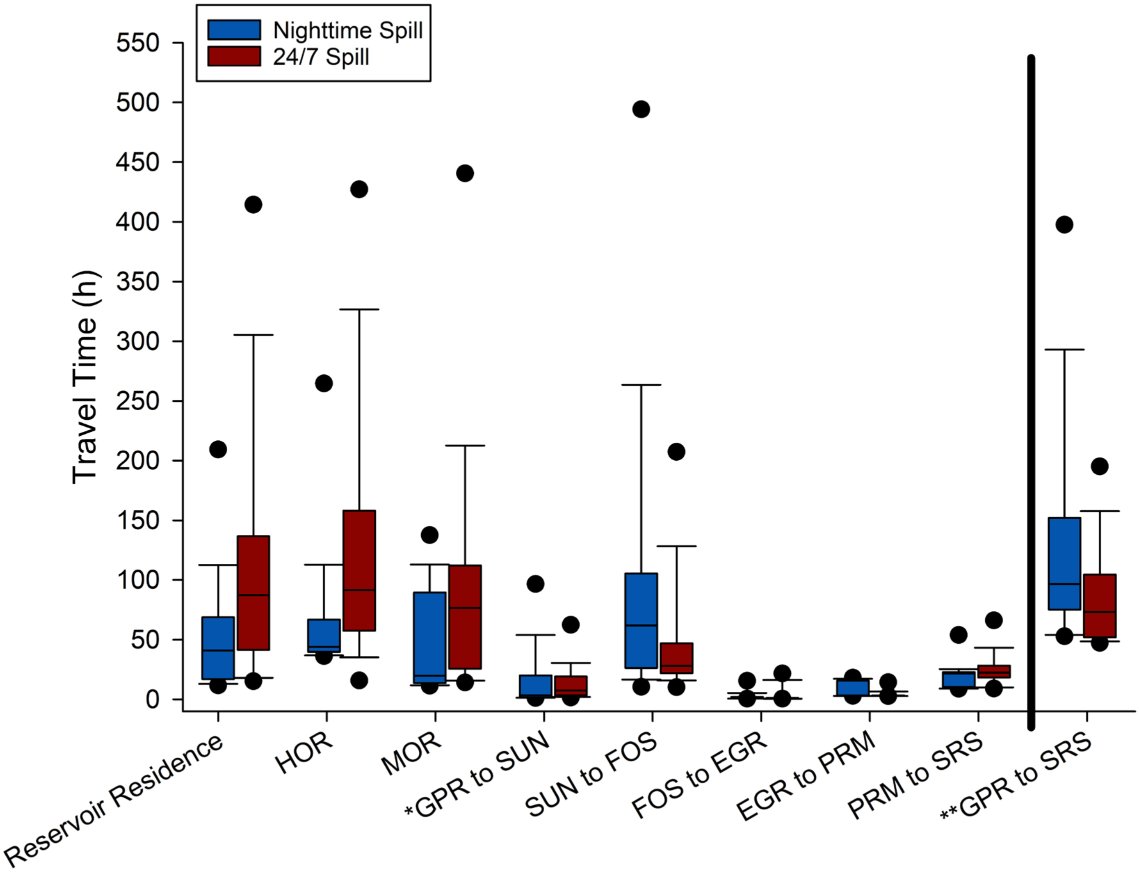

Figure 3-4. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir; MOR = mid-of-reservoir), and travel times between reaches for yearling Chinook salmon released at Green Peter (GPR; SUN = Sunnyside, FOS = Foster, EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). 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.

3.2.1.3 Passage Distributions

Of the 212 live fish released during the nighttime spill treatment, 163 were detected in the forebay and used for analyses (V_1; Figure 2-3). The remaining 49 fish had unknown fates (i.e., could have been predated, moved upstream, died, etc.) and were excluded from analyses. A few fish (*n* = 6) were never detected at Green Peter but were detected on other RT arrays either at Green Peter or downstream, potentially indicating no route predation (i.e., never detected at Green Peter after release; Table 3-2). Of those detected at the forebay, 77% (*n* = 126) moved downstream of Green Peter (Table 3-2). Nineteen percent of fish (*n* = 31) detected at the forebay were never detected passing the dam (Table 3-2).

At total of 208 live fish were released during 24/7 spill operations, but only 128 were detected in the forebay (Table 3-2). Of those fish, 98 (76.6%) passed downstream of the dam (Table 3-2). Two of the downstream passage fish were found caught in the screw trap. These fish were included in the dam passage proportional estimates but were removed from further survival analyses. The virtual release group for 24/7 spill treatment also included 80 fish that were never detected, and 4 fish were detected downstream as a potential indication of no route predation (i.e., never detected at Green Peter after release), and 26 that were detected by the forebay but never passed (Table 3-2).

Combining the nighttime spill and 24/7 spill treatments, the downstream passage fish represented 77.0% (*n* = 224) of the 291 total fish detected after release into Green Peter (Table 3-2). Fish detected at Green Peter may have also been predated. A total of 281 fish were detected in the Green Peter forebay or downstream (excluding no route predation fish), and 15 of those fish (5.3%) were detected and predated either in the Green Peter tailwaters or farther downstream (Table 3-2). 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.

Out of the 224 fish that passed downstream of Green Peter, 99.2% passed during the night during the nighttime spill treatment and 99.1% passed at night during the 24/7 spill (Table 3-3). One fish passed during the day (i.e., between 7:00 am and 6:59 pm) during the nighttime spill treatment (route unknown), and one fish passed by dam spill during the day under the 24/7 spill treatment. All other fish that passed Green Peter (*n* = 222, 99.1%) did so through the spill at night regardless of treatment.

Table 3-2. Movement summary of RT-tagged yearling Chinook salmon released at Green Peter Dam. The Virtual Release Group indicates fish that were detected after release.

Treatment	Virtual Release Group (*n*)	No Route Predation		Detected Forebay Only – Never Passed		Downstream Passage		Predation after Forebay or Downstream Detection	
		Proportion	***n***	**Proportion**	***n***	**Proportion**	***n***	**Sub Proportion**	***n***
Nighttime Spill	163	0.037	6	0.190	31	0.773	126	0.076	12
24/7 Spill	128	0.031	4	0.203	26	0.766	98	0.024	3
Overall	291	0.034	10	0.196	57	0.770	224	0.053	15

Table 3-3. 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 identified.

Treatment	Route	Overall		Day		Night	
		Proportion	***n***	**Proportion**	***n***	**Proportion**	***n***
Nighttime Spill	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	0.992	117	0.000	0	0.992	117
	Dam – No Route	0.008	1	0.008	1	0.000	0
	Overall	0.527	118	0.008	1	0.992	117
24/7 Spill	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	1.000	106	0.009	1	0.991	105
	Dam – No Route	0.000	0	0.000	0	0.000	0
	Overall	0.473	106	0.009	1	0.991	105

3.2.1.4 Efficiency and Effectiveness

The turbines were not operated during either spillway operational period; therefore, the DPE and FPE values are the same. Although the ROs were operated during the daytime (50 cfs) during the nighttime spill treatment to keep the river flowing, they were not evaluated as a route of passage. No route fish were not included in the DPE and FPE estimates as their route of passage was unknown. Nighttime spill and 24/7 spill treatments had similar DPEs ($P = 0.163$), and the majority of yearling Chinook salmon reaching the near forebay ultimately passed the dam (84.9% and 77.9%, respectively; Table 3-4; Figure 3-5). Because all fish passed via the spillway instead of the turbines, the fish passage efficiency was the same as DPE (Table 3-4). Additionally, almost all fish that passed Green Peter did so at night, resulting in a night DPE and FPE of 84.2% for the nighttime spill treatment and 77.2% for the 24/7 spill treatment, which was not a significant difference ($P = 0.169$). All fish passing via the spillway instead of the turbines also led to the SPE being equal to 100%, regardless of treatment or diel passage period (Table 3-4).

Effectiveness was based on SPE and discharge through the dam. Because all discharge and all fish passed via the spillway, the spillway effectiveness was 1.0, regardless of treatment or diel passage period (Table 3-4; Figure 3-5).

Table 3-4. Passage efficiencies and effectiveness for yearling Chinook salmon at Green Peter in Spring 2022. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while Spillway Passage Efficiency (SPE) is relative to the total number of fish that passed the dam (as indicated by "|| Dam"). Spillway Effectiveness (Effect.) is based on the SPE and the total dam discharge through those routes. Standard errors are in parentheses.

	Overall		**Day**		**Night**	
Metric	**Nighttime Spill**	**24/7 Spill**	**Nighttime Spill**	**24/7 Spill**	**Nighttime Spill**	**24/7 Spill**
DPE	**0.849 (0.030)**	**0.779 (0.036)**	**0.007 (0.007)**	**0.007 (0.007)**	**0.842 (0.031)**	**0.772 (0.014)**
FPE	**0.849 (0.030)**	**0.779 (0.036)**	**0.007 (0.007)**	**0.007 (0.007)**	**0.842 (0.031)**	**0.772 (0.014)**
SPE || Dam	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
Spillway Effect.	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (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 Green Peter through Spill Bays 1–2.
Spillway Effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.

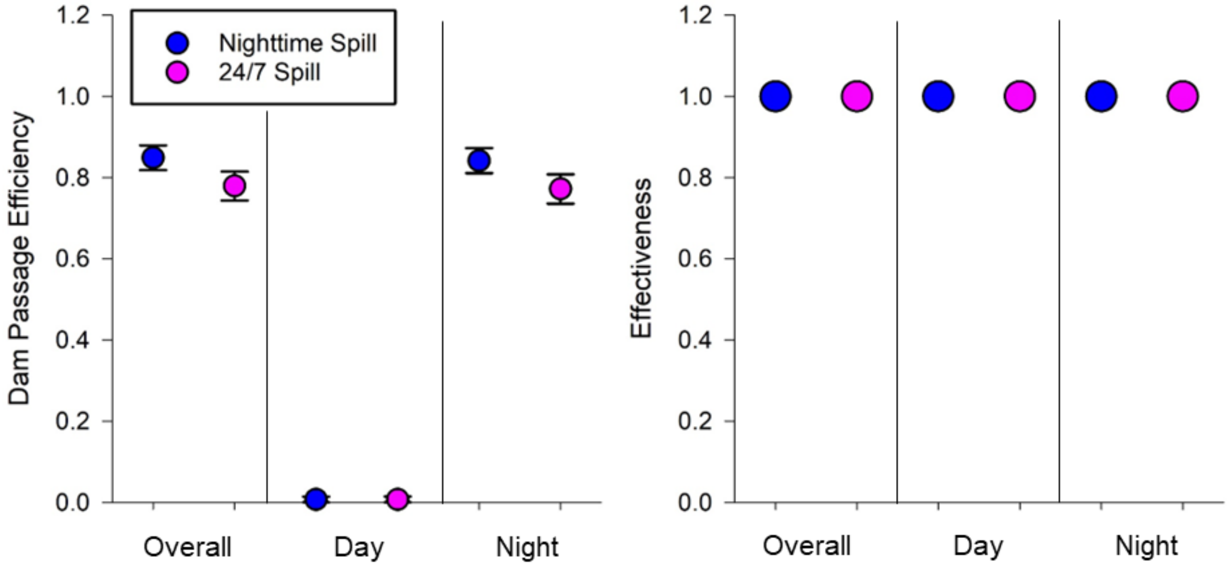

Figure 3-5. Dam passage efficiency, spillway passage efficiency, and effectiveness of yearling Chinook salmon released at Green Peter in Spring 2022. Error bars represent standard errors (SE). A lack of error bars indicates the SE was 0.000. Note: FPE and SPE are not depicted as FPE was the same as DPE, and SPE was the same as Effectiveness.

3.3 Foster Dam

The following sections for the Foster study first discuss the spring study by species. Yearling Chinook salmon results are presented first (Section 3.3.1), followed by results for the age-2 winter steelhead (Section 3.3.2). The final section (Section 3.3.3) describes the fall study with only one species, subyearling Chinook salmon.

3.3.1 Spring – Yearling Chinook Salmon

The following subsections describe survival, reservoir residency and travel time, passage distributions, and efficiency and effectiveness results for yearling Chinook salmon released at Foster during the spring study period.

3.3.1.1 Survival

Reservoir Survival

During spring low pool (March–mid-May; ~614.5 fmsl), a total of 318 RT-tagged yearling Chinook salmon were released at two locations in Foster Reservoir (N = 158 at the head of reservoir and N = 160 at mid-reservoir). Fish released at the head of reservoir had an estimated survival probability of 0.469 (SE = 0.040) from release to Foster and those released at mid-reservoir had an estimated survival of 0.619 (0.038) from release to Foster.

During spring high pool (late May–June; ~636 fmsl), a total of 547 RT-tagged yearling Chinook salmon were released in Foster Reservoir (N = 273 at the head of reservoir and N = 274 at mid-reservoir). Fish released at the head of reservoir had an estimated survival probability of 0.580 (0.030) from release to Foster and those released at mid-reservoir had an estimated survival of 0.708 (0.028) from release to Foster.

Dam Passage Survival

During spring low pool, three dead-tagged yearling Chinook salmon and two dead-tagged steelhead were detected at or downstream of the Egress Array. Because the proportion detected was similar between species, all dead-tagged fish released during spring low pool were combined for ViRDCt survival estimation. Dead-tagged fish were released each day live tagged fish were released. However, it took a few days for the first live-released fish to begin passing Foster. Therefore, the temporal distribution of dead-tagged fish releases did not match that of live-released yearling Chinook salmon mortality (Wilcoxon χ^2 = 18.336; P < 0.001; Figure 3-6). Truncating the dead fish releases by removing the first 32 dead-tagged fish that were released in March resulted in a temporal distribution that more closely matched that of the live-released yearling Chinook salmon mortality (Wilcoxon χ^2 = 2.377; P = 0.123; Figure 3-7).

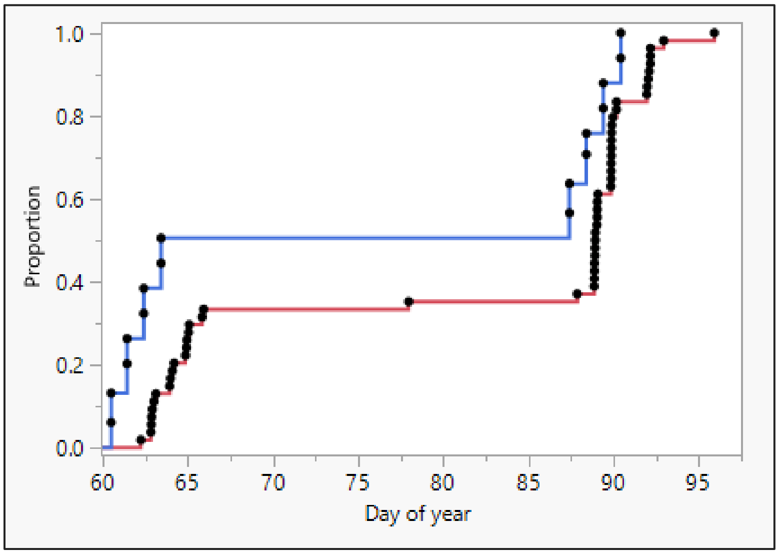

Figure 3-6. Cumulative proportions of live-released RT-tagged yearling Chinook salmon mortality (red) and all dead-tagged fish releases (blue) at Foster during spring low pool.

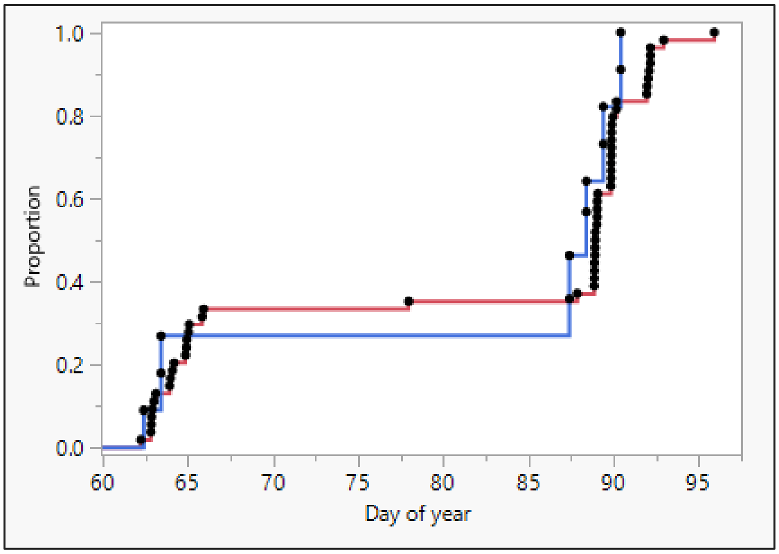

Figure 3-7. Cumulative proportions of live-released RT-tagged yearling Chinook salmon mortality (red) and truncated dead-tagged fish releases (blue) at Foster during spring low pool.

Of the remaining 67 dead-tagged fish released at Foster during spring low pool, one was detected at the Egress Array, and one was detected at the Lebanon Array. Therefore, the full ViRDCt model was used to estimate dam passage (Foster to Egress Array) survival for yearling Chinook salmon during spring low pool.

A total of 172 RT-tagged yearling Chinook salmon passed Foster during spring low pool with an estimated dam passage survival probability (S_D) of 0.847 (0.029) (Table 3-5), which is similar to the ViRDCt-derived dam passage survival estimate obtained in 2018 (S_D = 0.867; SE = 0.039). The majority (156 of 172) of tagged yearling Chinook salmon passed Foster at night during spring low pool in 2022 with an estimated S_D of 0.831 (0.031; Table 3-5). All 16 yearling Chinook salmon that passed during the day were detected at the Egress Array, preventing survival estimation using the ViRDCt model. The single-release survival estimate for Chinook that passed during the day (S = 1.000; SE = 0.000) was significantly lower than the single-release estimate for Chinook that passed at night (χ^2 = 5.395; P = 0.020; Table 3-5).

Table 3-5. Tag life, detection, and survival probability estimates for RT-tagged yearling Chinook salmon (CH1) that passed Foster (FOS) during spring low pool, 2022. Estimates are shown for all RT-tagged CH1 and by diel period of Foster passage. Standard errors (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, NA = insufficient detections for estimation, nan = not estimated. Note: 171 tagged CH1 passed Foster via the spillway and 1 passed through an unknown route during spring low pool.

Reach	Tag life prob. (SE)	Det. Prob. (SE)	Survival (SE)
	All (N = 172)		
FOS – EGR[1]	*nan*	*0.986 (0.012)*	*0.847 (0.029)*
FOS – PRM	1.000 (0.000)	0.973 (0.015)	0.687 (0.036)
FOS – LEB	1.000 (0.000)	1.000 (0.000)	0.646 (0.037)
FOS – SRS[2]	*1.000 (0.000)*	*0.938 (0.030)*	*0.422 (0.038)*
FOS – COI	0.998 (0.002)	0.801 (0.048)	0.422 (0.038)
	Day (N = 16)		
FOS – EGR[1]	*nan*	*1.000 (NA)*	*1.000 (NA)*
FOS – PRM	1.000 (0.000)	1.000 (0.000)	0.938 (0.061)
FOS – LEB	1.000 (0.000)	1.000 (0.000)	0.813 (0.098)
FOS – SRS[2]	*1.000 (NA)*	*0.840 (0.146)*	*0.446 (0.127)*
FOS – COI	0.964 (NA)	0.423 (0.187)	0.446 (0.127)
	Night (N = 156)		
FOS – EGR[1]	*nan*	*0.984 (0.014)*	*0.831 (0.031)*
FOS – PRM	1.000 (0.000)	0.969 (0.017)	0.661 (0.038)
FOS – LEB	1.000 (0.000)	1.000 (0.000)	0.628 (0.039)
FOS – SRS[2]	*1.000 (0.000)*	*0.948 (0.029)*	*0.419 (0.040)*
FOS – COI	1.000 (0.000)	0.880 (0.065)	0.401 (0.045)

[1] Dam passage survival; [2] Reach survival.

During spring high pool, five dead-tagged yearling Chinook salmon and 4 dead-tagged juvenile steelhead were detected at or downstream of the Egress Array. Because the proportions were similar between species, they were combined for ViRDCt survival estimations. Similar to spring low pool, the temporal distribution of all dead-tagged fish releases did not match that of live-released yearling Chinook salmon passage mortality during spring high pool (Wilcoxon χ^2 = 4.025; *P* = 0.045; Figure 3-8). Truncating the dead fish releases by removing the first 10 dead tagged fish that were released in May resulted in a temporal distribution that more closely matched that of the live-released yearling Chinook salmon mortality (Wilcoxon χ^2 = 0.913; *P* = 0.339; Figure 3-9).

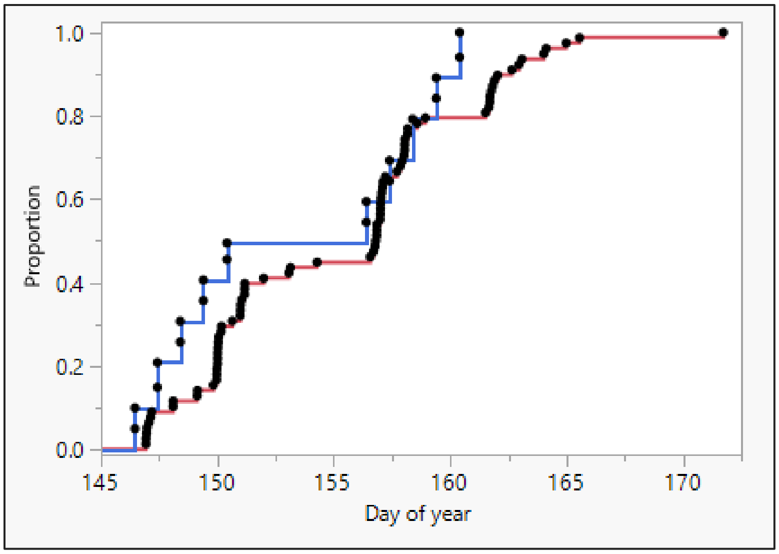

Figure 3-8. Cumulative proportions of live-released RT-tagged yearling Chinook salmon mortality (red) and all dead-tagged fish releases (blue) at Foster during spring high pool.

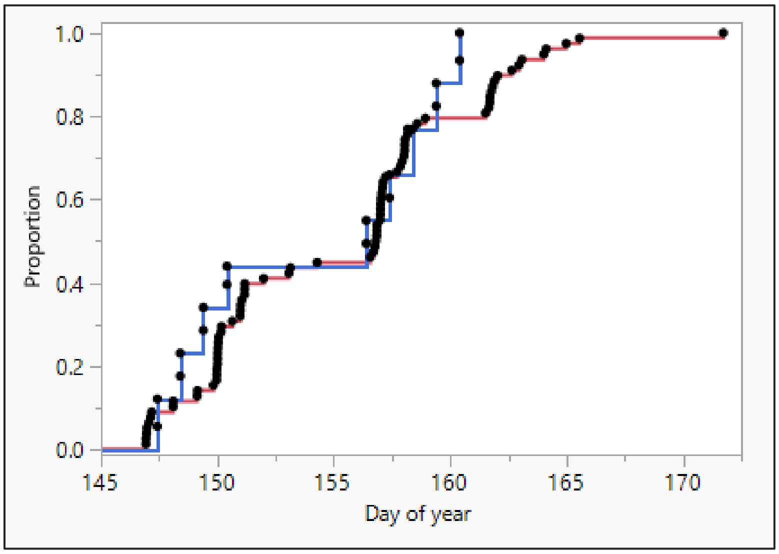

Figure 3-9. Cumulative proportions of live-released RT-tagged yearling Chinook salmon mortality (red) and truncated dead-tagged fish releases (blue) at Foster during spring high pool.

Of the remaining 91 dead-tagged fish released at Foster during spring high pool, five were detected at the Egress Array, and two were detected downstream of the Egress Array. Therefore, the full ViRDCt model was used to estimate dam passage (Foster to Egress Array) survival for yearling Chinook salmon that passed Foster during spring high pool.

A total of 351 RT-tagged yearling Chinook salmon passed Foster during spring high pool with an estimated S_D of 0.909 (0.017; Table 3-6), which was greater than the ViRDCt-derived dam passage survival estimate obtained in 2018 ($S_D = 0.809$; SE = 0.034). Dam passage survival estimates were similar for tagged yearling Chinook salmon that passed Foster during night (S_D = 0.918; SE = 0.019) and day (S_D = 0.878; SE = 0.039) in 2022 (Table 3-6). For route-specific survival, all but five tagged yearling Chinook salmon that passed Foster during spring high pool in 2022 did so via the spillway with S_D = 0.910 (0.017). Four fish passed through the turbines and had an estimated S_D of 0.750 (0.241).

Table 3-6. Tag life, detection, and survival probability estimates for RT-tagged yearling Chinook salmon (CH1) that passed Foster Dam (FOS) during spring high pool, 2022. Estimates are shown for all RT-tagged CH1 and by diel period of Foster passage. Standard errors (SE) are shown in parentheses. PRM = Waterloo Primary array, LEB = Lebanon Dam array, SRS = I-5 Santiam Rest Stop array, COI = Cole Island array, nan = not estimated. Note: 346 tagged CH1 passed Foster via the spillway, 4 passed through the turbines, and 1 passed via an unknown route during spring high pool.

Reach	**Tag life prob. (SE)**	**Det. Prob. (SE)**	**Survival (SE)**
	All (N = 351)		
FOS – EGR[1]	*nan*	*0.969 (0.011)*	*0.909 (0.017)*
FOS – PRM	1.000 (0.000)	0.940 (0.015)	0.779 (0.022)
FOS – LEB	0.999 (0.000)	0.980 (0.009)	0.765 (0.023)
FOS – SRS[2]	*1.000 (0.000)*	*0.963 (0.012)*	*0.722 (0.024)*
FOS – COI	1.000 (0.000)	0.985 (0.009)	0.703 (0.025)
	Day (N = 79)		
FOS – EGR[1]	*nan*	*0.987 (0.017)*	*0.878 (0.039)*
FOS – PRM	1.000 (0.000)	0.918 (0.035)	0.772 (0.047)
FOS – LEB	1.000 (0.000)	0.983 (0.017)	0.773 (0.047)
FOS – SRS[2]	*1.000 (0.000)*	*0.966 (0.024)*	*0.747 (0.049)*
FOS – COI	1.000 (0.000)	0.980 (0.020)	0.750 (0.049)
	Night (N = 272)		
FOS – EGR[1]	*nan*	*0.965 (0.013)*	*0.918 (0.019)*
FOS – PRM	1.000 (0.000)	0.947 (0.016)	0.780 (0.025)
FOS – LEB	0.999 (0.000)	0.979 (0.010)	0.763 (0.026)
FOS – SRS[2]	*1.000 (0.000)*	*0.963 (0.014)*	*0.714 (0.028)*
FOS – COI	1.000 (0.000)	0.986 (0.010)	0.690 (0.028)

[1] Dam passage survival; [2] Reach survival.

Reach Survival

Adjustments for tag life were minor and were only applied to estimates of survival from Foster to the Cole Island Array for yearling Chinook salmon that passed during spring low pool (Table 3-5). An estimated 68.7% of tagged yearling Chinook salmon that passed Foster during spring low pool survived from Foster to the Waterloo Primary Array (Table 3-5), which was similar to the pooled survival estimate from 2015, 2016, and 2018 (S = 0.615; SE = 0.016; χ^2 = 3.337; P = 0.068). Survival was estimated to be 0.646 (SE = 0.037) and 0.422 (SE = 0.038) to the Lebanon and I-5 Santiam Rest Stop arrays, respectively, in 2022 (Table 3-5).

The 16 tagged yearling Chinook salmon that passed Foster during the day in spring low pool of 2022 had a significantly higher probability of surviving to the Waterloo Primary Array (S = 0.938; SE = 0.061) than those that passed at night (S = 0.661; SE = 0.038; χ^2 = 6.575; P = 0.010; Table 3-5). However, estimates of survival from Foster to the Lebanon and I-5 Santiam Rest Stop arrays did not differ significantly by diel passage period (Table 3-5). No tagged yearling Chinook salmon were detected passing through the turbines during spring low pool. Therefore, a comparison of spillway and turbine survival was not possible.

The probability of tags being active was estimated to be ≥ 99.9% at all downstream arrays for yearling Chinook salmon that passed Foster during spring high pool (Table 3-6). Therefore, adjustments for tag life were minor. An estimated 77.9% of tagged yearling Chinook salmon that passed Foster during spring high pool survived from Foster to the Waterloo Primary Array (Table 3-6), which was similar to the pooled survival estimate from 2015 and 2016 (S = 0.814; SE = 0.023) and significantly greater than the survival estimate from 2018 (S = 0.646; SE = 0.028; χ^2 = 14.082; P < 0.001). Survival was estimated to be 0.765 (SE = 0.023) and 0.722 (SE = 0.024) to the Lebanon and I-5 Santiam Rest Stop arrays, respectively, in 2022 (Table 3-6).

Estimates of survival from Foster to the Waterloo Primary, Lebanon, and I-5 Santiam Rest Stop arrays were similar for yearling Chinook salmon that passed Foster during day and night during spring high pool (Table 3-6). Only four tagged yearling Chinook salmon passed Foster through the turbines during spring high pool, with an estimated survival probability of 0.500 (0.250) to the I-5 Santiam Rest Stop Array. The small sample size of turbine-passed fish precluded a meaningful comparison of survival between turbine- and spillway-passed fish.

3.3.1.2 Reservoir Residency and Migration Travel Times

Tagged fish released during low pool had a median reservoir residence time of 35 h (Figure 3-10). For fish released during high pool, tagged fish had a median reservoir residence time of 59 h (Figure 3-10). Reservoir residence times observed in 2022 for yearling Chinook salmon were either significantly lower than, or similar to, those from past study years. The reservoir residence time of yearling Chinook salmon released into Foster Reservoir during low pool in 2022 was significantly lower than the residence time observed in 2016 (Z = 4.062, P < 0.001) but similar to the residence times of 2015 and 2018 (Z ≤ 0.914, P ≥ 0.361). Yearling Chinook salmon released during high pool in 2022 had significantly lower reservoir residence times than all past years (Z ≥ 2.792, P ≤ 0.005).

With one exception, travel times from Foster to downstream arrays were similar (Z ≤ 1.784, P ≥ 0.073) for Chinook salmon that passed the dam during day and night. The exception was yearling Chinook salmon that passed Foster at night during high pool, which took significantly less time to reach the Egress Array than those that passed during the day (Z = 2.677, P < 0.001).

Travel times from Foster to the Waterloo Primary Array for Chinook salmon released during low pool in 2022 were significantly shorter than those observed in 2015 (Z = 2.848, P = 0.004), similar to those from 2016 (Z = 0.418, P = 0.676), and significantly longer than those from 2018 (Z = 7.030, P < 0.001). Differences can partially be explained by differences in flow between years. Early spring of 2015 was characterized by low flows, which averaged about 1,200 cfs at the USGS gauge near Foster (USGS gauge station 14187200). During passage of RT-tagged Chinook salmon during low pool of 2016, flow ranged from about 1,500 to 3,000 cfs. In 2018, discharge ranged from about 2,000 to 4,000 cfs during low pool. During passage of RT-tagged Chinook salmon during spring low pool of 2022, discharge ranged from about 1,000 to 3,500 cfs.

Yearling Chinook salmon that passed Foster during spring high pool took significantly less time to reach the Waterloo Primary Array compared to all past study years (Z ≥ 6.561, P < 0.001). Again, differences in discharge between years help to explain differences in travel times. In 2015, 2016, and 2018, discharge during spring high pool remained less than 2,500 cfs. In 2022, discharge ranged from about 3,000 to 12,500 cfs.

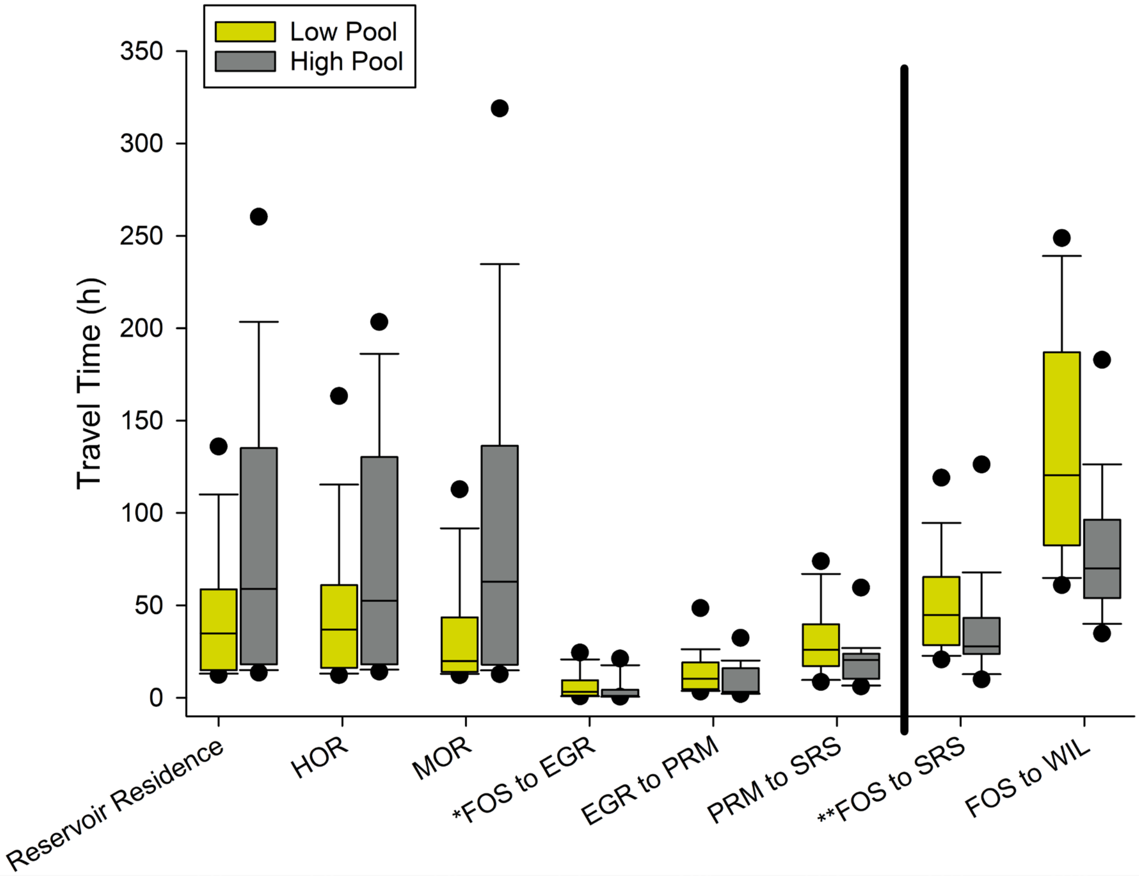

Figure 3-10. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir; MOR = mid-of-reservoir), and travel times between reaches for yearling Chinook salmon released at Foster (FOS; EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). 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.

3.3.1.3 Passage Distributions

The majority (70%) of yearling Chinook salmon that were detected moved downstream of Foster (Table 3-7). Regardless of low or high pool elevation, more fish passed during the nighttime spillway operations (82.5%) compared to the daytime turbine operations (17.5%; Table 3-8).

During low pool, 278 fish released were detected at the forebay and used for analyses (V_1; Figure 2-3). Approximately 62% of fish (*n* = 172) successfully moved downstream (Table 3-7). Less than 2% of fish (*n* = 5) had likely indications of no route predation (i.e., never detected at Foster after release). Approximately 34% of fish (*n* = 94) were detected at the dam but did not pass (Table 3-7).

During high pool, of the 544 fish released, 468 were detected at the forebay and used for analyses (V_1; Figure 2-3). Approximately 74% of fish (*n* = 348) successfully moved downstream (Table 3-7). Less than 1% of fish (*n* = 3) had no detections except when there was a likely indication of no route predation (i.e., never detected at Foster after release). Nearly 20% of fish (*n* = 93) approached the near forebay but never passed the dam during high pool (Table 3-7).

Fish detected at Foster were also predated (i.e., detected after release before predation). Of the fish detected in the extended forebay, near forebay, or passed downstream (*n* = 738), approximately 9% (*n* = 69) were predated. A similar number of fish were predated during low (*n* = 32) and high pools (*n* = 37), although the proportion was greater during low pool (12%) compared to high pool (8%; Table 3-7). The fate of the predated fish is likely a minimum estimate, as the fates of the undetected fish are unknown, and it is possible they were also predated.

Table 3-7. Movement summary of RT-tagged yearling Chinook salmon released at Foster Dam. The Virtual Release Group indicates fish that were detected after release.

Pool Elevation	Virtual Release Group (*n*)	No Route Predation		Extended Forebay Detection – Never Passed		Near Forebay Detection – Never Passed		Downstream Passage		Predation after any Forebay or Downstream Detection	
		Proportion	*n*	Proportion	*n*	Proportion	*n*	Proportion	*n*	Sub Prop.	*N*
Low	278	0.018	5	0.025	7	0.338	94	0.619	172	0.117	32
High	468	0.006	3	0.051	24	0.199	93	0.744	348	0.080	37
Overall	746	0.011	8	0.042	31	0.251	187	0.697	520	0.093	69

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 3-8) were excluded.

During low pool, all tagged yearling Chinook salmon that passed Foster did so via the spillway regardless of day or night passage. The spillway could be operated during the day to pass excess water, which would explain the 16 fish that passed via the spillway during the day (Table 3-8). The spillway (primarily Spill Bay 4) was the primary route of passage, with 99% of fish passage via the spillway, and 90% passing via Spill Bay 4 (Table 3-8; Figure 3-11). This was similar during high pool, with 98% of fish passing via the spillway. However, more fish passed via Spill Bays 1 and 2 (42% and 51%, respectively) during high pool (Table 3-8; Figure 3-11). This was because Spill Bay 4 was not operated during high pool and was only opened on June 15th for 30 min. Very few fish ($n = 4$ during high pool only) passed via the turbines, and very few fish ($n = 4$ for low and high pools) were unable to be assigned a specific route of passage (Table 3-8).

Table 3-8. Passage proportions by route of passage for RT-tagged yearling Chinook salmon 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 identified.

		Overall		Day		Night	
Pool Elevation	**Route**	**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	**0.994**	**171**	**0.094**	**16**	**0.906**	**155**
	Spill Bay 1	0.006	1	0.063	1	0.000	0
	Spill Bay 2	0.006	1	0.000	0	0.006	1
	Spill Bay 3	0.088	15	0.188	3	0.077	12
	Spill Bay 4	0.901	154	0.750	12	0.916	142
	Dam	**0.006**	**1**	**0.000**	**0**	**1.000**	**1**
	No Route	1.000	1	0.000	0	1.000	1
	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	0.000	0	0.000	0	0.000	0
	Overall		**172**	**0.093**	**16**	**0.907**	**156**
High	**Turbines**	**0.012**	**4**	**0.250**	**1**	**0.750**	**3**
	Unit 1	1.000	4	1.000	1	1.000	3
	Unit 2	0.000	0	0.000	0	0.000	0
	Spillway	**0.979**	**330**	**0.215**	**71**	**0.785**	**259**
	Spill Bay 1	0.076	25	0.211	15	0.039	10
	Spill Bay 2	0.418	138	0.197	14	0.479	124
	Spill Bay 3	0.506	167	0.592	42	0.483	125
	Spill Bay 4	0.000	0	0.000	0	0.000	0
	Dam	**0.009**	**3**	**0.333**	**1**	**0.667**	**2**
	No Route	0.333	1	1.000	1	0.000	0
	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	0.667	2	0.000	0	1.000	2
	Overall		**337**	**0.217**	**73**	**0.783**	**264**

Note: Fish that passed during mid pool (May 15, 2022, at 6:00 am through May 27, 2022, at 5:59 am) or summer pool (June 15, 2022, at 12:01 pm through the end of the study on Sept. 14, 2022, at 2:30 pm), were excluded from the analyses as there were no operational treatments during these periods.

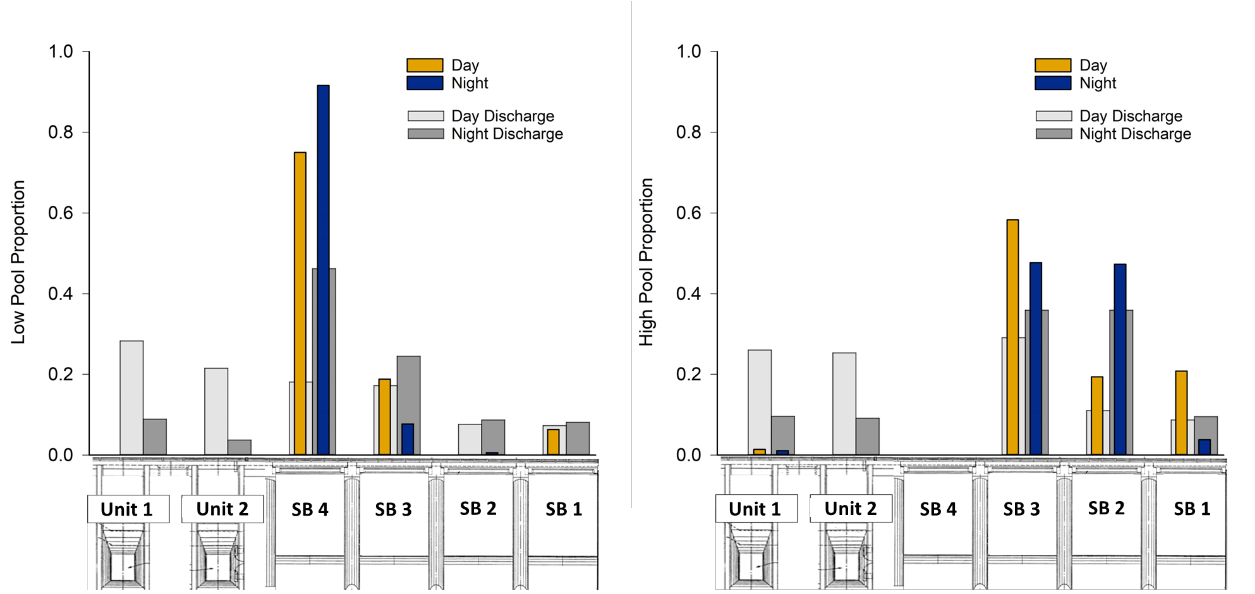

Figure 3-11. Diel passage proportions for yearling Chinook salmon released during the Foster spring season compared to the amount of discharge through the same route. SB = Spill Bay and the view of the routes is looking downstream.

3.3.1.4 Efficiency and Effectiveness

Yearling Chinook salmon had DPEs of 67.1% during low pool and 77.0% during high pool (Table 3-9; Figure 3-12). During low pool, all fish passed via a non-turbine route (i.e., Spill Bays 1–4); therefore, the FPE was the same as the DPE. Night passage DPE was also similar for low and high pools (approximately 60%) and was 6.3% and 16.6% for day passage for low and high pools, respectively (Table 3-9). Because only 4 fish passed via the turbines during high pool (1.2%) it had little effect on the overall FPE; thus, there was little change for the night and day passage FPEs (Table 3-9).

Comparisons of low pool DPE and FPE to past study years indicated that overall and nighttime DPE and FPE did not increase significantly in 2022 from levels observed in 2015, 2016, and 2018 ($P \geq 0.990$; Table 3-10; Liss et al. 2020). However, daytime DPE and FPE did increase during low pool in 2022 from all previous study years ($P \leq 0.002$; Table 3-10). During high pool, overall and daytime DPE and FPE were significantly greater in 2022 compared to 2015 and 2016 ($P < 0.001$; Table 3-10) but not 2018 ($P \geq 0.845$; Table 3-10). Nighttime DPE and FPE did not increase significantly during high pool in 2022 compared to past study years ($P \geq 0.096$).

All fish passing via the spillway instead of the turbines also led to the SPE being equal to 100% during low pool, regardless of day or night passage (Table 3-9; Figure 3-12). The SPE was ~99% during high pool, regardless of day or night passage (Table 3-9; Figure 3-12). The spillway effectiveness was above 1.0 (range: 1.14–2.02) for both pool elevations and diel passage times, indicating it was an effective route of passage for downstream migrating yearling Chinook salmon.

Table 3-9. Passage efficiencies and effectiveness for yearling Chinook salmon at Foster in spring 2022. 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.

	Overall		Day		Night	
Metric	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**
DPE	**0.671 (0.029)**	**0.770 (0.020)**	**0.063 (0.015)**	**0.166 (0.018)**	**0.608 (0.031)**	**0.604 (0.023)**
FPE	**0.671 (0.029)**	**0.760 (0.020)**	**0.063 (0.015)**	**0.164 (0.018)**	**0.608 (0.031)**	**0.597 (0.024)**
SPE || Dam	1.000 (0.000)	0.988 (0.001)	1.000 (0.000)	0.986 (0.014)	1.000 (0.000)	0.989 (0.007)
Spillway Effect.	1.513 (0.000)	1.589 (0.010)	1.991 (0.000)	2.023 (0.028)	1.144 (0.000)	1.216 (0.008)

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.

Table 3-10. Passage Efficiencies and Effectiveness for yearling Chinook salmon at Foster in Spring 2015, 2016, 2018, and 2022. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay. Standard errors are in parentheses.

	2015		2016		2018		2022 – Overall		2022 – Day		2022 – Night	
	Low Pool	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**
DPE	**0.952 (0.007)**	**0.663 (0.028)**	**0.955 (0.009)**	**0.680 (0.021)**	**0.900 (0.018)**	**0.853 (0.019)**	**0.671 (0.029)**	**0.770 (0.020)**	**0.063 (0.015)**	**0.166 (0.018)**	**0.608 (0.031)**	**0.604 (0.023)**
FPE	**0.642 (0.017)**	**0.645 (0.029)**	**0.589 (0.023)**	**0.630 (0.022)**	**0.756 (0.025)**	**0.850 (0.019)**	**0.671 (0.029)**	**0.760 (0.020)**	**0.063 (0.015)**	**0.164 (0.018)**	**0.608 (0.031)**	**0.597 (0.024)**

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).
Note: 2015, 2016, and 2018 data show the overall DPE and FPE. Please see Liss et al. (2020) for the breakdown of DPE and FPE by day and night for those study years.

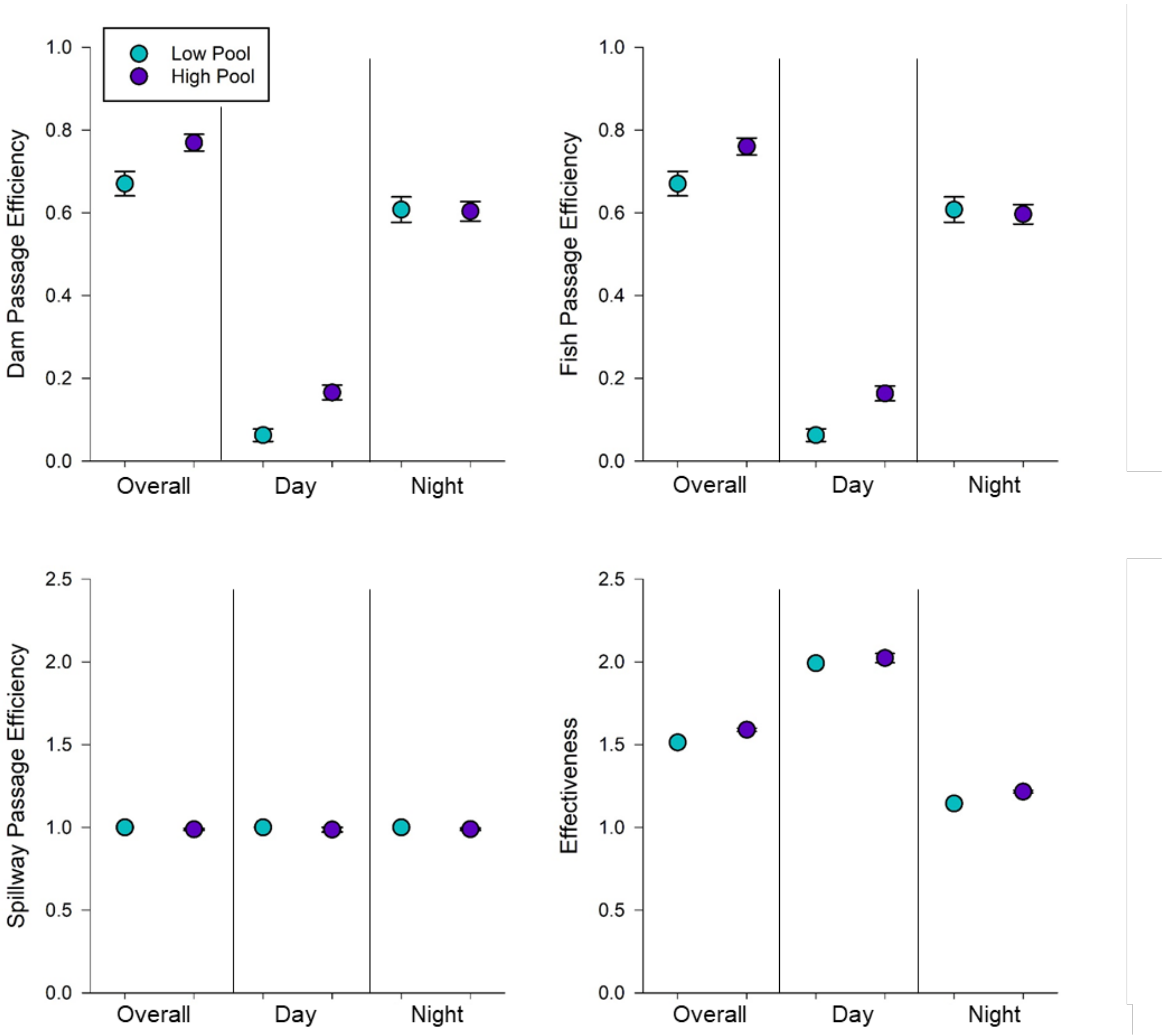

Figure 3-12. Dam passage efficiency, fish passage efficiency, spillway passage efficiency, and effectiveness of yearling Chinook salmon released at Foster in Spring 2022. Error bars represent standard errors (SE) of the mean. A lack of error bars indicates the SE was 0.000.

3.3.2 Spring – Age-2 Winter Steelhead

The following subsections describe survival, reservoir residency and travel time, passage distributions, and efficiency and effectiveness results for age-2 winter steelhead released at Foster during the spring study period.

3.3.2.1 Survival

Reservoir Survival

During spring low pool (March–early May; ~614.5 fmsl), a total of 647 RT-tagged steelhead were released at two locations in Foster Reservoir (N = 323 at the head of reservoir and N = 324 at mid-reservoir). Fish released at the head of reservoir had an estimated survival probability of 0.118 (0.018) from release to Foster and those released at mid-reservoir had an estimated survival of 0.202 (0.023) from release to Foster.

During spring high pool (June–July; ~636 fmsl), a total of 894 RT-tagged steelhead were released in Foster Reservoir (N = 446 at the head of reservoir and N = 448 at mid-reservoir). Fish released at the head of reservoir had an estimated survival probability of 0.179 (0.018) from release to Foster and those released at mid-reservoir had an estimated survival of 0.224 (0.020) from release to Foster.

Dam Passage Survival

As mentioned previously, the proportions of dead-tagged yearling Chinook salmon and steelhead detected downstream of Foster were similar; therefore, they were combined. The temporal distribution of all dead-tagged fish releases did not match that of live-released steelhead mortality during spring low pool (Wilcoxon χ^2 = 7.926; *P* = 0.005; Figure 3-13). Therefore, dead-tagged fish releases were truncated by removing the first 13 dead tagged fish that were released in March, resulting in a temporal distribution that more closely matched that of the live-released steelhead mortality (Wilcoxon χ2 = 3.084; *P* = 0.079; Figure 3-14).

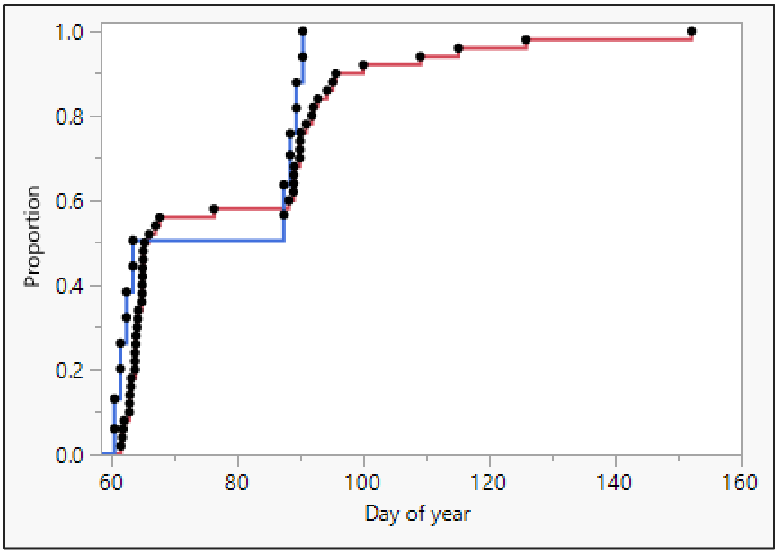

Figure 3-13. Cumulative proportions of live-released RT-tagged steelhead mortality (red) and all dead-tagged fish releases (blue) at Foster during spring low pool.

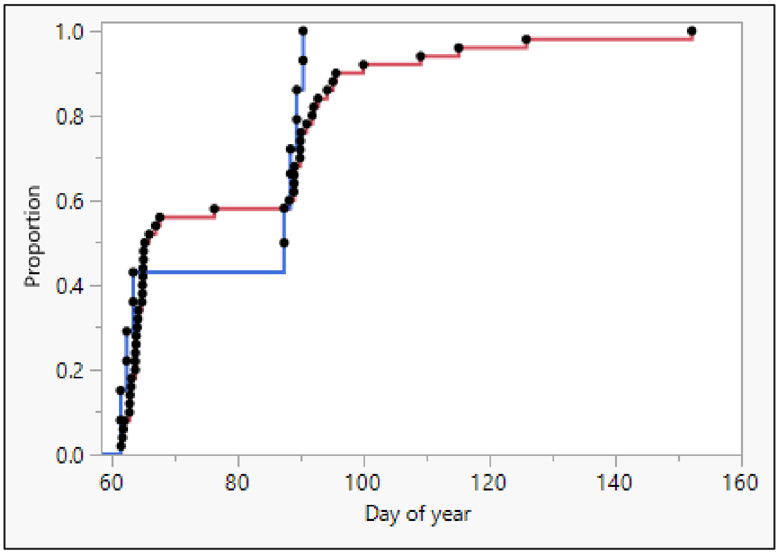

Figure 3-14. Cumulative proportions of live-released RT-tagged steelhead mortality (red) and truncated dead-tagged fish releases (blue) at Foster during spring low pool.

Of the remaining 86 dead-tagged fish released at Foster during spring low pool, one was detected at the Egress Array, and one was detected downstream of the Egress Array. Therefore, the full ViRDCt model was used to estimate dam passage (Foster to Egress Array) survival for steelhead that passed Foster during spring low pool.

A total of 99 RT-tagged steelhead passed Foster during spring low pool with an estimated S_D of 0.745 (0.048) (Table 3-11), which is similar to the ViRDCt-derived dam passage survival estimate obtained in 2018 ($S_D = 0.734$; SE = 0.047). Dam passage survival estimates were similar for tagged steelhead that passed Foster during night ($S_D = 0.736$; SE = 0.054) and day ($S_D = 0.779$; SE = 0.105) in 2022 (Table 3-11). All but eight tagged steelhead that passed Foster during spring low pool in 2022 did so via the spillway with $S_D = 0.757$ (0.049). The eight fish that passed through the turbines had an estimated S_D of 0.621 (0.173).

Table 3-11. Tag life, detection, and survival probability estimates for RT-tagged steelhead (STH) that passed Foster (FOS) during spring low pool, 2022. Estimates are shown for all RT-tagged STH and by diel period of Foster Dam passage. Standard errors 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, NA = insufficient detections for estimation, nan = not estimated. Note: 91 tagged STH passed Foster via the spillway and 8 passed through the turbines during spring low pool.

Reach	Tag life prob. (SE)	Det. Prob. (SE)	Survival (SE)
		All (N = 99)	
FOS – EGR[1]	*nan*	*0.945 (0.034)*	*0.745 (0.048)*
FOS – PRM	1.000 (0.001)	0.884 (0.049)	0.515 (0.052)
FOS – LEB	1.000 (0.002)	0.941 (0.040)	0.441 (0.051)
FOS – SRS[2]	*0.997 (0.002)*	*0.871 (0.060)*	*0.349 (0.049)*
FOS – COI	0.988 (0.007)	0.769 (0.083)	0.332 (0.051)
		Day (N = 24)	
FOS – EGR[1]	*nan*	*0.906 (0.097)*	*0.779 (0.105)*
FOS – PRM	1.000 (NA)	0.889 (0.105)	0.422 (NA)
FOS – LEB	0.998 (NA)	0.750 (0.217)	0.445 (NA)
FOS – SRS[2]	*0.994 (NA)*	*0.750 (0.217)*	*0.168 (NA)*
FOS – COI	0.911 (NA)	0.667 (0.272)	0.206 (NA)
		Night (N = 75)	
FOS – EGR[1]	*nan*	*0.956 (0.035)*	*0.736 (0.054)*
FOS – PRM	1.000 (0.001)	0.882 (0.055)	0.544 (0.059)
FOS – LEB	0.998 (0.002)	0.967 (0.033)	0.456 (0.058)
FOS – SRS[2]	*0.998 (0.002)*	*0.889 (0.061)*	*0.406 (0.058)*
FOS – COI	0.999 (0.002)	0.783 (0.086)	0.375 (0.059)

[1] Dam passage survival; [2] Reach passage survival.

The Foster passage timing of tagged steelhead during spring high pool was protracted, with about 60 days elapsing between the first and last passage. Dead-tagged fish were released at Foster over a period of about 15 days. Therefore, the temporal distribution of dead-tagged fish releases did not match that of live-released steelhead mortality during spring high pool (Wilcoxon $\chi^2 = 36.092$; $P < 0.001$; Figure 3-15). Truncating the dead-tagged fish releases did not result in a dead fish distribution that came close to matching that of the live-released fish. Therefore, the ViRDCt assumption that the dead-tagged fish are representative of live-released fish that died during dam passage could have been violated if the probability of detecting dead fish changed after dead-tagged fish releases ceased. A change of this nature is a possibility due to the large increase in discharge from ~3,000 cfs to ~11,000 cfs that immediately followed the last dead-tagged fish release (Figure 3-16). An increase in discharge could cause dead fish to drift downstream to detection arrays at a higher rate. If the dead fish detection rate was underestimated, the dam passage survival estimate would be biased high.

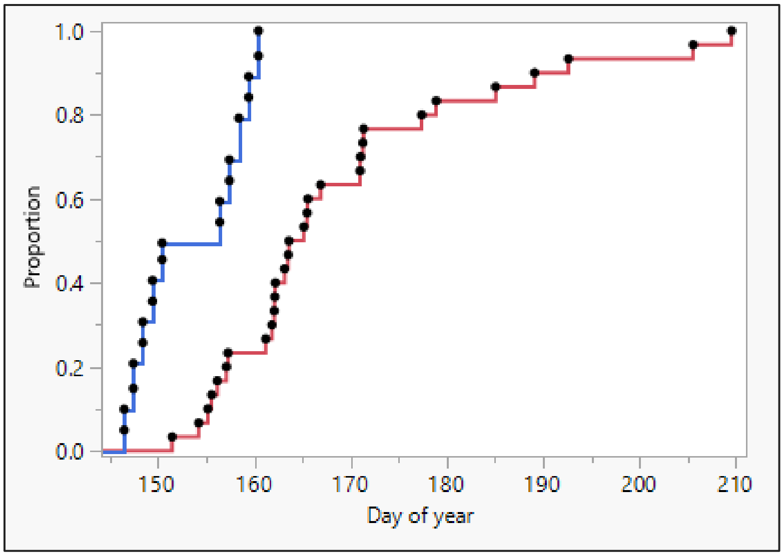

Figure 3-15. Cumulative proportions of live-released RT-tagged steelhead mortality (red) and all dead-tagged fish releases (blue) at Foster Dam during spring high pool.

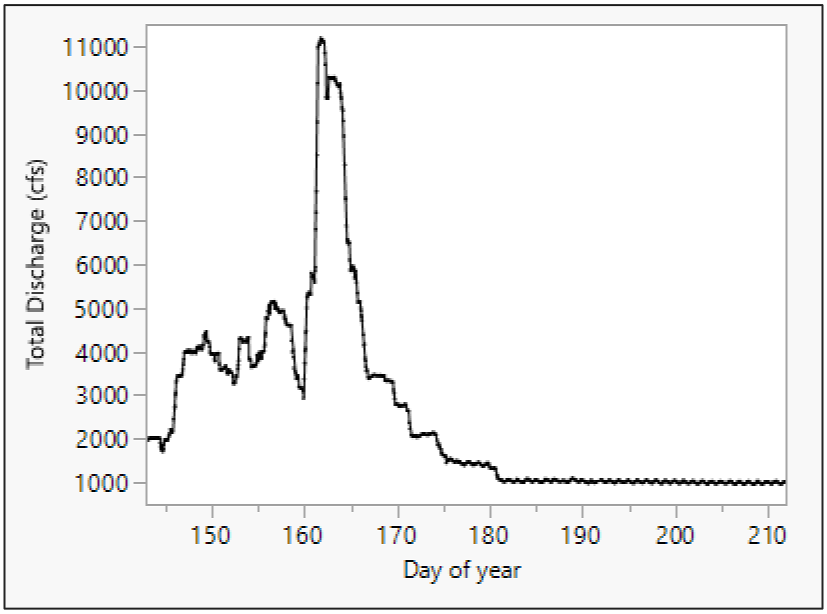

Figure 3-16. Total discharge at Foster Dam by day of year.

A total of 180 RT-tagged steelhead passed Foster during spring high pool with an estimated S_D of 0.837 (0.033) (Table 3-12), which is similar to the ViRDCt-derived dam passage survival estimate obtained in 2018 (S_D = 0.885; SE = 0.108). The S_D estimate obtained in 2022 was only slightly greater than the estimated survival to the Waterloo Primary Array (S = 0.829; SE = 0.028; Table 3-12). Therefore, it is unlikely that the S_D estimate was biased high due to violation of the representativeness of dead-tagged fish assumption. Dam passage survival was slightly higher for tagged steelhead that passed Foster during night (S_D = 0.872; SE = 0.033) compared to day passage (S_D = 0.766; SE = 0.058) in 2022, but the difference was not statistically significant

(χ^2 = 2.767; *P* = 0.096; Table 3-12). All but four tagged steelhead that passed Foster during spring high pool in 2022 did so via the spillway with S_D = 0.837 (0.030). The four fish that passed through the turbines had an estimated S_D of 1.000 (NA).

Table 3-12. Tag life, detection, and survival probability estimates for RT-tagged steelhead (STH) that passed Foster Dam (FOS) during spring high pool, 2022. Estimates are shown for all RT-tagged STH and by diel period of Foster Dam passage. Standard errors are shown in parentheses. PRM = Waterloo Primary array, LEB = Lebanon Dam array, SRS = I-5 Santiam Rest Stop array, COI = Cole Island array, nan = not estimated. Note: 175 tagged STH passed Foster Dam via the spillway, 4 passed through the turbines, and 1 passed via an unknown route during spring high pool.

Reach	Tag life prob. (SE)	Det. Prob. (SE)	Survival (SE)
		All (N = 180)	
FOS – EGR[1]	*nan*	*0.953 (0.023)*	*0.837 (0.033)*
FOS – PRM	1.000 (0.000)	0.912 (0.023)	0.829 (0.028)
FOS – LEB	1.000 (0.000)	0.986 (0.010)	0.817 (0.029)
FOS – SRS[2]	*1.000 (0.000)*	*0.914 (0.024)*	*0.778 (0.031)*
FOS – COI	1.000 (0.000)	0.956 (0.017)	0.778 (0.031)
		Day (N = 61)	
FOS – EGR[1]	*nan*	*0.948 (0.037)*	*0.766 (0.058)*
FOS – PRM	1.000 (0.000)	0.936 (0.036)	0.771 (0.054)
FOS – LEB	1.000 (0.000)	0.979 (0.021)	0.771 (0.054)
FOS – SRS[2]	*1.000 (0.000)*	*0.833 (0.058)*	*0.708 (0.059)*
FOS – COI	1.000 (0.000)	0.968 (0.032)	0.695 (0.060)
		Night (N = 119)	
FOS – EGR[1]	*nan*	*0.957 (0.022)*	*0.872 (0.033)*
FOS – PRM	1.000 (0.000)	0.900 (0.030)	0.859 (0.032)
FOS – LEB	1.000 (0.000)	0.990 (0.010)	0.841 (0.034)
FOS – SRS[2]	*1.000 (0.000)*	*0.948 (0.023)*	*0.815 (0.036)*
FOS – COI	1.000 (0.000)	0.958 (0.020)	0.815 (0.036)

[1] Dam passage survival; [2] Reach survival.

Reach Survival

For all tagged steelhead that passed Foster during spring low pool, the probability of tags being active was ≥ 0.988 at downstream detection sites (Table 3-12). Therefore, adjustments for tag life were minor. An estimated 51.5% of tagged steelhead that passed Foster during spring low pool survived from Foster to the Waterloo Primary Array (Table 3-5), which was similar to the pooled survival estimate from 2015, 2016, and 2018 (*S* = 0.550; SE = 0.025). Survival probability was estimated to be 0.441 (SE = 0.051) and 0.349 (SE = 0.049) to the Lebanon and I-5 Santiam Rest Stop arrays, respectively, in 2022 (Table 3-12).

The 24 tagged steelhead that passed Foster during the day in spring low pool of 2022 had a significantly lower probability of surviving to the I-5 Santiam Rest Stop Array (*S* = 0.168; SE =

NA) than those that passed at night (*S* = 0.406; SE = 0.058) (Table 3-12; χ^2 = 4.950; *P* = 0.026). However, estimates of survival from Foster to the Waterloo Primary, Lebanon, and Cole Island arrays did not differ significantly by diel passage period (Table 3-12). Only eight tagged steelhead were detected passing through the turbines at Foster during spring low pool. Those eight fish had an estimated survival probability of 0.125 (0.108) to the I-5 Santiam Rest Stop array, which could not be significantly differentiated from the survival of spillway-passed fish (*S* = 0.369; SE = 0.051) due to the small sample size of turbine-passed fish.

All steelhead that passed Foster during spring high pool migrated through the study area before the first tag life tag died. Therefore, tag life probability was 1.000 and no tag life adjustments were required (Table 3-12). The probability of surviving from Foster to the Waterloo Primary Array was estimated to be 0.829 (0.028) for tagged steelhead that passed Foster during spring high pool (Table 3-12), which was similar to the pooled survival estimate from 2015, 2016, and 2018 (*S* = 0.775; SE = 0.024; χ^2 = 2.078; *P* = 0.149). Survival was estimated to be 0.817 (SE = 0.029) and 0.778 (SE = 0.031) to the Lebanon and I-5 Santiam Rest Stop arrays, respectively, in 2022 (Table 3-12).

Estimates of survival from Foster to the Waterloo Primary, Lebanon, and I-5 Santiam Rest Stop arrays were similar for tagged steelhead that passed Foster during day and night during spring high pool (Table 3-12). Only four tagged steelhead passed Foster through the turbines during spring high pool, with an estimated survival probability of 0.500 (SE = NA) to the I-5 Santiam Rest Stop array. The small sample size of turbine-passed fish precluded a meaningful comparison of survival to spillway-passed fish.

3.3.2.2 Reservoir Residency and Migration Travel Times

When HOR and MOR were combined, fish released during low pool spent approximately 45 h in the reservoir before passing Foster (Figure 3-17). However, the HOR fish alone spent approximately 83 h before migrating and the fish released at MOR spent approximately half (41 h) that time in the reservoir before migrating. This indicated more fish passed after release from the MOR, as the median for both release locations was 45 h. During high pool, fish spent approximately 137 h collectively in the reservoir before passing Foster (Figure 3-17). Fish released at HOR spend 140 h in the reservoir before passing and fish released at MOR spent 124 in the reservoir before passing Foster (Figure 3-17).

The reservoir residence time of steelhead released into Foster Reservoir in 2022 were lower than, or similar to, those observed in past study years. During low pool in 2022, reservoir residence time was significantly lower than the residence times from all past years (*Z* ≥ 3.433, *P*

< 0.001). Steelhead released during high pool had significantly lower reservoir residence times than those released in 2016 and 2018 ($Z = 4.748$, $P < 0.001$) but similar to those released in 2015 ($Z = 1.366$, $P = 0.172$).

During low pool, travel times from Foster to downstream arrays were similar between steelhead that passed at night and during the day ($Z \leq 1.846$, $P \geq 0.065$). During high pool, steelhead that passed Foster at night had significantly shorter travel times to all downstream arrays than those that passed during the day ($Z \geq 2.313$, $P \leq 0.021$).

Steelhead that passed Foster during low and high pool had significantly shorter travel times to the Waterloo Primary Array in 2022 compared to all past study years (≥ 2.311, $P \leq 0.021$). With the exception of 2018 low pool, discharge was generally higher in 2022 during the period of RT-tagged steelhead passage compared to past study years.

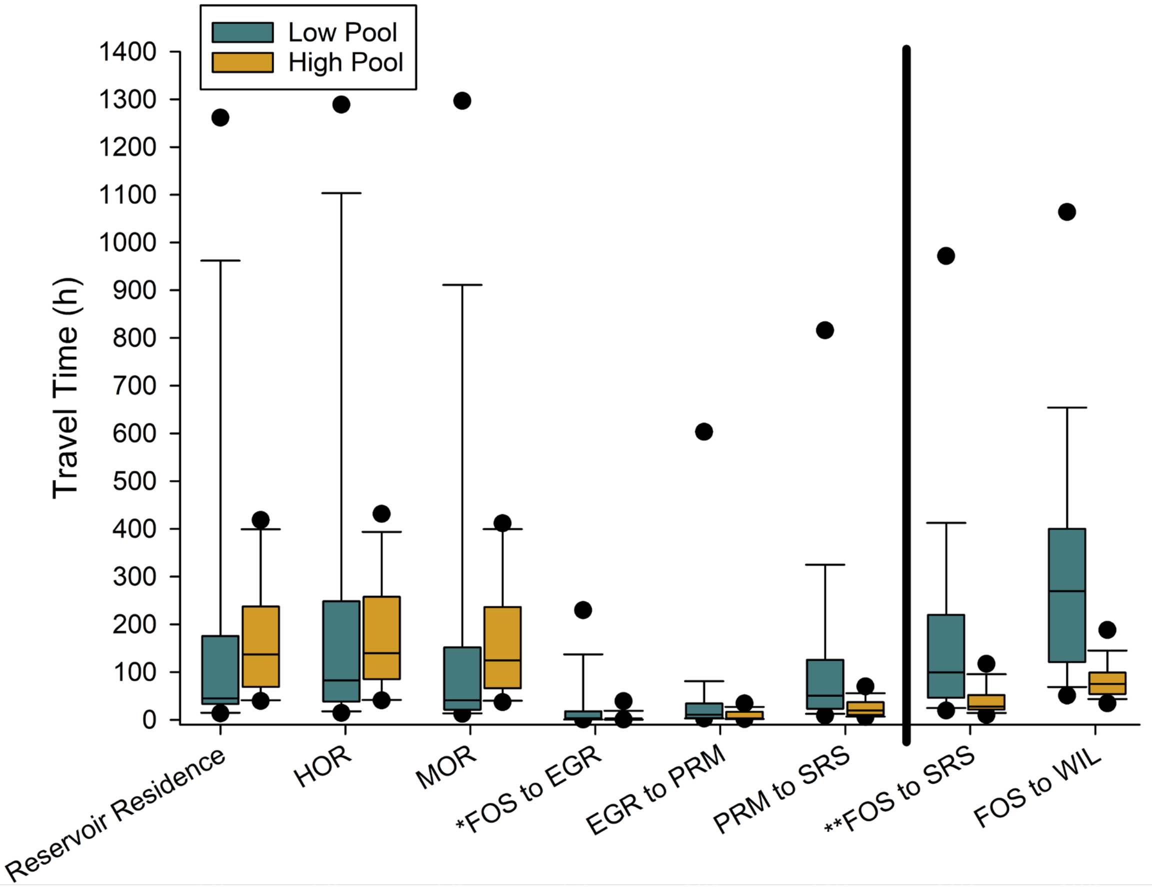

Figure 3-17. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir; MOR = mid-of-reservoir), and travel times between reaches for age-2 winter steelhead released at Foster (FOS; EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). 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.

3.3.2.3 Passage Distributions

A small proportion of age-2 steelhead moved downstream of Foster (~24%; Table 3-13). Similar to age-1 Chinook salmon, the majority of the fish passed during the nighttime spillway operations (76% and 80.1% for low and high pool elevation, respectively). During low pool, the spillway (primarily Spill Bay 4) was the primary route of passage for steelhead, with 91% of fish passage via the spillway, and 86% passing via Spill Bay 4 (Table 3-14). This was similar during high pool, with 96% of fish passing via the spillway. However, more fish passed via Spill Bays 1, 2, and 3 (18%, 48%, and 33%, respectively) during high pool. This may have been because Spill Bay 4 was closed for the majority of the high pool operations and was only opened on June 15th for 30 min. Very few fish (n = 11 for low and high pools) passed via the turbines, and very few fish (n = 3 for low and high pools) were unable to be assigned a specific route of passage (Table 3-14).

During low pool, 526 fish were detected at the forebay and were used for analysis (V_1; Figure 2-3). The majority of these fish (74.5%) were detected at the near forebay (i.e., dam face) but did not pass Foster (Table 3-13). Only 19% of steelhead moved downstream of Foster (Table 3-13). A small proportion of fish were identified as no route predation (1%; i.e., never detected at Foster after release) or were detected in the extended forebay only (5%) but did not approach the dam (Table 3-13).

A similar trend of low downstream passage proportions was observed at Foster during high pool. Of the 660 fish detected and used for analyses, the majority (67%) of fish were detected in the near forebay but did not pass (Table 3-13). However, a higher proportion (27%) of steelhead passed during high pool than low pool (Table 3-13). Again, a small proportion of fish were identified as no route predation only (~3%; i.e., never detected at Foster after release) or were detected in the extended forebay only (~9%) but did not approach the dam (Table 3-13).

A large amount (20%) of potential predation of steelhead occurred after detection in the Foster forebay (i.e., detected after release and before predation) during low and high pools compared to yearling Chinook salmon (9%; Table 3-13). This may have been caused by the high proportion of steelhead detected at the near forebay that did not pass, as birds (Cormorants) were also frequently observed near the dam face (near forebay).

Table 3-13. Movement summary of RT-tagged age-2 winter steelhead released at Foster Dam. The Virtual Release Group indicates fish that were detected after release.

	Virtual Release Group	No Route Predation		Extended Forebay Detection – Never Passed		Near Forebay Detection – Never Passed		Downstream Passage		Predation after any Forebay or Downstream Detection	
Pool Elevation	**(*n*)**	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***	**Sub Prop.**	***N***
Low	526	0.011	6	0.053	28	0.745	392	0.190	100	0.210	111
High	660	0.026	17	0.088	58	0.615	406	0.271	179	0.193	128
Overall	**1186**	**0.019**	**23**	**0.073**	**86**	**0.673**	**798**	**0.235**	**279**	**0.201**	**239**

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 3-14) were excluded.

During low pool, the spillway (primarily Spill Bay 4) was the primary route of passage for steelhead, with 91% of fish passage via the spillway, and 86% passing via Spill Bay 4 (Table 3-14). This was similar during high pool, with 96% of fish passing via the spillway. However, more fish passed via Spill Bays 1, 2, and 3 (18%, 48%, and 33%, respectively) during high pool. Spill Bay 4 was not operated during high pool and was only opened on June 15th for 30 min. Very few fish (*n* = 11 for low and high pools) passed via the turbines, and very few fish (*n* = 3 for low and high pools) were unable to be assigned a specific route of passage (Table 3-14).

Table 3-14. Passage proportions by route of passage for RT-tagged age-2 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 identified.

		Overall		Day		Night	
Pool Elevation	**Route**	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***
Low	**Turbines**	**0.070**	**7**	**0.857**	**6**	**0.143**	**1**
	Unit 1	0.571	4	0.500	3	1.000	1
	Unit 2	0.429	3	0.500	3	0.000	0
	Spillway	**0.910**	**91**	**0.198**	**18**	**0.802**	**73**
	Spill Bay 1	0.000	0	0.000	0	0.000	0
	Spill Bay 2	0.011	1	1.274	1	0.000	0
	Spill Bay 3	0.132	12	5.097	4	0.000	8
	Spill Bay 4	0.857	78	16.564	13	0.000	65
	Dam	**0.020**	**2**	**0.000**	**0**	**1.000**	**2**
	No Route	0.500	1	0.000	0	1.000	1
	Turbines	0.500	1	0.000	0	1.000	1
	Spillway	0.000	0	0.000	0	0.000	0
	Overall		**100**	**0.240**	**24**	**0.760**	**76**
High	**Turbines**	**0.031**	**4**	**0.080**	**2**	**0.019**	**2**
	Unit 1	0.500	2	0.000	0	1.000	2
	Unit 2	0.500	2	1.000	2	0.000	0
	Spillway	**0.961**	**124**	**0.185**	**23**	**0.815**	**101**
	Spill Bay 1	0.177	22	0.174	4	0.178	18
	Spill Bay 2	0.484	60	0.522	12	0.475	48
	Spill Bay 3	0.331	41	0.261	6	0.347	35
	Spill Bay 4	0.008	1	0.043	1	0.000	0
	Dam	**0.008**	**1**	**0.000**	**0**	**1.000**	**1**
	No Route	0.000	0	0.000	0	0.000	0
	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	1.000	1	0.000	0	1.000	1
	Overall		**129**	**0.194**	**25**	**0.806**	**104**

Note: Fish that passed during mid pool (May 15, 2022, at 6:00 am through May 27, 2022, at 5:59 am) or summer pool (June 15, 2022, at 12:01 pm through the end of the study on Sept. 14, 2022, at 2:30 pm), were excluded from the analyses as there were no operational treatments during these periods.

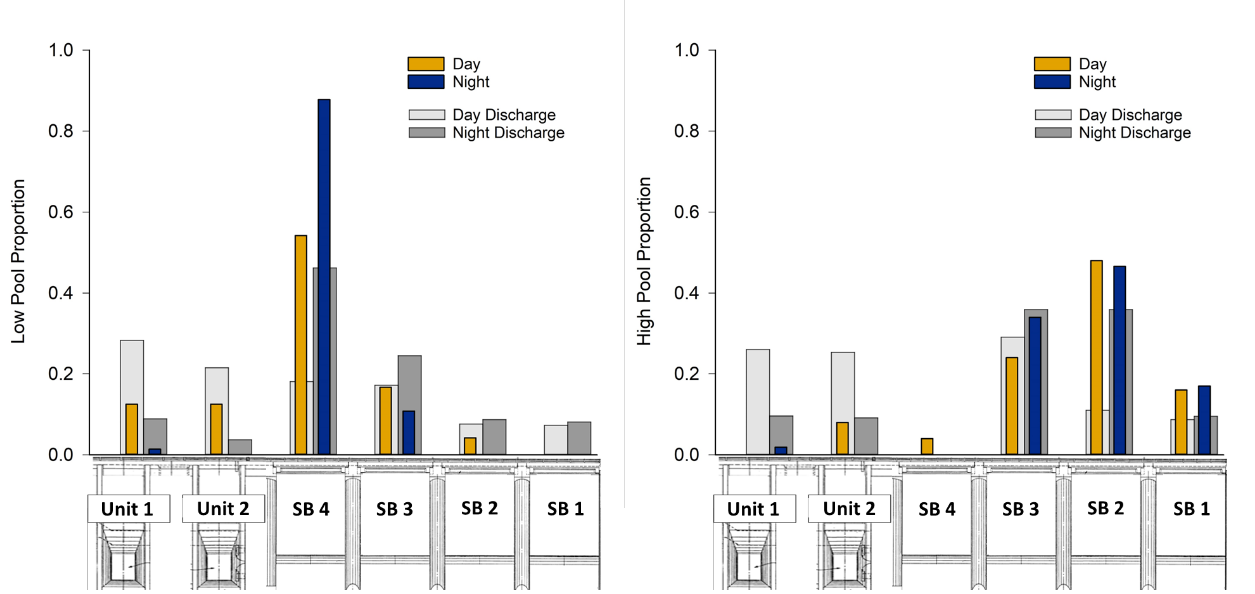

Figure 3-18. Diel passage proportions for age-2 winter steelhead released during the Foster spring season compared to the amount of discharge through the same route. SB = Spill Bay and the view of the routes is looking downstream.

3.3.2.4 Efficiency and Effectiveness

Age-2 winter steelhead had poor overall DPE for low (21.3%) and high (27.1%) pool, as well as during day and night (range: 5.2–21.8%; Table 3-15; Figure 3-19). The FPE was also poor and was lower than DPE as 7 fish passed via the turbines during low pool and 4 fish passed via the turbines during high pool (Table 3-14; Table 3-15; Figure 3-19. 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).

Comparisons to past study years revealed that overall, daytime, and nighttime DPE and FPE did not increase significantly in low pool 2022 compared to 2015, 2016, and 2018 for age-2 winter steelhead (*P* ≥ 0.815; Table 3-16; Liss et al. 2020). For high pool, overall and daytime estimates of DPE and FPE from 2022 were not significantly greater than those from past years (*P* ≥ 0.999). Nighttime DPE and FPE were significantly greater during high pool in 2022 compared to 2018 (*P* = 0.007) but not greater than the estimates from 2015 and 2016 (*P* = 1.000).

Additionally, despite DPE and FPE being low, the SPE was high (≥ 92%) for low and high pools overall, as well as during night passage when the majority of fish passed (Table 3-14). The lowest SPE occurred during low pool and day passage (75%), which may have also been a result of discharge (Table 3-15; Figure 3-19). For the steelhead that passed Foster, the effectiveness of spillway passage was also high (≥ 1.1), indicating that the spillway was an effective route of passage (Table 3-15; Figure 3-19).

Table 3-15. Passage efficiencies and effectiveness for age-2 winter steelhead at Foster in spring 2022. 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.

	Overall		Day		Night	
Metric	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**
DPE	**0.213 (0.019)**	**0.271 (0.020)**	**0.052 (0.010)**	**0.053 (0.010)**	**0.161 (0.017)**	**0.218 (0.019)**
FPE	**0.198 (0.019)**	**0.263 (0.020)**	**0.039 (0.009)**	**0.049 (0.010)**	**0.159 (0.017)**	**0.214 (0.019)**
SPE || Dam	0.929 (0.026)	0.969 (0.015)	0.750 (0.088)	0.920 (0.054)	0.986 (0.013)	0.981 (0.014)
Spillway Effect.	1.405 (0.039)	1.558 (0.025)	1.494 (0.176)	1.887 (0.111)	1.128 (0.015)	1.206 (0.017)

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.

Table 3-16. Passage Efficiencies and Effectiveness for age-2 winter steelhead at Foster in Spring 2015, 2016, 2018, and 2022. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay. Standard errors are in parentheses.

	2015		2016		2018		2022 – Overall		2022 – Day		2022 – Night	
	Low Pool	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**
DPE	**0.432 (0.026)**	**0.762 (0.021)**	**0.529 (0.035)**	**0.667 (0.024)**	**0.464 (0.023)**	**0.378 (0.028)**	**0.213 (0.019)**	**0.271 (0.020)**	**0.052 (0.010)**	**0.053 (0.010)**	**0.161 (0.017)**	**0.218 (0.019)**
FPE	**0.355 (0.026)**	**0.749 (0.022)**	**0.375 (0.035)**	**0.649 (0.025)**	**0.319 (0.022)**	**0.371 (0.028)**	**0.198 (0.019)**	**0.263 (0.020)**	**0.039 (0.009)**	**0.049 (0.010)**	**0.159 (0.017)**	**0.214 (0.019)**

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).
Note: 2015, 2016, and 2018 data show the overall DPE and FPE. Please see Liss et al. (2020) for the breakdown of DPE and FPE by day and night for those study years.

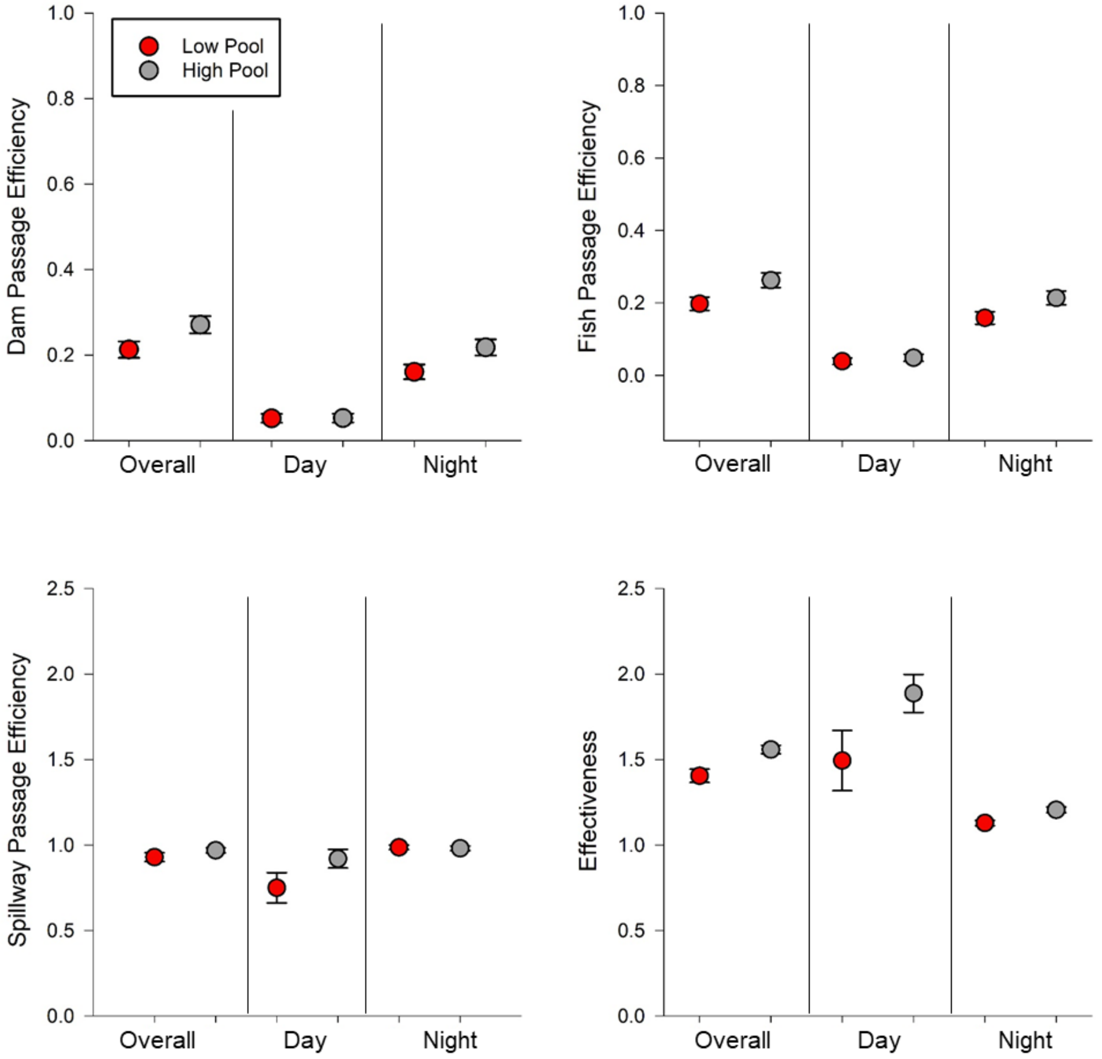

Figure 3-19. Dam passage efficiency, fish passage efficiency, spillway passage efficiency, and effectiveness of age-2 winter steelhead released at Foster in Spring 2022. Error bars represent standard errors (SE) of the mean. A lack of error bars indicates the SE was 0.000.

3.3.3 Fall – Subyearling Chinook Salmon

The following subsections describe survival, reservoir residency and travel time, passage distributions and efficiency and effectiveness results for subyearling Chinook salmon released at Foster during the fall study period.

3.3.3.1 Fall Tag Life Study

Tags retained for the fall study assessment of operational tag life had a mean life of 66.8 d (range = 28.9–80.2 d). The Vitality model provided the best fit to the observed tag life and was used to adjust reach survival estimates for the probability of tag failure (Figure 3-20).

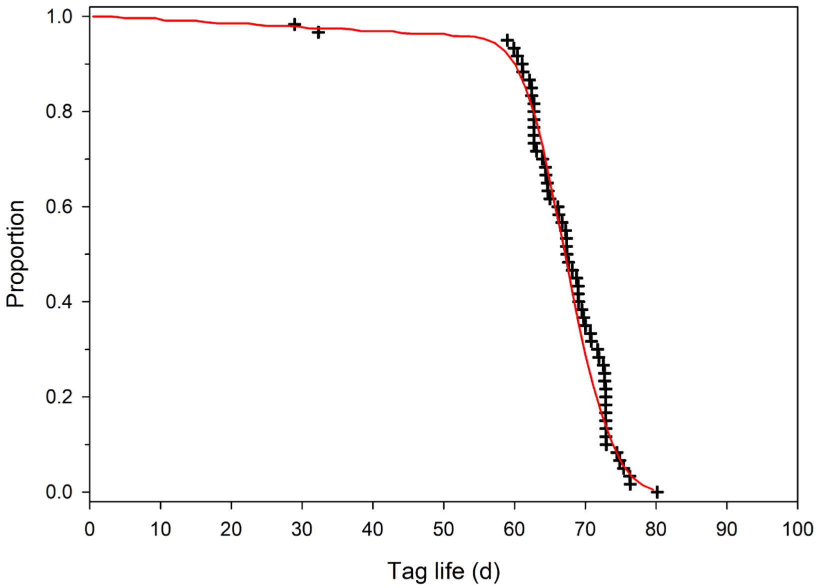

Figure 3-20. Vitality model fit to the observed tag life of radio tags used during the 2022 fall survival study at Foster.

3.3.3.2 Survival

Reservoir Survival

During fall low pool, a total of 643 RT-tagged subyearling Chinook salmon were released at two locations in Foster Reservoir (N = 327 at the head of reservoir and N = 316 at mid-reservoir). Fish released at the head of reservoir had an estimated survival probability of 0.495 (0.028) from release to Foster and those released at mid-reservoir had an estimated survival of 0.614 (0.028) from release to Foster.

Dam Passage Survival

Similar to the spring study, dead-tagged fish were released each day live tagged fish were released yet it took a few days for the first live-released fish to begin passing Foster. Therefore, the temporal distribution of dead-tagged fish releases did not match that of live-released subyearling Chinook salmon mortality (Wilcoxon χ2 = 16.533; *P* < 0.001; Figure 3-21). Truncating the dead fish releases by removing the first 20 dead tagged fish that were released in October resulted in a temporal distribution that more closely matched the timing of live-released subyearling Chinook salmon mortality (Wilcoxon χ^2 = 3.703; *P* = 0.054; Figure 3-22).

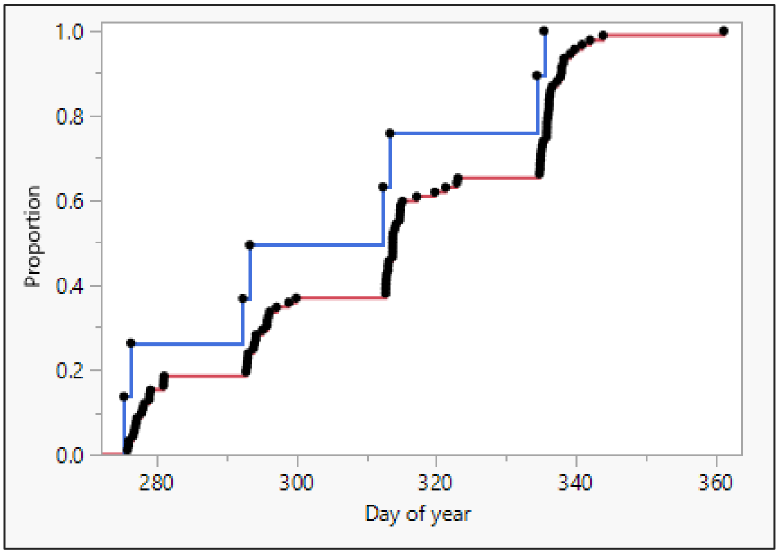

Figure 3-21. Cumulative proportions of live-released RT-tagged subyearling Chinook salmon mortality (red) and all dead-tagged fish releases (blue) at Foster during fall low pool.

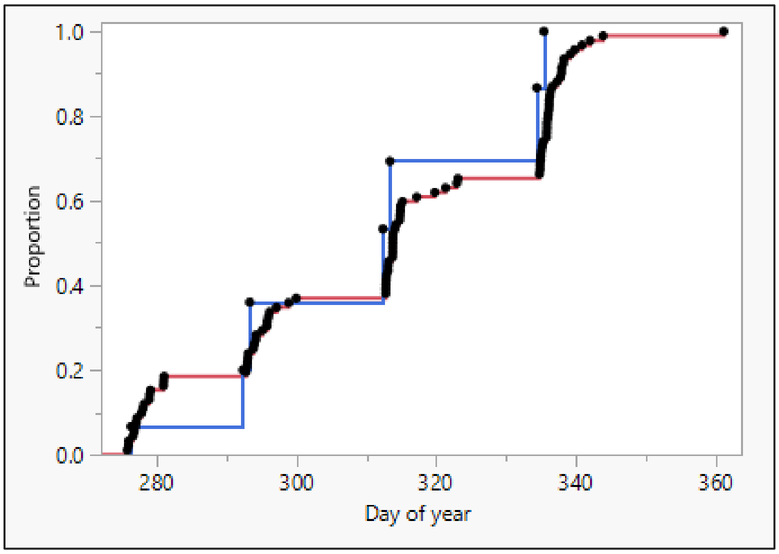

Figure 3-22. Cumulative proportions of live-released RT-tagged subyearling Chinook salmon mortality (red) and truncated dead-tagged fish releases (blue) at Foster during fall low pool.

Of the remaining 75 dead-tagged fish released at Foster during fall low pool, three were detected at the Egress Array, and none were detected downstream of the Egress Array. Therefore, the reduced ViRDCt model was used to estimate dam passage (Foster to Egress Array) survival for subyearling Chinook salmon that passed Foster during fall low pool.

A total of 354 RT-tagged subyearling Chinook salmon passed Foster during fall low pool with an estimated S_D of 0.924 (0.015) (Table 3-17), which is similar to the ViRDCt-derived dam passage survival estimate obtained in 2018 (S_D = 0.879; SE = 0.017). Dam passage survival estimates were similar for tagged subyearling Chinook salmon that passed Foster during night ($S_D = 0.928$; SE = 0.017) and day ($S_D = 0.913$; SE = 0.031) in 2022 (Table 3-17). All but 17 tagged subyearling Chinook salmon that passed Foster during fall low pool in 2022 did so via the spillway with $S_D = 0.931$ (0.015). The 13 fish that passed through the turbines had an estimated S_D of 0.810 (0.143) and the four fish that passed through an undetermined route had an estimated S_D of 0.912 (NA).

Table 3-17. Tag life, detection, and survival probability estimates for RT-tagged subyearling Chinook salmon (CH0) that passed Foster (FOS) during fall low pool, 2022. Estimates are shown for all RT-tagged CH0 and by diel period of Foster passage. Standard errors 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 = not estimated. Note: 337 tagged CH0 passed Foster via the spillway, 13 passed through the turbines, and 4 passed through undetermined routes during fall low pool.

Reach	Tag life prob. (SE)	Det. Prob. (SE)	Survival (SE)
		All (N = 354)	
FOS – EGR[1]	*nan*	*0.981 (0.009)*	*0.924 (0.015)*
FOS – PRM	0.998 (0.004)	0.943 (0.015)	0.738 (0.026)
FOS – LEB	0.998 (0.003)	0.973 (0.013)	0.698 (0.027)
FOS – SRS[2]	*0.989 (0.008)*	*0.923 (0.022)*	*0.428 (0.029)*
FOS – COI	0.988 (0.009)	0.908 (0.033)	0.425 (0.030)
		Day (N = 91)	
FOS – EGR[1]	*nan*	*0.971 (0.020)*	*0.913 (0.031)*
FOS – PRM	0.999 (0.013)	0.955 (0.026)	0.749 (0.058)
FOS – LEB	0.998 (0.009)	0.975 (0.025)	0.734 (0.056)
FOS – SRS[2]	*0.969 (0.031)*	*0.917 (0.046)*	*0.458 (0.060)*
FOS – COI	0.967 (0.026)	0.944 (0.054)	0.421 (0.061)
		Night (N = 263)	
FOS – EGR[1]	*nan*	*0.985 (0.009)*	*0.928 (0.017)*
FOS – PRM	0.998 (0.001)	0.938 (0.018)	0.735 (0.028)
FOS – LEB	0.997 (0.001)	0.973 (0.016)	0.686 (0.030)
FOS – SRS[2]	*0.995 (0.002)*	*0.924 (0.026)*	*0.418 (0.031)*
FOS – COI	0.995 (0.002)	0.915 (0.027)	0.418 (0.031)

[1] Dam passage survival; [2] Reach survival.

Reach Survival

For all tagged subyearling Chinook salmon that passed Foster during fall low pool, the probability of tags being active was ≥ 0.988 at downstream detection sites (Table 3-17). Therefore, adjustments for tag life were minor. An estimated 73.8% of tagged subyearling Chinook salmon that passed Foster during fall low pool survived from Foster to the Waterloo Primary Array (Table 3-17), which was similar to the survival estimate from 2016 ($S = 0.755$; SE = 0.014) but significantly lower than the estimates from 2015 ($S = 0.855$; SE = 0.012; $\chi^2 = 21.284$; $P < 0.001$)

and 2018 ($S = 0.805$; SE = 0.020; $\chi^2 = 4.669$; $P = 0.031$). Survival probability was estimated to be 0.698 (SE = 0.027) and 0.428 (SE = 0.029) to the Lebanon and I-5 Santiam Rest Stop arrays, respectively, in 2022 (Table 3-17).

Estimates of survival from Foster to the Waterloo Primary, Lebanon, I-5 Santiam Rest Stop, and Cole Island arrays did not differ significantly by diel passage period for subyearling Chinook salmon (Table 3-17). Only 13 tagged subyearling Chinook salmon were detected passing through the turbines at Foster during fall low pool. Those 13 fish had an estimated survival probability of 0.231 (0.117) to the I-5 Santiam Rest Stop array, which could not be statistically differentiated from the survival of spillway-passed fish ($S = 0.440$; SE = 0.029) due to the small sample size of turbine-passed fish.

3.3.3.3 Reservoir Residency and Migration Travel Times

Only one pool elevation was evaluated for subyearling Chinook salmon released during the fall at Foster: low pool. Fish resided in the reservoir for approximately 35 h after release at the HOR, and approximately 16 h after release at the MOR (Figure 3-23). Comparing reservoir residency time in 2022 to past study years indicated subyearling Chinook salmon spent significantly less time in Foster Reservoir in 2022 compared to 2015 and 2018 ($Z \geq 5.138$, $P < 0.001$), but significantly more time than in 2016 ($Z = 2.682$, $P = 0.007$).

The median travel time was 1.5 h (Figure 3-23). It took fish a median of 32 h to travel to the confluence (I-5 Santiam Rest Stop Array) from Foster. Travel times from Foster to the Egress Array were similar for subyearling Chinook salmon that passed Foster during day and night ($Z = 0.318$, $P = 0.751$). However, downstream of the Egress Array, travel times were significantly shorter for fish that passed Foster during the day compared to those that passed at night ($Z \geq 2.388$, $P \leq 0.017$). The mean discharge at Foster during fall low pool was 2,129 cfs, with approximately equal discharge being passed during the day (2,081 cfs) and night (2,176 cfs).

Comparing 2022 Foster to Waterloo Primary Array travel times to past study years indicated subyearling Chinook salmon took significantly less time to reach the Waterloo Primary Array in 2022 compared to 2015 and 2018 ($Z \geq 10.569$, $P < 0.001$) but significantly more time compared to 2016 ($Z = 7.594$, $P < 0.001$). Some of the differences in travel time can be explained by differences in discharge between years. In 2022, discharge averaged about 2,750 cfs, which was higher than 2018, which was characterized by low flows throughout the fall, averaging less than 1,700 cfs. In 2015, discharge was low through November, before increasing substantially in December. In contrast, flows were high throughout most of the fall and early winter of 2016, averaging almost 5,000 cfs.

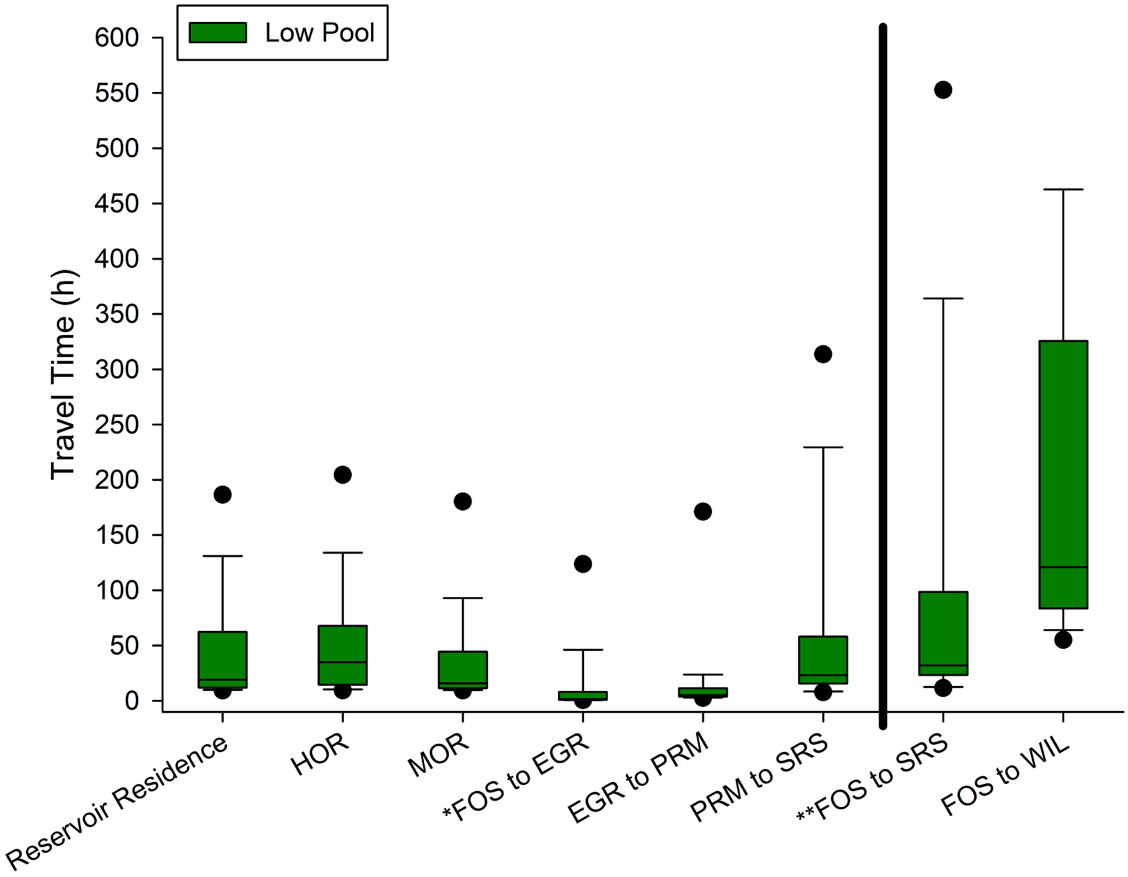

Figure 3-23. Boxplots of estimated reservoir residence time (including by release location: HOR = head-of-reservoir; MOR = mid-of-reservoir), and travel times between reaches for subyearling Chinook salmon released at Foster (FOS; EGR = Egress, PRM = Primary at Waterloo, SRS = I-5 Rest Stop, WIL = Willamette Falls). 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.

3.3.3.4 Passage Distributions

During the fall season, 64% of subyearling Chinook salmon moved downstream of Foster (Table 3-18). Similar to the spring season for both yearling Chinook salmon and steelhead, the majority of subyearling Chinook salmon (75%) passed Foster at night compared to during the daytime. The primary route of passage for subyearling Chinook salmon was via the spillway, with 95% of fish passing that route (Table 3-18). The majority of the fish passed via Spill Bay 4 (~65%), with Spill Bay 3 being the second most used route (~26%), followed by Spill Bay 1 (~6%), and Spill Bay 2 (~3%; Table 3-18). More subyearlings passed the turbines (n = 13) compared to yearling Chinook salmon (n = 4), although the number was similar to steelhead (n = 11). Approximately 2% of fish had undefined routes of passage (Table 3-18)

Of the fish used for analyses (*n* = 543; Table 3-18), approximately 1% were likely an indication of no route predation (i.e., never detected at Foster after release). Thirteen percent of subyearlings were detected at the extended forebay but did not approach the Foster near forebay (Table 3-18). Approximately 22% approached Foster near forebay but did not pass, and 64% of subyearlings migrated downstream of Foster (Table 3-18). Subyearlings detected at Foster were predated after detection on the extended forebay, near forebay, or after downstream passaged, although the proportion was small, approximately 2.5% (Table 3-18).

Table 3-18. Movement summary of RT-tagged subyearling Chinook salmon released at Foster Dam. The Virtual Release Group indicates fish that were detected after release.

		No Route Predation		Extended Forebay Detection – Never Passed		Near Forebay Detection – Never Passed		Downstream Passage		Predation after any Forebay or Downstream Detection	
Pool Elevation	**Virtual Release Group (*n*)**	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***	**Sub Prop.**	***N***
Low	543	0.013	7	0.129	70	0.217	118	0.641	318	0.026	14

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 3-19) were excluded.

The primary route of passage for subyearling Chinook salmon was via the spillway, with 95% of fish passing that route (Table 3-19; Figure 3-24). The majority of the fish passed via Spill Bay 4 (~65%), with Spill Bay 3 being the second most used route (~26%), followed by Spill Bay 1 (~6%), and Spill Bay 2 (~3%; Table 3-19; Figure 3-24). Thirteen subyearlings passed the turbines, and approximately 2% of fish had undefined routes of passage (Table 3-19).

Table 3-19. Passage proportions by route of passage for RT-tagged subyearling Chinook salmon 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 identified.

		Overall		Day		Night	
Pool Elevation	**Route**	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***
Low	**Turbines**	**0.037**	**13**	**0.769**	**10**	**0.231**	**3**
	Unit 1	0.615	8	0.500	5	1.000	3
	Unit 2	0.385	5	0.500	5	0.000	0
	Spillway	**0.946**	**332**	**0.162**	**76**	**0.838**	**256**
	Spill Bay 1	0.057	19	0.013	1	0.070	18
	Spill Bay 2	0.036	12	0.026	2	0.039	10
	Spill Bay 3	0.259	86	0.211	16	0.273	70
	Spill Bay 4	0.648	215	0.750	57	0.617	158
	Dam	**0.017**	**6**	**0.500**	**3**	**0.500**	**3**
	No Route	0.667	4	0.667	2	0.667	2
	Turbines	0.000	0	0.000	0	0.000	0
	Spillway	0.333	2	0.333	1	0.333	1
	Overall		**351**	**0.254**	**89**	**0.746**	**262**

Note: Fish that passed from Dec. 16, 2022, at 7:00 am, through the end of the study on Feb. 21, 2023, at 10:00 am were excluded from the analyses as there were no operational treatments during this period.

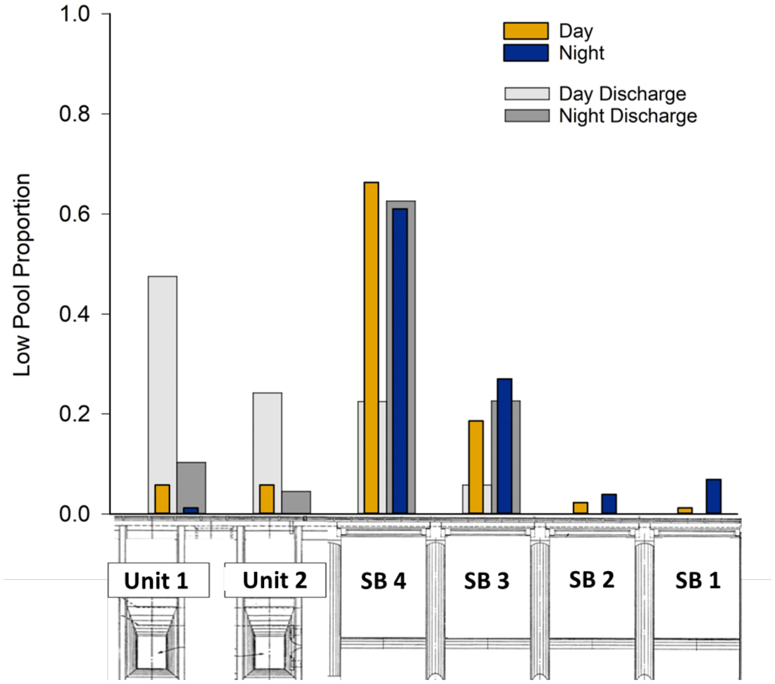

Figure 3-24. Diel passage proportions for subyearling Chinook salmon released during the Foster fall season compared to the amount of discharge through the same route. SB = Spill Bay and the view of the routes is looking downstream.

3.3.3.5 Efficiency and Effectiveness

Subyearling Chinook salmon had an overall DPE of 74.4%. The DPE during night passage was 55.8% and was 18.5% during day passage (Table 3-20; Figure 3-25). A similar finding was observed for the FPE, as the majority of fish passing Foster did so via a non-turbine route (Table 3-19). However, the SPE was high (≥ 88.4%) and as efficient at passing subyearling Chinook salmon via the spillway. This was also reflected in the spillway effectiveness, as it was ≥ 1.15. For day passage, spillway effectiveness was very high at 3.1, potentially because it did not depend on discharge (Table 3-20; Figure 3-25). During fall low pool, the mean daily discharge through the spillway was 1,222 cfs (mean daily discharge for all routes was 2,128 cfs).

Overall FPE was significantly greater in the fall of 2022 compared to 2015, 2016, and 2018 for subyearling Chinook salmon ($P \leq 0.010$; Table 3-21; Liss et al. 2020). Overall DPE in 2022 was significantly greater compared to 2018 ($P < 0.001$) but not 2015 and 2016 ($P \geq 0.999$; Table 3-21). Daytime DPE and FPE were significantly greater in 2022 compared to all past study years ($P < 0.001$). At night, DPE was not greater in 2022 compared to past years ($P \geq 0.416$). Nighttime FPE in 2022 was significantly greater when compared to 2018 ($P < 0.001$) but not 2015 and 2016 ($P = 0.998$).

Table 3-20. Passage efficiencies and effectiveness for subyearling Chinook salmon at Foster in fall 2022. 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	Day	Night
DPE	**0.744 (0.020)**	**0.185 (0.018)**	**0.558 (0.023)**
FPE	**0.716 (0.021)**	**0.164 (0.017)**	**0.552 (0.023)**
SPE || Dam	0.962 (0.010)	0.884 (0.035)	0.988 (0.007)
Spillway Effect.	1.656 (0.018)	3.071 (0.120)	1.151 (0.008)

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.
Note: These calculations are inclusive only of fall passage (10/3/22-12/16/22) and do not include fish that passed outside of the treatment period.

Table 3-21. Passage Efficiencies and Effectiveness for subyearling Chinook salmon at Foster during low pool in Fall 2015, 2016, 2018, and 2022. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay. Standard errors are in parentheses.

	2015	2016	2018	2022 – Overall	2022 – Day	2022 – Night
DPE	**0.816 (0.009)**	**0.968 (0.004)**	**0.557 (0.019)**	**0.744 (0.020)**	**0.185 (0.018)**	**0.558 (0.023)**
FPE	**0.648 (0.011)**	**0.669 (0.011)**	**0.358 (0.018)**	**0.716 (0.021)**	**0.164 (0.017)**	**0.552 (0.023)**

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).

Note: 2015, 2016, and 2018 data show the overall DPE and FPE. Please see Liss et al. (2020) for the breakdown of DPE and FPE by day and night for those study years.

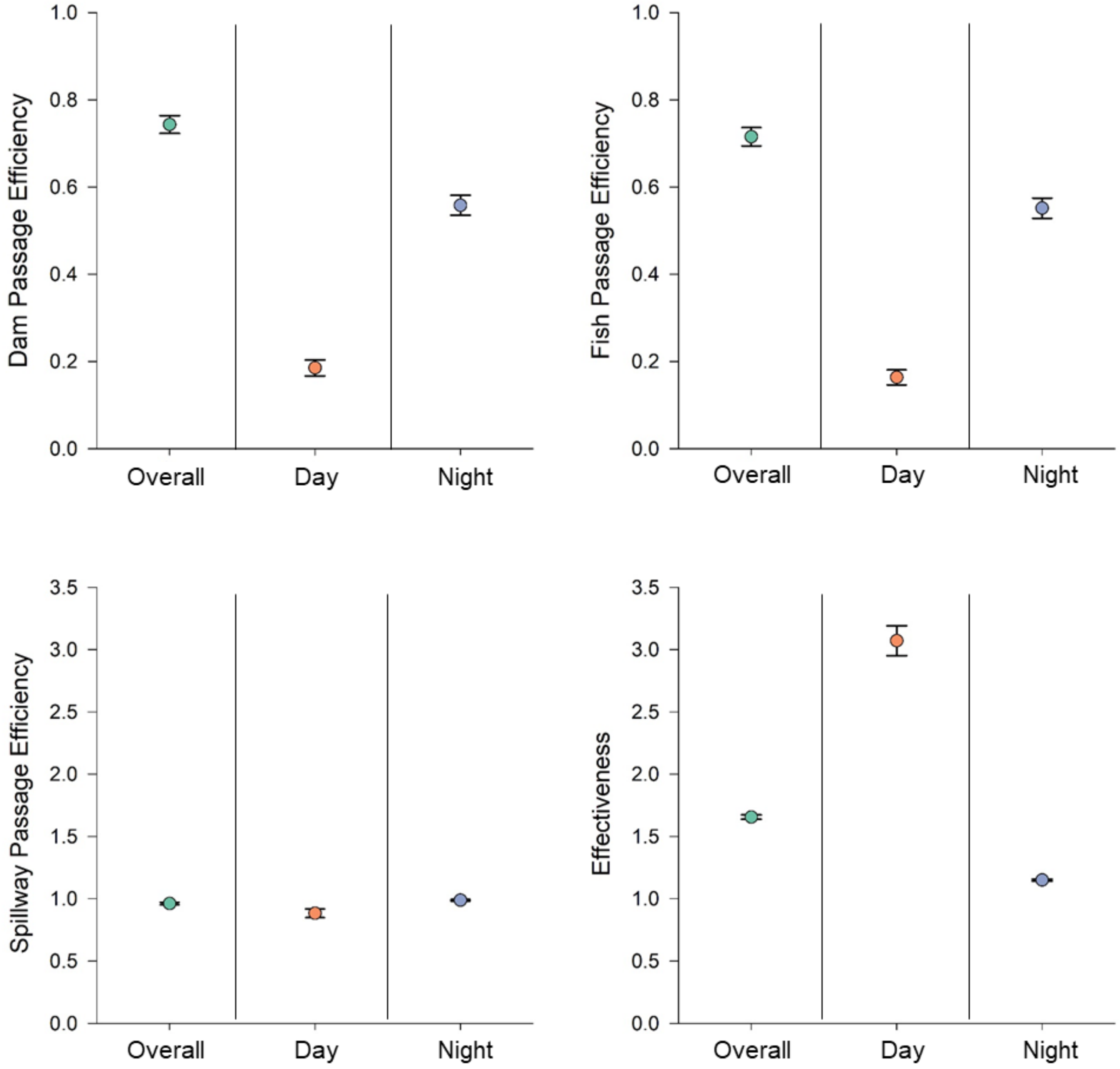

Figure 3-25. Dam passage efficiency, fish passage efficiency, spillway passage efficiency, and effectiveness of subyearling Chinook salmon released during low pool at Foster in Fall 2022. Error bars represent standard errors (SE) of the mean. A lack of error bars indicates the SE was 0.000.

4.0 Discussion

Survival

Dam passage survival for the Green Peter spring spillway operations for yearling Chinook salmon was estimated to be 69.1% (SE: 3.2%) whereas it was 32.1% (SE: 3.1%) for reach survival to the confluence of the Santiam River with the mainstem Willamette River. At Foster during spring low pool, dam passage survival was 84.7% (SE: 2.9%; yearling Chinook salmon) and 74.5% (SE: 4.8%; steelhead), whereas reach survival estimates were 42.2% (SE: 3.8%) and 33.2% (SE: 5.1%), respectively. During high pool, dam passage survival for yearling Chinook salmon was 90.9% (SE: 1.7%) and 83.7% (SE: 3.3%) for steelhead and reach survival estimates were 72.2% (SE: 2.4%) and 77.8% (SE: 3.1%), respectively. During fall low pool at Foster, dam passage survival was 92.4% (SE: 1.5%) for subyearling Chinook salmon, compared to the reach survival of 42.8% (SE: 2.9%). The higher dam passage survival estimates observed at Foster are likely due to its shorter river distance between the survival array, as passage survival is estimated approximately 5 rkm downstream of Green Peter and approximately 3 rkm downstream of Foster. Reach survival estimates were approximately 81 rkm downstream of Green Peter and approximately 69 rkm downstream of Foster. 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 2022 study objectives changed to evaluate dam passage (ViRDCt) survival and reach survival compared to the 2015, 2016, and 2018 studies. Dam passage using ViRDCt occurred only in the 2018 study and reach survival (i.e., to the Confluence of the Santiam and Willamette rivers) was not evaluated in the 2015, 2016, or 2018 studies. Instead, the 2015 2016, and 2018 studies evaluated dam survival + tailwaters to the Waterloo Primary Array. Additionally, no previous studies were conducted to evaluate Green Peter operations, so no comparisons to previous study years could be made for Green Peter. However, comparisons could be made to the 2018 study for dam passage survival estimates for fish released at Foster in spring and fall. Survival of yearling Chinook salmon released at Foster during spring low pool in 2022 was similar to the 2018 study year (2018 low: 86.7%; SE: 3.9%) and improved relative to 2018 during spring high pool (2018 high: 80.9%; SE: 3.4%; Liss et al. 2020). Dam passage survival for winter steelhead in 2022 was also similar to the dam passage survival during low pool in 2018 (73.4%;

SE: 4.7%) and high pool in 2018 (88.5%; SE: 10.8%). The dam passage survival estimates for subyearling Chinook salmon released at Foster during fall low pool were also similar to the 2018 results (87.9%; SE: 1.7%). Although conditions (i.e., dam operations, discharge, river temperature, fish genetics, etc.) were different in 2018, fish trended towards passing the dam at night which was similar to the 2022 study. Survival estimates in 2022 were similar to 2018, potentially supporting the nighttime spillway operations (i.e., nighttime spillway operations during fall and spring months for downstream fish passage).

Discharge

Although low and high pools were not intended to be compared to each other, it is noteworthy that the spring reach survival estimates for fish released during high pool starkly contrasted the reach survival estimates for fish released during low pool (72–78% compared to 33–42%, respectively). There was no change in pool elevation during the study at Green Peter; however, these fish releases coincided with the Foster low pool elevation and the overall reach survival estimates at Green Peter (32%) were similar to those observed during the Foster low pool study. A possible reason for this may have been due to discharge. During the spring season at Foster, discharge was noticeably different for low and high pools. Again, low and high pools were not intended to be compared, but the discharge may have played a role in fish migrations or potentially survival to nearby arrays. The mean daily discharge at Foster during low pool was 2,955 cfs (daytime daily: 2,901 cfs; nighttime daily: 3,033 cfs) compared to the 5,182 cfs mean daily discharge during high pool (daytime daily: 5,176 cfs; nighttime daily: 5,190 cfs). Increased discharge may help fish migrate more quickly and safely from the tailwaters. Tailwaters are a known location where bird or fish predation occurs for juvenile fish passing dams, as juvenile fish are often disoriented after passage and are more susceptible to predation (Hostetter et al. 2012; Evans et al. 2016). This was also noted in our study. In spring, one large rainbow trout was caught by a local angler with 11 RT tags from our fish in its gut. These fish were released dead (DFR) and highlights the potential for fish predation in the tailwaters if fish are unable to migrate quickly downstream. Additionally, fish predation is likely being under-reported as there is no way to know if a fish is predated if its signal stops being detected or maintains behavior typical of out-migrating juvenile salmonids.

Avian Predation

Avian predation was originally reported for the Foster study area in the 2018 study (Liss et al. 2020) and was again observed in the 2022 study. Fish travel times were analyzed with extra scrutiny for behaviors that could most likely be explained by avian predation, such as impossibly quick travel downstream or returning to sites upstream of a dam. The results indicated that spring-released steelhead suffered the greatest amount of predation (22.1% of detected fish), while fall-released subyearling Chinook salmon were predated the least (3.9%). Steelhead are disproportionately predated compared to other salmonids, with other studies estimating minimum predation rates as high as 16.0% at a double-crested cormorant (*Phalacrocorax auratus*) nesting colony in the Columbia River estuary (Evans et al. 2012, Zamon et al. 2014). Additional factors such as increased reliance on fish as a food source for inland bird colonies could also contribute to the higher predation rate observed here (Evans et al. 2012, Hostetter et al. 2012). Avian predation is likely underestimated by using post-hoc analyses, as released fish that were never detected by any array also could have been predated by piscivorous birds before detection. Although it is nearly impossible to determine the source of the avian predation events using RT alone, the presence of numerous cormorants sitting on the log boom in the Foster forebay, as well as cormorant nest colonies near the Lebanon Dam downstream site, has been observed.

Reservoir Residency and Travel Times

Reservoir residency times varied. At Green Peter, yearling Chinook salmon released during the nighttime spill treatment spent significantly less time in the reservoir (41 h; median) than fish released during the 24/7 spill treatment (87 h; median). Once fish passed the dam; however, travel times for the nighttime spill released fish were significantly slower than the 24/7 spill released fish (with the exception of Green Peter to the first array at Sunnyside). Directional cues provided by flow are necessary for salmon migrations (Morrice et al. 2020). Discharge may have affected travel times to the Sunnyside Array, as the diel discharges varied. During the nighttime spill, the mean discharge at night was 2,219 cfs through the spillway. The mean discharge during the 24/7 spill treatment was 1,186 cfs during the day and 1,196 cfs at night, resulting in a reduced flow at night (when most fish passed the dam) for the 24/7 spill treatment compared to the nighttime spill treatment. It is also possible that the additional time fish spent in the reservoir during the 24/7 spill treatment provided extra time to recover from the stress of tagging and transport, allowing those fish to migrate quickly once they passed Green Peter.

During spring low pool at Foster, yearling Chinook salmon had a median reservoir residency of 35 h. This was reduced relative to the 2016 study and was similar to the reservoir residence times of the 2015 and 2018 studies. Thereafter, travel times downstream were varied compared to previous study years (slower, similar, and faster). Interestingly, the mean daily discharge during low pool at Foster was 2,956 cfs, although this did not appear to affect reservoir residency times or travel times.

Yearling Chinook salmon released during spring high pool had a median residency of 59 h in the Foster Reservoir. This was significantly shorter than all previous study years (2015, 2016, and 2018). Thereafter, fish traveled quickly with a median travel time of 28 h to the confluence. Fish had a median travel time of 1.0 h to the Egress Array (approximately 3 rkm) and around 3 h from the Egress to the Waterloo Primary Array (approximately 16 rkm). Travel times from Foster the Waterloo Primary Array were also faster in 2022 compared to all previous study years. It is possible dam operation discharge influenced and helped shorten reservoir residence times in 2022 compared to the previous study years. Higher flows from either dam operations or other external factors (snowmelt/rain) in 2022 may have influenced the faster speed of migration downstream of the dam. The mean daily discharge was 5,182 cfs during high pool compared to 2,956 cfs during the low pool spill operation. This faster trend for fish spending more time in the reservoir before migrating was similar to the yearling Chinook salmon released at Green Peter during the 24/7 spill treatment.

Steelhead released during spring low pool had a shorter reservoir residency time in 2022 compared to all previous study years. During high pool, the reservoir residency time was shorter than two of three previous study years . Steelhead released during low pool had a median reservoir residency of 45.4 h, whereas the steelhead released during high pool spent 137.2 h (median) in the reservoir. Travel times to the Waterloo Primary Array was shorter in 2022 than all previous study years for both low and high pools. Discharges and reservoir and river conditions were the same for steelhead and Chinook salmon, as fish were tagged and released together during each pool elevation and release period. The greater discharge during high pool compared to previous study years may have influenced reservoir residency time and travel times; however, the lower discharge during low pool compared to previous study years did not appear to have an effect on reservoir residency or travel times.

During the fall study season, subyearling Chinook salmon spent a median of 19.2 h in the reservoir before migrating downstream. This was shorter than in 2015 and 2018, although it was greater than the reservoir residency time in 2016. Travel times to the Waterloo Primary were faster in 2022 than in some previous study years (2015 and 2018), even though discharge was lower in 2022. For example, in 2018 mean daily discharge was 4,300 cfs, compared to 2,128 cfs in 2022. However, the lower discharge did not affect migration times for the 2022 subyearling Chinook salmon.

Passage Distributions

Passage distributions for Green Peter and Foster study fish of all species, stocks, seasons, and pool elevations had similar overall trends. The key findings indicate the majority of fish passed at night and the primary route of passage was through the spillway at both dams. At Green Peter, yearling Chinook salmon overwhelmingly passed at night (99.1–99.2%) and through the spillway (100%), regardless of treatment. This was likely because the turbines were not operated during either spillway operational period. However, even if the turbines were operated the entrance is located approximately 155 feet (depending on pool elevation) underwater and it is unlikely Chinook salmon would have sounded to that depth to pass the dam.

Yearling Chinook salmon nighttime passage at Foster was 90.7% during low pool and 78.3% during high pool. The primary route of passage was the spillway, with 99.4% using these routes (specifically Spill Bay 4 at 90.1%) during low pool and 97.9% during high pool. During high pool Spill Bays 2 and 3 were used (41.8% and 50.6%, respectively). Spill Bay 4 was not operated during high pool and was not an optional route of passage.

For the steelhead that passed Foster, 76.0% passed at night during low pool and 80.6% during high pool. Spillway passage was 91% during low pool (with 85.7% passage through Spill Bay 4), and 96.1% during high pool (with 48.4% and 33.1% passage through Spill Bays 2 and 3, respectively). Although Spill Bay 4 was not open, it did not seem to have an effect on spillway passage proportions for yearling Chinook salmon or steelhead as the other routes of passage through the spillway remained available.

Finally, subyearling Chinook salmon released during fall low pool at Foster had 74.6% passage at night, with 94.6% passage through the spillway. All four spill bays were operated throughout the treatment period, and the two most used were Spill Bay 4 (64.8%) and Spill Bay 3 (25.9%). These key takeaways for the current study were similar to previous study year findings (Hughes et al. 2016, 2017; Liss et al. 2020).

Nighttime passage for yearling Chinook salmon, steelhead, and subyearling Chinook salmon varied from 65–99%, with the exception of steelhead during 2018 high pool where 62% of steelhead passed during the day. This again supports the continued nighttime spillway operations during fall and spring months for downstream fish passage.

Efficiency and Effectiveness

Efficiency metrics varied by dam and by species and stock for DPE and FPE. Because the spillway was the primary route of passage regardless of dam, species, stock, pool elevation, or season, the overall SPE was typically high overall (≥ 92.9%). Just like SPE, the effectiveness metrics for Green Peter and Foster for all species, stocks, seasons, and pool elevations also had similar overall trends. Spillway effectiveness was high, ranging from 1.0–1.7.

At Green Peter, DPE and FPE were the same because all fish passage via a non-turbine route (i.e., the spillway). Because all fish passed via the spillway, SPE was 100%. The DPE and FPE during the nighttime spill treatment were 84.9% and 77.9% during the 24/7 spill treatment. Results were similar between the two treatments for nighttime passage (84.2% DPE and FPE during the nighttime spill treatment and 77.2% during the 24/7 spill treatment). Neither the overall nor the nighttime passage results were significantly different, and the results indicated the spillway operation at Green Peter was efficient at passing available yearling Chinook salmon. Because SPE was 100% and all discharge passed via the spillway, the spillway effectiveness also equal to 1.0.

The DPE and FPE at Foster were similar for yearling Chinook salmon during spring as the large majority of fish (100% during low pool and 98.8% during high pool) passed via a non-turbine route. Because of this overall SPE was high, at 100% for low pool and 98.8% for high pool. However, DPE and FPE were around approximately 60% during nighttime passage for both low and high pools. Although not ideal, it was better than daytime passage, which was 6.3% during low pool and approximately 16% during high pool for DPE and FPE. This indicates Foster spillway was more efficient at passing available yearling Chinook salmon during the night than during the day. The results for overall DPE and FPE in 2022 were greater than two of the three previous study years (2015 and 2016), also providing support that the Foster spillway was efficient at passing available yearling Chinook salmon in 2022. With the majority of the fish passing via the spillway (high SPE) and most of the proportional discharge (66%) also going through the spillway, the spillway effectiveness was also high at 1.5.

Efficiency metrics for steelhead passage at Foster were also similar, as the majority of fish passed via the spillway. As a result, the overall SPE was high (92.9% for low pool and 96.9% for high pool), as the majority of steelhead that passed seemed to select the spillway. However, Foster was not very efficient at passing available study fish overall, with DPE and FPE ranging from around 20% during low pool and around 26.5% during high pool. Nighttime DPE and FPE (~16–21%) were greater than daytime DPE and FPE (4–5%) during both low and high pools. These results were similar to previous study years and indicates the change in operations did not improve the efficiency for Foster to pass available steelhead. Spillway effectiveness for steelhead was also high (1.4 for low pool and 1.6 for high pool), with most fish passing via the spillway and more than half the discharge (66%) going through the same routes.

Finally, subyearling Chinook salmon passage at Foster had more fish pass via a non-turbine route, leading to a difference between DPE and FPE. However, the majority of fish passed via the spillway, resulting in an overall SPE of 96%. Overall DPE was 74.4% and overall FPE was 71.6%. The overall FPE was greater in 2022 than previous study years, indicating the spillway was overall more efficient at passing available subyearling Chinook salmon. Nighttime DPE (55.8%) and FPE (55.2%) were better than daytime DPE (18.5%) and FPE (16.4%) in 2022. Although it was low, the daytime DPE and FPE were greater in 2022 than previous study years. Nighttime DPE and FPE did not increase from previous study years. However, nighttime FPE was higher in 2022 compared to 2018. This also supports the notion that Foster, and the spillway were efficient at passing available subyearling Chinook salmon. The spillway effectiveness was also high for subyearling Chinook salmon at 1.7. This is likely because the majority of the fish passed via the spillway and over half the discharge (57%) was also through those routes. Even though the mean daily discharge was lower in fall (2,128 cfs), it did not affect the ability for subyearling Chinook salmon to successfully pass the spillway.

5.0 Management Applications

The 2022 Evaluation of Foster Dam Spillway and Green Peter Dam Spillway Operations for Juvenile Fish Passage study successfully met the Green Peter baseline evaluation study objectives and the Foster study objectives. Where appropriate for Foster, results from the 2022 study were compared to previous study years (2015, 2016, and 2018). However, the study objectives for those study years were different in 2022; therefore, direct comparisons were not always feasible.

Based on the 2022 study results, the nighttime spill and 24/7 spill operations at Green Peter had similar dam passage and reach survival, passage distributions, and efficiencies and effectiveness. The only difference was in the reservoir residency and migration travel times. This may have occurred as a result of the higher discharge at night during the nighttime spill treatment that helped fish pass the dam more quickly, as most fish tended to migrate at night, although the lack of daytime flow from the spillway may have slowed their migrations once downstream of Green Peter. Additional studies evaluating similar discharge regimes are recommended to better understand if one operational treatment is better for yearling Chinook salmon at Green Peter compared to the other.

The objectives of the Foster task were to determine if the nighttime spillway operations provided safer and more efficient passage compared to daytime turbine operations for subyearling and yearling Chinook salmon and age-2 winter steelhead. Based on all the results from the 2022 study, and in comparing to previous study years, the majority of fish passed at night and had similar or improved dam passage survival. Efficiencies and effectiveness were also similar or improved in 2022; supporting the notion that nighttime spillway operations could be a safer and more efficient route compared to the turbines for yearling and subyearling Chinook salmon and steelhead. Travel times were more variable; however, this may have been an artifact of different operational or environmental conditions for the different study years. Regardless, it is suggested to continue the current nighttime spillway operations during fall and spring months for downstream fish passage.

Performing another study at Green Peter and Foster to account for interannual environmental and fish behavior and migration conditions is recommended. 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; day and night passage); therefore, it is important to have data from multiple study years. Future studies should utilize the same RT design setup for cross-years comparisons of dam passage survival and reach survival. This was the first year to evaluate fish passage and survival at Green Peter and reach survival estimates from Foster to the Santiam River confluence, so comparisons to previous study years were not possible.

A full-scale study at Green Peter is recommended to better understand if there are differences between operational treatments, and to continue to evaluate fish survival and migrations downstream of Green Peter. The 2022 study was the first time RT-tagged study fish were released in the reservoir and tracked in the forebay and through Green Peter. Future study years could utilize fish released at Green Peter to also evaluate passage and survival metrics at Foster. This would allow for one comprehensive evaluation of the system instead of separating the results by dam. That was the best choice for the 2022 study because Green Peter was a baseline evaluation with no prior knowledge of how fish would behave or if they would pass the dam. The 2022 study provided results from Green Peter that can be utilized for a future comprehensive multi-dam study.

6.0 References

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